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Using unmanned aerial vehicles for wildlife research and monitoring at Sea Lion Island

Project report - Update 2019/2020

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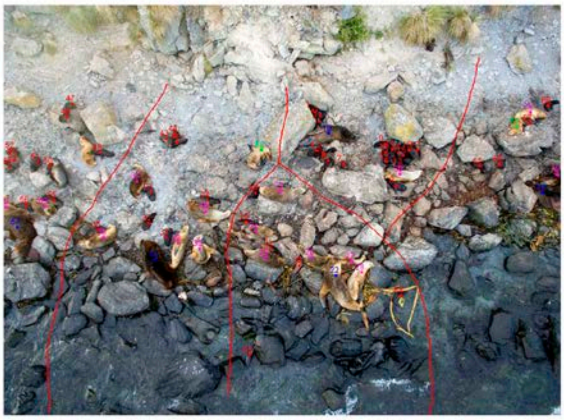


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Summary

There is an increasing interest in the use of drones or unmanned aerial vehicles (UAVs) for wildlife research and monitoring. The widespread recreational use of UAVs is producing an exponential increase in their technical specifications, and a corresponding drop in their price. UAVs permit to acquire aerial imagery on demand and at a very low cost compared to alternatives (aerial surveys, satellite imagery). Recreational UAV cameras produce high resolution pictures and video footage, and their quality is constantly increasing. If combined with mission planning software, UAVs can carry out semi-automatic surveys that are repeatable in time and space. UAVs photos and videos can be used to count birds and colonial species in particular, assess spatial distribution and social organization of pinnipeds, and observe behaviour at sea of marine mammals.

Having being involved in research of wildlife of Sea Lion Island in the past twenty five years, we are interested in testing methodologies and instruments that can improve our capability to carry out not only our specific research projects but also general environmental monitoring of the island. Sea Lion Island is a National Nature Reserve, an Important Bird Area, an Important Plant Area, a RAMSAR convention site, and the premiere destination of nature oriented tourism in the Falkland Islands. Notwithstanding this, the knowledge of its wildlife populations is scattered. Although some specific monitoring programmes are carried out at Sea Lion Island, including penguin surveys by Falklands Conservation and research on elephant seals, killer whales and Falklands skua by the Elephant Seal Research Group, and although spot wildlife surveys were carried out in the past, the island lacks an integrated environmental monitoring programme.

Starting in 2016, we made extensive trials to determine the effectiveness of UAVs in helping our specific research projects and the general wildlife monitoring of the island. In particular, we used UAVs for: 1) rapid assessment of colonial marine birds nesting and breeding success; 2) monitoring of bird species that are particularly affected by human disturbance and, therefore, should not be surveyed directly; 3) counts of southern sea lions, that breed in areas that are difficult to access; 4) study of the spatial distribution and social structure of elephant seal groups; 5) study of killer whale social and predation behaviour.

All together, the results were very positive. Our main concern was the effect of UAV flights on wildlife. UAVs can produce a significant low frequency noise, can be attacked by territorial birds, and can adversely affect flying birds at large. We observed null to scarce reaction to UAVs from all the monitored species, and territorial birds (e.g., caracaras) showed a scarce interest in flying UAVs, much below our own expectation. Disturbance to marine mammals, both on land and at sea, was scarce to null. UAVs proved very useful to increase accuracy and reduce disturbance of birds' counts, improved the monitor of breeding southern sea lions, increased our capability to study elephant seals groups, and produced a quantum leap in our understanding of killer whale behaviour, in particular during pod mixing and predation events.

We plan to increase the use of mission planning software to regularly carry out semi-automated surveys, and we are working on a full featured photo post-processing pipeline that should streamline and simplify the production of results that can be useful both for our research projects and for the management of the island.

Introduction

In recent years there has been an increasing interest for the use of unmanned aerial vehicles (UAVs) for wildlife monitoring and research. UAVs have the potential to produce a methodological revolution in wildlife biology (Chabot and Bird 2015; Christie et al. 2016), permitting the on-demand collection of accurate, high resolution imagery at a very low cost compared to alternatives (traditional aerial surveys, satellite imagery). UAVs are being used for all aspects of wildlife monitoring (Gonzalez et al. 2016), and to count indicator species in difficult environments (Zmar et al. 2015).

In 1995 the Elephant Seal Research Group (ESRG, www.eleseal.org) begun wildlife research at Sea Lion Island (Falkland Islands; SLI hereafter). For twenty five years we carried out a long term research project on the behavioural ecology of southern elephant seals (*Mirounga leonina*), that have at SLI their main Falklands breeding colony. More recently (2013) we begun a study of killer whales (*Orcinus orca*), focusing on sociality and impact of killer whales predation on the demography of their potential preys (southern elephant seals, southern sea lions *Otaria byronia*, and various species of penguins). In 2014, we begun a study of the Falklands skua (*Catharacta antarctica antarctica*), to assess nesting success and to study the vocal communication system. Moreover, we are monitoring nesting success of various bird species, including various species of ducks and geese, imperial (*Leucocarbo albiventer*) and rock shags (*Phalacrocorax magellanicus*), and caracaras (*Phalcoboenus australis*), and we are carrying out regular counts of southern sea lions. All these research and monitoring activities can be improved by using UAVs imagery.

UAVs have been shown to produce more accurate counts of colonial birds than human observers (Hodgson et al. 2016) and to reduce biases due to the different accessibility of different colonies of birds and seals (Pomeroy et al. 2015). Moreover, they have been shown to have a great potential in the monitoring of elusive species (Goebel et al. 2015), that are greatly affected by human distance and are difficult to be located and counted with traditional approaches. UAVs have been frequently used to carry out marine mammal surveys (Koski et al. 2009; Koski et al. 2010), and to study their demography (Koski et al. 2010), size and development (Durban et al. 2016), and behaviour (Fiori et al. 2017). UAVs have been also used in creative manners to sample marine mammals at sea (Acevedo-Whitehouse et al. 2010).

Objectives

We are assessing the usability, advantages and negative impacts of UAVs for the following wildlife monitoring tasks:

1) Aerial surveys of marine bird breeding colonies to count nests and chicks, with a specific focus on gentoo and rockhopper penguins, and imperial and rock shags.

2) Aerial surveys of breeding colonies of species that are much affected by human disturbance, with specific focus on gull species (dolphin and kelp gulls, *Leucophaeus scoresbii* and *Larus dominicanus*) and night herons (N*ycticorax nycticorax*).

3) Counts of southern sea lions in their main breeding colony that, due to the local topography, is very difficult to count accurately and safely.
4) Surveys of elephant seal groups, to assess UAV use in the study of spatial distribution and social organizations, and in mapping and measuring of individual seals.
5) Observations from the air of killer whales, to study their activity, sociality and hunting behaviour.

