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Tracking at sea the elephant seals of Sea Lion Island. 2011 report.

Ensenada, BC, Mexico, 28/01/2012

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Abstract

We deployed a total of 24 satellite linked tags on female southern elephant seals at Sea Lion Island (Falkland Islands; SLI hereafter) during the 2009-2011 breeding season, to track their movements at sea. Although southern elephant seal females have been frequently satellite tagged in other populations of the South Georgia stock, this was the first tracking-at-sea project carried out on elephant seals of the Falklands. In this report we briefly summarize the rationale of the project, we describe the deployment procedure, we present results on the movements of the tagged females, we discuss the pros and cons of the project, and of the deployment procedure in particular, and we examine the perspectives of the project follow up. We conclude that: 1) the deployment procedure has been successful, with modest risk for the animals and collection of useful data; 2) SLI represents an ideal place for a large scale tracking project, due to the tameness of the seals, the easiness of the logistics, and the availability of a large amount of background information on the possible subjects; 3) the information collected until now highlights some very interesting, and not expected, patterns, with most seals foraging rather close to the Falklands and/or on the continental shelf; 4) the fact that the majority of females forage close and in some cases very close to the Falklands coast, changes the perspective, because increases the chances of a direct interaction with human activities (fisheries, oil exploration) and implies a greater local responsibility in securing a safe future to SLI elephant seals; 5) with the use of more sophisticated tags, with better data collection capabilities, it would be possible not only to improve the knowledge about SLI elephant seals, but also to generate data and information of general relevance, both locally (e.g., oceanographic data useful for the fisheries operations) and internationally (e.g., integration in the SEaOS, “Southern Elephant Seals as Oceanographic Samplers”, project). All together, we are convinced that the first years of the study were a success, and we plan to follow up for at least one more breeding season, thanks to the licence granted by the Falkland Islands Government in 2010. During the next (2012) breeding season we would like to deploy 12 more satellite tags, including some tags with diving data collection capabilities, and we are currently trying to secure funding to achieve this goal.

Project rationale

Southern elephant seals (*Mirounga leonina*) have been tracked at sea in various populations of the South Georgia stock, including South Georgia (McConnell and Fedak 1996), the Valdés Peninsula (Campagna et al. 1998, 1999), and King George Island (Bornemann et al 2000). On the contrary, no research project on the aquatic phase of their lifecycle has been completed on elephant seals of the Falklands, although there is an ongoing study on individuals that moult on Carcass Island. The Falklands population of elephant seals is very small, and mostly limited to a single breeding colony at Sea Lion Island (SLI hereafter), so there are apparently no compelling arguments to set up a project of global relevance. On the other hand, SLI elephant seals are an important component of the Falklands biodiversity (Falkland Islands Species Action Plan for Seals and Sea Lions 2008 – 2018), and may represent a conduit for gene flow among the two main populations of the stock, South Georgia and the Valdés Peninsula, and among stocks (Fabiani et al. 2003).

During the past 17 years we have run a long term research project on the seals of Sea Lion Island (see www.eleseal.org), which shelter about 90% of the elephant seals of the Falklands. Our interest was, and still is, focused on the lifetime survival and breeding strategies of individual seals, and their implications for evolution theories. Therefore, we accumulated a large database of information on individual life histories of a large number of seals, but we almost completely lacked information on the aquatic phases of the elephant seal life cycle. Although re-sights of seals marked with cattle tags is giving us some indications, only the tracking at sea can answer questions about feeding areas, movement patterns, and strategies used to recovery from the prolonged fast and large weight loss experienced during the land phase of breeding.

Project goals

Being a small scale operation, limited by the funds availability and the constraints of the research licence (maximum of 12 satellite tagged females per season), the project was set up with some simple goals in mind, to build a first knowledge base of SLI elephant seals movements at sea and foraging. Therefore, our specific goals were:

1) To work out the details of a good protocol for chemical sedation (including emergency procedures), monitoring of the subject, collection of samples, and deployment of the satellite tag
2) To collect data about movements at sea, and to determine the elephant seals feeding areas
3) To carry out a comparison with feeding areas and patterns of other populations of the South Georgia stock, using information available in the literature
4) To assess the potential overlap and interaction between SLI seals feeding at sea and human activities, including fisheries and oil exploration
5) To compare the movements at sea and the feeding areas of females of different ages classes, and with different breeding histories

6) To set up the basis for a larger scale deployment project, covering all the sex/age classes, and employing tags with better data collection capabilities

Methods

See Appendix I for annotated pictures of the various phases of the satellite tag deployment.