Methods

Field work was carried out at SLI between September 2016 and April 2020. We used two four-engine UAVs: 1) a Phantom 3 Professional (DJI, https://www.dji.com/phantom-3-pro; Figure 1, left), which is a small UAV (weight = 1280 g, diagonal size = 350 mm), fitted with a 20mm high resolution camera, capable to take 12.4 megapixels pictures and 4K videos; 2) a Mavic Pro Platinum (DJI, https://www.dji.com/mavic-pro-platinum; Figure 1, right), which is a very small but powerful UAV (weight = 734 g, diagonal size = 335 mm; 12.35 megapixels camera, 28mm lens), with longer flight duration than the Phantom (25 min vs 17 min). The UAVs were operated from an Android tablet using DJI software for manual flights (Phantom: DjiGo 3.1.52; Mavic: DjiGo4 4.3.24) or Litchi software (4.17.0; flylitchi.com/) for semi-automated aerial surveys.

Figure 1 - The UAV platforms: the Phantom 3 on the left and the Mavic Pro on the right.

A peculiar aspect of UAVs is that they require good weather conditions, and in particular rather low wind, to be flown safely. The Falklands are surely not an ideal place for UAVs flying, due to the common high winds. Therefore, we were in an ideal position to test UAVs because we spent the whole spring and summer at SLI, and we were, therefore, able to operate our UAVs only on days with optimal weather conditions (wind speed <= 15 knots). Our UAVs were used only when the wind and weather conditions were optimal to safely fly. In particular we avoided flying our UAVs when it was raining or very wet and when there was fog or mist. When surveying wildlife UAV was always launched far from the subject animals, usually more than 50 meters.

Although the use of UAVs for wildlife research and monitoring can produce notable benefits, it has drawbacks that should be taken into account. In particular, UAVs can produce stress and fear on the study subjects, often in subtle ways that are not easy to be recognized (e.g., increase in heart rate, Ditmer et al 2015). The impact of UAVs on marine mammals is not well established (Smith et al. 2016). Assessment of noise effect on some marine species showed that UAV disturbance is modest, and is a minor factor compared to other sources of disturbance (Christensen et al. 2016; Erbe et al. 2017). We strictly applied best practice guidelines for the use of UAVs in wildlife research (Hodgson and Koh 2016) and followed the suggestions for flying UAVs on bird colonies based on the results of previous studies (Vas et al. 2015), but we also carefully evaluated ourselves the effect of UAV flying on each of the species and colonies that was monitored. During each flight a second operator observed and recorded ad libitum notes about the reaction of the subjects. These notes were reviewed with the UAV pilot after each flight. Summary flight logs were saved using the UAV control software at the end of each flight, and detailed logs were regularly downloaded from the UAV internal memory, to document the application of best practice guidelines. Logs were decoded to CSV files, and analyzed using custom scripts. Details of the specific methods used for each objective of the project follow.

Marine bird colonies

We used our UAVs to obtain counts of penguins and cormorants that nest in high density colonies (Figure 2). Direct counts of these species are difficult due to the large number of nests densely packed in space. Moreover, gentoos nest in colonies with different topography and, therefore, the accuracy of counts changes from one colony to the other, mostly because sometimes it is difficult or impossible to see all nests together from the same location. The accuracy of counts can be greatly improved by taking pictures of the colony from the air and carrying out the counting in these pictures, using image analysis software that permits to mark and number the counted nests (Goebel et al. 2015). UAVs have been used previously in the Falklands to obtain counts of penguin colonies (Ratcliffe et al. 2015). We obtained pictures of all breeding colonies of the target species, at different times of the season. Counting in pictures permits to have replicated counts, to estimate intra and inter-operator reliability. For each colony we obtained imagery at peak nesting and at peak presence of chicks, to estimate nesting success and net productivity. Some colonies were small enough to require just a single picture. For colonies covered by multiple pictures, we either counted animals on the different pictures (annotating on the pictures which area was to be counted and which was counted on an adjacent pictures) or we stitched pictures together using

Photoshop (version Creative Cloud 2015, Adobe) before counting. Stitching can be problematic because it can produce artefacts (deletion or addition of nests/animals), so various trials were made using the different algorithms available in Photoshop, and quality of the stitching was manually checked in all pictures. Usually the “reposition” algorithm, with the “blend images together” option, gave the best stitching result.

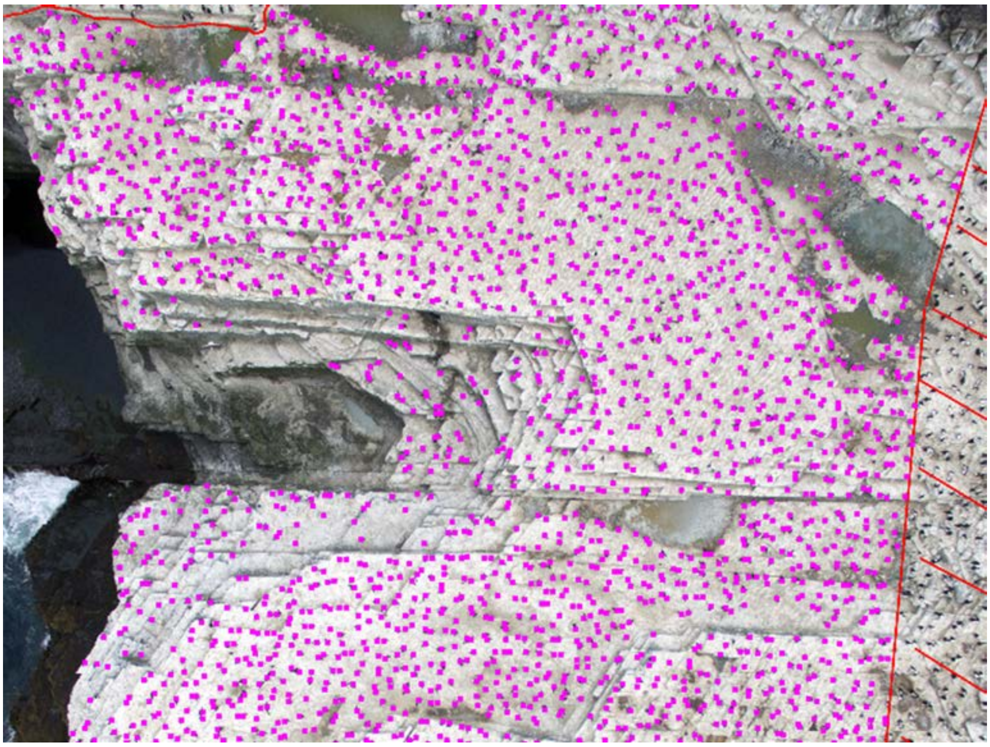

Figure 2 - Example of a high density marine bird aggregation. The picture shows imperial shags roosting at Sea Lion Island in the Sheffield Memorial area. Up to about 15000 shags can roost together, and manual counts proved to be impossible. Red lines mark out the areas that should not be counted because they will be counted on adjacent pictures.

Counts were carried out using the ObjectJ plugin (https://sils.fnwi.uva.nl/bcb/objectj/) of the ImageJ software (https://imagej.nih.gov/ij/). Pictures were counted by three different operators. In each picture we counted number of occupied nests, number of adults per nest, number of chicks per nest, number of adults and chicks in the colony but not on the nest. We counted and analyzed three main classes: the total number of nesting pairs, the total number of adults (on the nest or not, but within the colony limit), and the total number of chicks. Repeatability of UAV counts (Lessels and Boag 1987) was calculated using mixed models, and its standard error and confidence interval were calculated by bootstrap (1000 replicates; Manly 2007). Penguins UAV counts were compared to two different and independent manual counts: ESRG counts, and counts carried out by very experienced observers in the contest of the Falkland Islands Seabird Monitoring Programme (Crofts and Stanworth 2018).

Bird species particularly sensitive to disturbance

Kelp gulls are very sensitive to human disturbance while nesting. When humans approach them at close distance they usually leave the nest and fly over it, exposing the eggs and chicks to the predation by other gulls, or other species, including caracaras and skuas. Skua predation can be particularly intense, and in the past we observed mass skua attacks, favoured by the presence on unaware SLI visitors, that produced dramatic drops in kelp gull productivity (unpublished data, ESRG). Kelp gulls often nest together with dolphin gulls, which are also potential predators of their eggs. The use of UAV permitted us to get pictures of gull nesting colonies and, therefore, to obtain counts without any need to have operators approaching the colonies.

Southern sea lions

At SLI, the southern sea lions have a single breeding colony, with a total productivity of about 100 pups (unpublished data, ESRG). The topography of this colony, that is at the bottom of a steep cliff with unsteady and slipping ground on top, makes direct counts of pups difficult, and variable, depending on how many pups are out of view from the top of the cliff (Figure 3).

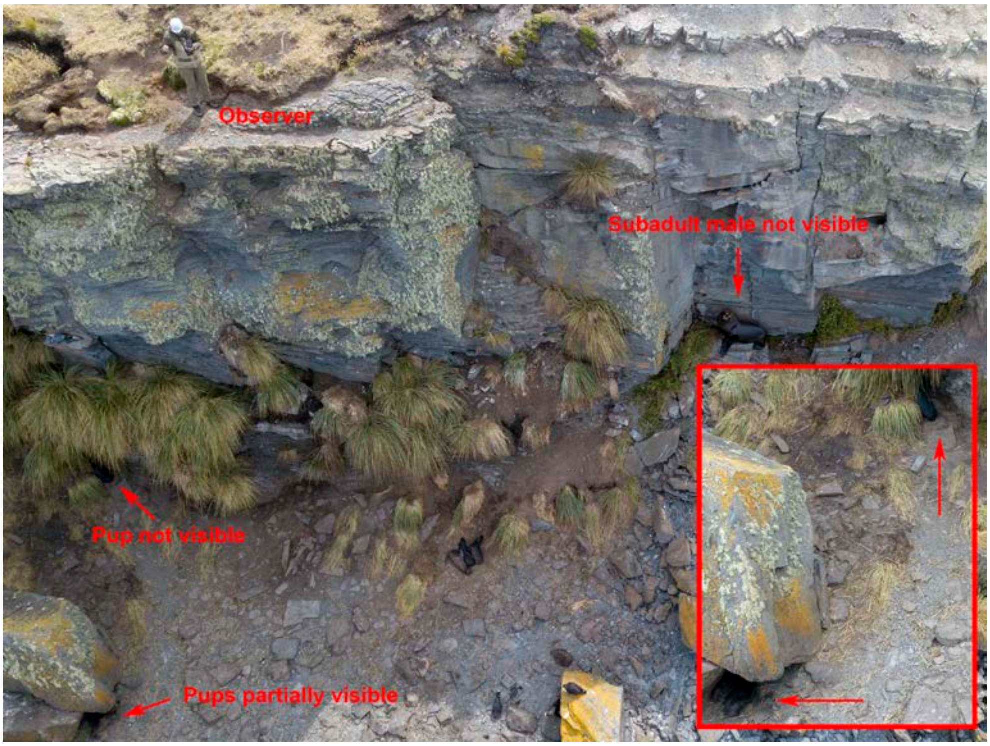

Figure 3 - The southern sea lion breeding colony at Sea Lion Island. The picture shows a portion of the colony at the bottom of a steep cliff, an observer that will count from the cliff top, the sea lions that rest so close to the cliff to be impossible to see from the top, and the ones that are partially visible, being masked by boulders and tussac grass (see enlargement on the right).

Pups tend to aggregate at the very bottom of the cliffs, to stay in the shade and be safe from high tide and rough sea and, therefore, can be particularly difficult to count form top of the cliffs. Repeated counts carried out at different time of the day showed that a single count from top of the cliffs can underestimate the actual number of pups by up to 25% (unpublished data, ESRG). Although the use of a camera mounted on a pole can improve the reliability of counts (unpublished data, ESRG), this solution is far from perfect. UAVs permitted us to take pictures of the whole colony, with sufficient resolution to count pups in groups, and recognize sex and age classes. We recognized the following classes: adult males, breeding females, pups, sub-adult males, juvenile males, yearlings, and two year old individuals. During manual counts, but not in UAV counts, we split sub-adult males and juvenile males in three size classes (small, medium, large).

Southern elephant seals

One of the main goals of our long term study of southern elephant seals is the effect of the spatial distribution of seals on their social behaviour. Although we are already collecting data on seal spatial distribution using GPS receivers and laser telemetry, the availability of aerial pictures of groups can greatly help. Therefore, we used our UAVs to obtain aerial pictures of harems during the breeding season and of elephant seal groups during the moulting season. Resolution of pictures was good enough to recognize not only size and age classes, but also individual seals bearing dye marks (Figure 4). We are currently testing the reliability of measurement of size of marked individuals in UAV photos.

Figure 4 - UAV picture of pregnant elephant seal females with clearly readable dye marks.

Killer whales

A great limitation of our killer whale study is that it is land based, and we are carrying out observations only from the coast of SLI. On the other hand, the behaviour of cetaceans can be greatly affected by the presence of boats at close distance (Guerra et al 2014). Boat noise not only may adversely affect killer whales (Williams et al. 2014), but there are clear demonstration that their behaviour is modified by the presence of boats even at long distance (100+ meters; Noren et al. 2009). Therefore, using a boat will not solve the limitations of our observation protocol. Our UAVs permitted us to obtain high resolution images and video footage of the killer whales and their behaviours. When killer whales were close to the coast they tended to stay quite close to the sea surface when submerged and, therefore, they were easily observed in the screen of the tablet controlling the UAV, and in the video footage. To recognize individual killer whales in UAV photos and videos, we used a combination of written notes taken by a land observer, audio notes taken with a digital recorder by the UAV pilot, and photo-identification on photos taken from land at the same time of the UAV flight (Figure 5). This was required because although some killer whales can be recognized directly from the top view of the UAV, most individuals are better recognized from natural signs in the saddle patch and dorsal fin that are not clearly visible from the top. Observations from UAV were carried out mostly during pod mixing, socialization and hunting events.

Figure 5 - Identification of killer whales in a frame of UAV video footage.

Results and discussion

Gentoo penguins

We flew our UAV over gentoo penguin colonies at an average altitude of 22.4 meters (10.6 to 52.5), depending on the size of the colony, and the number of pictures that were required to cover the full colony (Figure 6). Pictures taken at about 50 meters of altitude over the colony were still useful for nest counting (Figure 7).

We observed no reaction of nesting gentoos when flying the drone at the range of altitudes used for photographic surveys. We made some trials flying at lower attitudes, down to 5 meters, and we did not observe any significant reaction of the nesting gentoos if UAV was flown slowly and smoothly. At the end of the season, when the nesting phase was over, gentoos had a stronger reaction to the UAV. This change in reaction with the phase of annual cycle is evident also toward airplanes overflying the colonies (ESRG, unpublished data). All together, in the flying range used to take pictures useful for counting, the impact of the UAV flight was almost null.

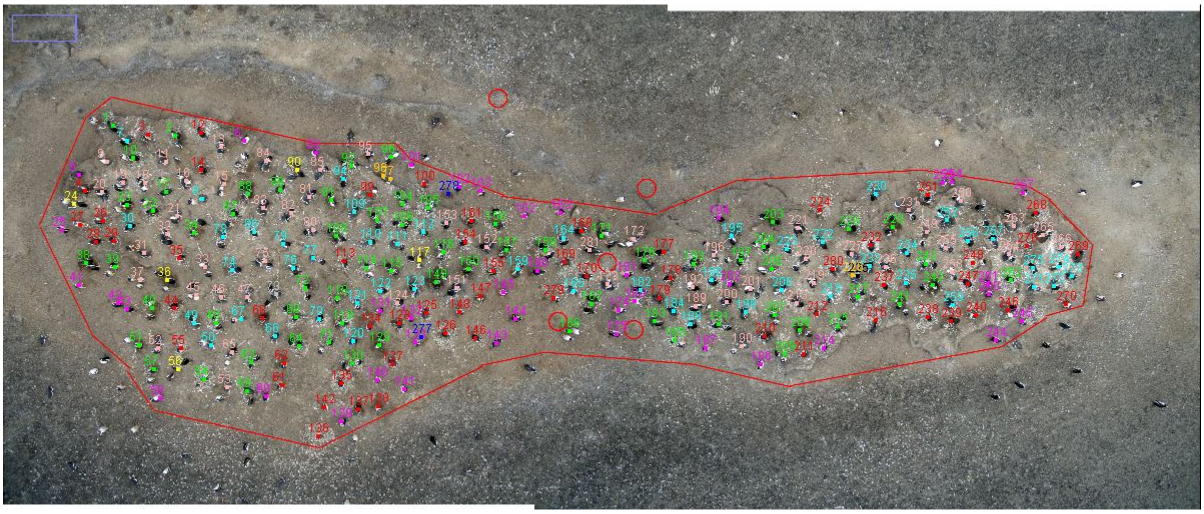

Figure 6 - UAV imagery of a gentoo colony that required two stitched pictures to obtain full coverage of the nests. The red line is the outer limit of the colony. The red circles were used to improve the stitching process.

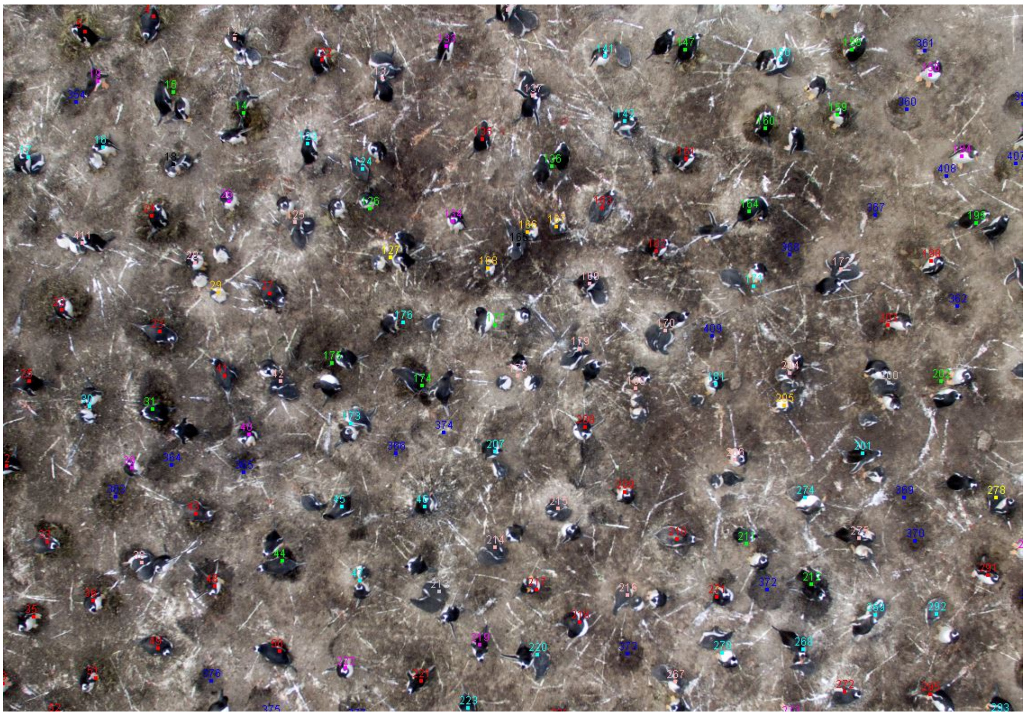

Figure 7 - Enlargement of a gentoo penguin colony with count markers. Dots of different colours represent different gentoo classes (e.g., single adult on the nest).

An advantage of the drone is that the flying time over each colony is short, usually < 60 seconds, so the disturbance, if any, is short and concentrate. Moreover, the UAV was launched far away from the colonies (> 500 m), reducing to zero the direct human-subjects interaction. This is in sharp contrast with direct counting, in which up to 20 minutes of walking around the colonies is required to each operator to carry repeated counts of the largest colonies. Moreover, to assess inter-observer agreement at least two independent operators are required. The short flying times spent over each colony permitted us to carry out a full survey of all SLI colonies using just two UAV batteries, i.e., a total of about 50 minutes of flight.

a) Nests

Dataset	Colonies	N	R	se(R)	LCL(R)	UCL(R)
All	40	120	0.9965	0.0010	0.9940	0.9979
First date	20	60	0.9965	0.0014	0.9924	0.9983
Second date	20	60	0.9965	0.0014	0.9925	0.9984

b) Adults

Dataset	Colonies	N	R	se(R)	LCL(R)	UCL(R)
All	40	120	0.9999	0.0000	0.9998	0.9999
First date	20	60	1.0000	0.0000	0.9999	1.0000
Second date	20	60	0.9998	0.0001	0.9997	0.9999

C) Chicks

Dataset	Colonies	N	R	se(R)	LCL(R)	UCL(R)
All	40	120	0.9951	0.0013	0.9916	0.9971
First date	20	60	0.9424	0.0214	0.8830	0.9726
Second date	20	60	0.9980	0.0008	0.9957	0.9990

Table 1 - Repeatability of different kinds of gentoo penguin counts obtained from UAV pictures. a): total number of nesting pairs; b): total number of adults (on nest or not); c): total number of chicks. Colonies: number of gentoo colonies (20 for each date); N: number of counts (three replicates for each colony); R: repeatability; se(R): standard error of repeatability; LCL(R) and UCL(R): lower and upper limits of the 95% confidence interval of repeatability.

Count	R min alt	CI(R min alt)	R max alt	CI(R max alt)
Nests	0.9875	0.9657-0.9955	0.9746	0.9318-0.9908
Adults	0.9998	0.9995-0.9999	0.9990	0.9973-0.9996
Chicks	0.9927	0.9798-0.9974	0.9627	0.9014-0.9864

Table 2 - Repeatability of counts obtained from minimum altitude UAV pictures versus maximum altitude pictures. Count: type of count; R min alt, Rmax alt: repeatability of counts of minimum and maximum altitude pictures; CI: 95% confidence interval of repeatability.

During each season we obtained UAV imagery of all the breeding colonies of gentoo penguins. We calculated repeatability of counts for the 2016-2017 season, considering 20 colonies, three operators and two dates (N = 120 counts, 60 per date), and using for each colony the picture taken at lower altitude. Repeatability of counts was very high for all types of counts (Table 1). To assess the effect of flying altitude on count repeatability we compared the repeatability of counts carried out on the picture taken at minimum altitude with the picture taken at maximum altitude. The repeatabilities of high altitude pictures were only marginally lower than the ones of low altitude pictures (Table 2).

The overall variability of counts depended on the gentoo penguin class counted. The total number of adults showed the minimum variation, with an average percentage difference between repeated counts of the same colony of 1.71% (0 to 8.33). The total number of chicks had an average difference of 5.31% (0 to 20.00), while the total number of nesting pairs had the highest average difference, 8.22%, but a smaller range than chick counts (1.84 to 12.92%).

Accuracy of counting of gentoo penguins in UAVs photos improved with experience. We observed an improvement of counts precision and accuracy of inexperienced counters in following counts, and the improvement was greatest for bigger colonies, that are more difficult to count (Figure 8). Therefore, even our field helpers that had no previous experience of penguin counts were able to obtain very good counts after some training.

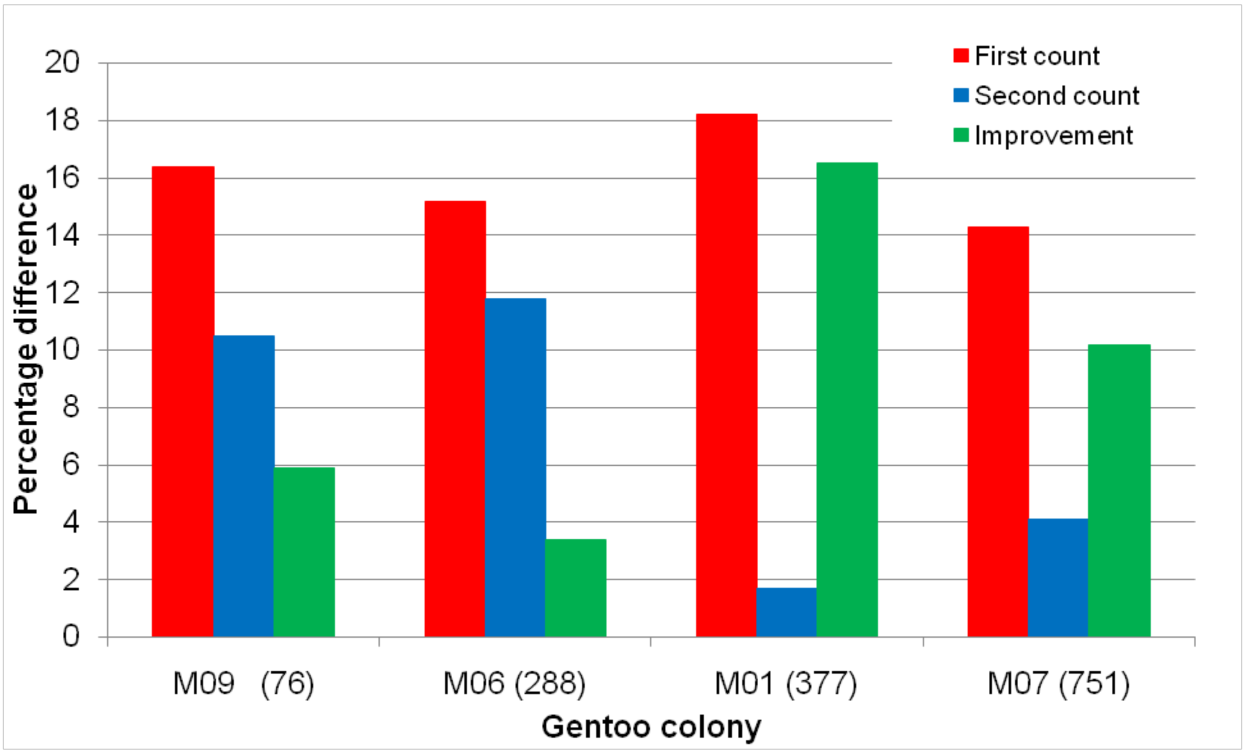

Figure 8 - Improvement of count accuracy with increasing counting experience. The red bars are differences among operators (one experienced operator used as baseline, plus two inexperienced ones) during the first count of all gentoo colonies. The blue bars are differences in the second count, and the green bars are the improvement between counts. In parentheses number of nesting pairs in the colony.

Rockhopper penguins

To obtain rockhopper penguins imagery we flew our UAVs at 10 to 25 meters. We never went below 10 meters, and pictures taken above 25 meters were not useful to count rockhoppers. We noted modest rockhoppers reaction even at the lowest altitude.

Rockhopper penguins often nested in mixed colonies together with imperial shags, but the two species were easily discriminated in UAV pictures (Figure 9). Counts carried out on the four rockhopper penguin colonies over three consecutive breeding seasons (2016-2017 to 2018-2019) showed that there was positive relationship between manual and UAV counts of both nests (N =12, R^2 = 0.9834, se(R^2) = 0.0569, LCL(R^2) = 0.6162, UCL(R^2) = 0.9966) and chicks (N =12, R^2 = 0.9934, se(R^2) = 0. 0060, LCL(R^2) = 0.9650, UCL(R^2) = 0.9993). On the other hand, manual counts systematically underestimated both the number of nests (mean = -4.6%, maximum = -25.8%) and chicks (mean = -5.8%, maximum = -21.0), although the difference was concentrated in the biggest colony (250-300 nesting pairs).

Figure 9 - A mixed colony where rockhopper penguins nested together with imperial shags.

All together, UAV counts improved over manual counts, but the improvement was smaller than the one observed in gentoo penguins. Moreover, rockhopper chicks aggregated in crèches often hidden below rocks, rendering quite difficult to obtain accurate counts both manually and from drone pictures (Figure 10).

Figure 10 - Enlargement of a UAV picture of rockhopper penguin chicks aggregated in crèches.

Imperial shags

To obtain imperial shags imagery we flew our UAV at altitudes between 15 and 50 meters. Due to the size of their largest colony (up to 1300 nesting pairs, Figure 11), multiple images and stitching were required. Reaction of imperial shags was the lowest of all colonial birds, probably due to the heavy background noise of their large colonies. As a precaution, we flew our UAVs over imperial shag colonies when aerial activity of adults leaving or returning to the nests was minimal.

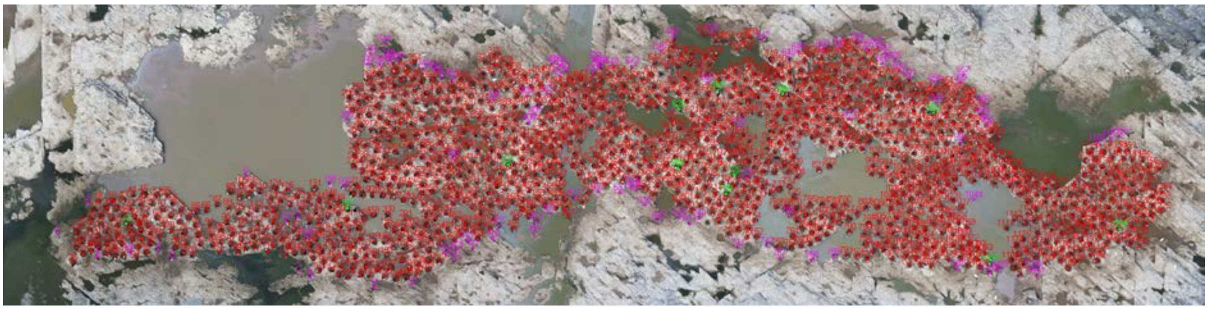

Figure 11 - Composite image of the main imperial shag colony. The image was obtained by stitching together various UAV pictures taken from an altitude of 15 meters.

Figure 12 - Enlargement of a UAV picture of an imperial shag colony taken at maximum altitude. Notwithstanding the picture was taken from an altitude of 50 meters the different imperial shag classes were easily discriminated.

Counting of imperial shag nests in UAV pictures was very easy. In composite pictures of the main SLI colony we obtained accurate counts even by inexperienced field helpers, and even using imagery taken at the highest altitude (50 m; Figure 12). The only drawback of counting large imperial shag colonies on UAV pictures was the stitching of the pictures, which required careful manual validation to avoid the creation of artefacts like the duplication of nests in the border areas.

The total number of nests was remarkably similar between counters, with coefficient of variations of about 0.01 for the composite image from low (19 m), medium (25 m) and high (50 m) altitude UAV pictures. Similar CVs of about 0.01 were obtained for the total number of adults. All together, the counts of imperial shag nests showed the better agreement between counters of all bird species. On the other hand, counting of imperial shag chicks was very difficult, because chicks were often masked by brooding adults and, being fully black, they were difficult to separate from the background. We were also able to count roosting imperial shags in UAV pictures when manual counting was impossible (counts of up to 15300 adults).

Rock shags

Rock shags present peculiar problems for counting, because they nest on cliffs which bottom is usually difficult or impossible to access (Figure 13). Rock shag nests can possibly be counted by boat, but this is strongly weather and site dependent. We were unable to test the effectiveness of boat counts because of the lack of a suitable boat. UAV pictures are ideal to count rock shags because they permit to easily cover the whole SLI cliff coastline without introducing any observability bias.

Figure 13 - Rock shag nesting area.

In 2018 72 UAV pictures were required to cover all rock shag breeding sites. Two operators counted the pictures. Repeatability of counts was very high (Table 3). The operators counted the same total number of nests and the difference in total number of adults was very small

(0.9%). On the other hand the less experienced operator underestimated the total number of chicks (-11.3%).

Count	R	se(R)	LCL(R)	UCL(R)
Nests	0.9971	0.0007	0.9953	0.9981
Chicks	0.9822	0.0042	0.9719	0.9888
Adults	0.9973	0.0006	0.9957	0.9983

Table 3 - Repeatability of rock shag counts obtained from UAV pictures. R: repeatability; se(R): standard error of repeatability; LCL(R) and UCL(R): lower and upper limits of the 95% confidence interval of repeatability.

Kelp and dolphin gulls

In 2016-2017 we had a single mixed kelp and dolphin gull breeding colony, located in a flat grass area close to Sea Lion Lodge and, therefore, much exposed to human disturbance. We refrained to carry out direct counts in this sensitive situation, and we conducted just UAV surveys. The UAV was flown at 15 to 30 meters of altitude over the colony (Figure 14).

Figure 14 - A mixed kelp and dolphin gull breeding colony. Taken from 15 meters of altitude. The two species can be easily discriminated, and resolution is high enough to permit chick identification.

In all surveys none of the nesting gull, either kelp or dolphins, left the nest, so impact of breeding birds was minimal. In the pictures taken we were able to recognize the two species and count adults, occupied nests, and chicks all along their development. Pictures taken at altitude above 30 meters were not useful because in those pictures it was difficult to recognize nesting adults, and almost impossible to accurately count chicks.

Southern sea lions

Sea lion surveys were carried out by lunching the UAV from top of the cliff, and flying it at 10 to 30 meters of altitude (Figure 15).

On imagery taken above 30 meters of altitude it was still possible to count sea lions, but the accurate counting of pups was more difficult, and the safe recognition of sex and age classes was not fully possible. In particular, it was difficult to discriminate females from juvenile males. Sea lions showed no reaction to the UAV during counting survey. We made trials flying the UAV over specific groups of sea lions to obtain footage to be used for a pilot behavioural study, and we were surprised by the lack of sea lions reaction. We flew the UAV at 5 meters distance over groups of pups playing in shallow water, to obtain footage to be used to determine play behavioural modules, and the pups had a totally natural behaviour, never directing attention to the UAV. With the UAV we were able to survey places previously totally inaccessible to us. In the case of sea lions, we were able to fly over Rum Island, and we identified pups born there.

Figure 15 - UAV picture of the southern sea lion colony. It is possible to count accurately individuals of the different sex and age classes, including pups (red dots). Moreover, it is possible to determine territorial limits (red lines) and, therefore, assign females and pups to the different territorial males.

The comparison of manual counts vs UAV counts showed that manual counts were a rather poor predictor of UAV counts. The percentage of variance in drone counts explained by the linear regression on the corresponding manual counts ranged from 23% for juveniles to 89%

for adult males, and was below 70% for the two most important classes, breeding females and pups (Table 3). Manual counts underestimated the number of pups in all cases (Figure 16), with an average difference of -15.2% (maximum = -44.0%). Manual counts also underestimated the total number of sea lions, with an average difference of -10.1% (maximum = -30.7%). The difference was mostly due to the fact that individuals resting at the base of cliffs surrounding the breeding colony were not visible from the top of the cliffs and , therefore, were impossible to count manually.

Class	**R^2**	**se(R^2)**	**LCL(R^2)**	**UCL(R^2)**
Adult males	0.8931	0.0441	0.7821	0.9637
Females	0.5819	0.2017	0.1065	0.8805
Pups	0.6803	0.0952	0.5047	0.8778
Sub-adult males	0.6720	0.1087	0.2818	0.8549
Juvenile males	0.2258	0.1829	0.0222	0.6956
Y+YY	0.5022	0.1628	0.1561	0.8548
Total	0.5352	0.1939	0.0003	0.7756

Table 3 - Linear relationship between manual and UAV counts of southern sea lions. R^2: coefficient of determination of the linear regression of UAV counts on manual counts (= % of variance explained); se(R^2): standard error of the coefficient of determination. LCL(R^2) and UCL(R^2): lower and upper limits of the 95% confidence interval of the coefficient of determination.

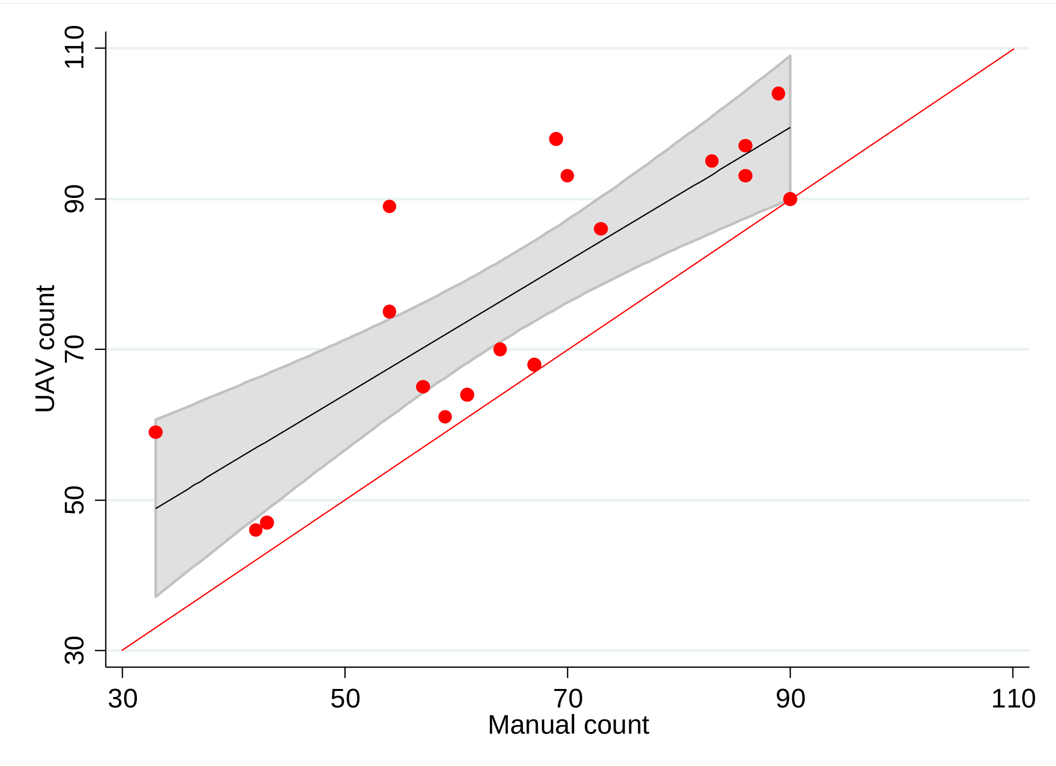

Figure 16 - Linear regression of UAV counts of pups on manual counts. Black line: linear regression line. Grey area: 95% confidence band of the regression. Red line: line of equality between UAV and manual counts.

All together, manual counts can provide a poor estimate of the number of sea lions, and in particular of pups and breeding females, and only UAV counts can provide a reliable assessment of population status, productivity, and trend. An advantage of manual counts over UAV counts is that direct observation is useful to improve the recognition of male classes. In UAV photos it is often difficult to recognize in UAV large juveniles from small sub-adults, and large sub-adults from adults.

Elephant seals

To obtain imagery useful to study southern elephant seals harem structure we flew the UAV at an altitude between 15 and 50 meters (Figure 17). At these altitudes, it was possible to safely count all sex and age classes, and to safely discriminate males. It was often possible to identify seals by reading their dye marks.

Figure 17 - Group of moulting elephant seals, directing their attention toward the UAV. Taken at 10 meters of altitude.

Contrary to expectation, reactivity of elephant seals to the UAV was higher than the one of sea lions (Figure 17). Often, elephant seals directed their attention to the UAV and, on average, 10% of the seals raised their head towards the UAV when it was flown at low altitude. Reaction was brief and limited to oriented alert, and no seal moved away or interrupted resting. We made some trials flying the UAV at very low attitude, down to 2 meters over the seals, and in no case reaction was stronger that oriented alert (Figure 18). The higher reactivity of elephant seals was probably due to their acoustic sensitivity for low frequency sounds (Kastak & Schusterman 1998), similar to those produced by the UAV engines. An added value of the UAV use with elephant seals was that we were able to regularly survey Rum Island, confirming that there is no breeding of elephant seals there, and being able to count seals there, and identify dye marked individuals, during the moulting season.

Figure 18 - Testing very low altitude flight over an elephant seal harem. Some breeding females raised their heads and looked at the UAV, but resumed resting almost immediately. Pups showed no reaction to the UAV.

Figure 19 - Spatial structure of an elephant seal harem on a UAV photo. Points and lines of different colours are used to mark different classes of seals and different measures. The coordinate in pixels can be transformed in Cartesian coordinates using the altitude derived scale, and the resulting points can be studied using spatial point pattern analysis.

Figure 20 - Measurement of the elephant seal body size in a UAV photo. The UAV photos can be scaled using the camera sensor size, the photo size, the camera lens length and the UAV altitude. from the scaled photos various measurements of body size can be obtained, e.g., to determine the size distribution of breeding females.

Figure 21 - Measurement of the mother-pup distance in a UAV photo. Even UAV photos taken from high altitude (50 m) have enough resolution to permit measurement of individual features. In this case we were able to measure the body length of the female and the mother-pup distance.

By using the altitude information recorded in the EXIF of the UAV photos and the characteristics of the sensor and lens of the UAV camera we were able to determine the pixel size in cm, and, therefore, to scale pixels to real size. From the scaled photos, we were able to determine the study spatial structure of the group (Figure 19), to obtain various measures of the seal body size (Figure 20), and to estimate the inter-individual distances, with a specific focus on the mother-up distance (Figure 21).

Killer whales

The use of the UAVs produced a quantum leap in our understanding of killer whale behaviour and activity at large. The UAVs were flown at 5 to 50 meters of altitude. Killer whales have a highly structured social organization and a complex activity pattern, so it was normally not possible to follow all individuals at the same time and, therefore, video footages were obtained by concentrating on a single pod or individual. Due to the battery limitation of our UAVs, we were able to obtain just short video segments, but we combined more than one flight obtaining an almost full coverage of events, e.g., up to many hours of follow up during predation events. Reactivity of killer whales to the UAV was null, and we found no sign of UAV disturbance both in the behavioural sequence of each individual and in the global activity of the group.

Figure 22 - Killer whale suckling behaviour. Calf Pinnino (3 years old) was still suckling from its mother Puma, a behaviour that we were never able to observe from land.

The overall killer whale activity and association observed in UAV footage were very different from the ones observed from land. In particular, killer whale video footage showed more variable association patterns than the ones observed from land.

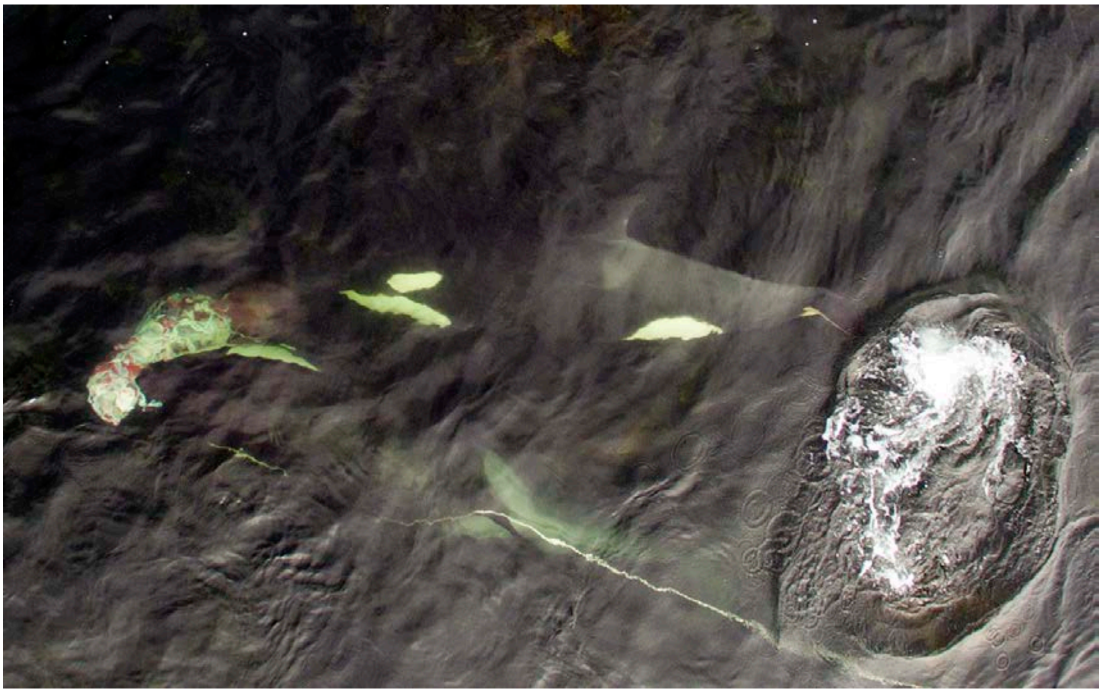

Figure 23 - Killer whales with sea lion prey. During this predation event the prey was never seen at the surface and, therefore, it would have been impossible to classify the event as a sure predation event by observing it from land.

Figure 24 - Prey sharing between adult and calf. The adult (top animal) is passing a piece of the prey to the calf (bottom animal).

In the UAV videos we observed complex behaviours that are impossible to observe from the coast, like calf suckling (Figure 22), underwater manipulation of the prey (Figure 23), prey sharing (Figure 24), and help and support by adults to the younger individuals, e.g., to keep prey carcass close to the sea surface.

To improve the follow up of killer whales during predation events we experimented flying two drones at the same time, keeping them either on different killer whale groups, or at different altitude, with a minimum separation of 10 meters. Flying two drones at the same time was particularly useful during elephant seal weanling predation events, because during those events often the individual carrying out the take and kill resumed the search for a new prey, while the calves continued the handling of the current one. The flying of two UAVs at the same time had no effect on killer whale behaviour.

Conclusion and perspectives

Our extensive testing of UAVs surveys of a large array of bird and mammal species showed that UAVs are an exceptionally productive tool for wildlife research and monitoring. For birds, it was possible to obtain accurate counting data of most species, and the disturbance of the UAV flights was low, and lower than direct counts. Counting in UAV pictures permitted to: 1) repeat counts and assess intra-counter reliability; 2) have more than one counter, and assess inter-counter reliability; 3) produce consensus estimates of the different counting classes by repeated inspection of the same picture. An added value of UAVs usage was the reduction of field time required for each colony or group compared to manual counts. For mammals, UAVs usage permitted to greatly improve the accuracy of southern sea lion counts, and to speed up the collection of demographic, spatial and phenotypic data for southern elephant seals. Moreover, UAVs produced a quantum leap in our understanding of killer whales behaviour, showing underwater grouping and association patterns that were different from surface patterns, and permitting us to observe underwater behaviours that were simply impossible to observe from land.

We have three main goals for the future. Firstly, we would like to improve the standardization of our UAV survey protocol. Our final goal is to run automated surveys, in which the UAV will follow established routes, taking pictures and/or video following a pre-programmed protocol, with the least human intervention possible. This will permit to repeat surveys along years producing comparable and repeatable imagery. Then, we are working on post survey pipelines to process the UAV pictures to reduce as much as possible the time and effort required to go from pictures to quantitative results that can be useful not only for monitoring but also for management actions. Lastly, we would like to use UAV surveys as the basis for an integrated environmental monitoring programme for Sea Lion Island.

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