Time and place of the deployments

We deployed 6 tags in 2009, 12 in 2010, and 6 in 2011. All deployments were carried out during a short time span (31/10-02/11/2009, 23-25/10/2010, and 21-22/10/2011), a few days after the peak haul out of females (that was on 20/10 in 2009 and on 19/10 in 2010 and 2011). Females were chosen in the two main elephant seal breeding areas, either on the South side or on the North side of the East tip of the island (Figure 1). These are the areas where most of the breeding females (> 90%) are concentrated. More details about the SLI population can be found elsewhere (Galimberti and Boitani 1999; see also www.eleseal.org). Just one of the subjects (Berta, 2009) was a solitary female. She was the first female that we tagged, and we chose a solitary female to handle the first subject without having other seals around. All other females belonged to harems representing the whole harem size range observed at SLI.

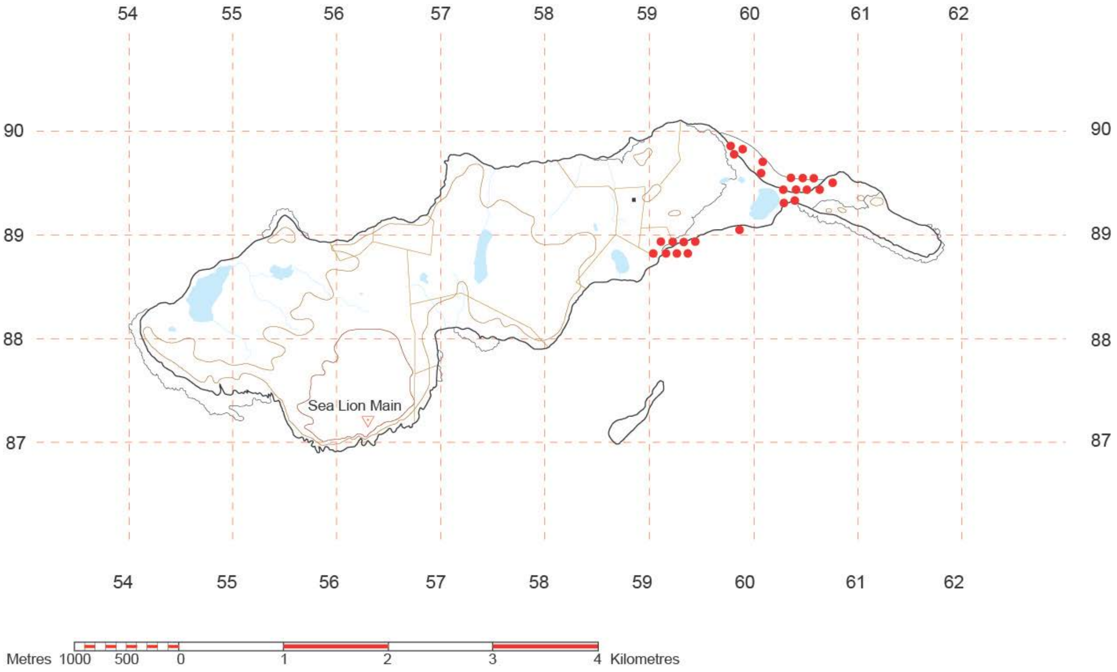

Figure 1 – Location of the deployment sites (each red dot is one tagged female).

Choice of the satellite tag model

We choose the SPOT5 tag (Wildlife Computers Inc., www.wildlifecomputers.com) because it is a simple (location only) and relatively cheap (approx 1400 USD) tag of proven reliability, that has been frequently deployed on elephant seals (e.g., Campagna et al. 2006) and that represents the entry level tag for this kind of study. The SPOT5 tag transmits messages to the Argos satellite system, that relays them to a ground stations system, where the messages are processed and used to calculate the location of the tags using the Doppler effect (see www.argosinc.com for more details about how the Argos system works). SPOT5 tags are lightweight (108 grams in the configuration used in this study), have a hydrodynamic shape (Figure 2), and are very often deployed on animals of much smaller size than breeding female elephant seals. SPOT5 tags are available with flat bottom and curved bottom. In 2009, we choose the second option because the tag was to be deployed on the head of the seal, to improve the likelihood of an effective transmission, and a curved bottom tag may fit better the head surface of a seal. Then, we noticed that the curved bottom does not really improve the fit, and complicates the fitting of the mesh (see below), and so in the following deployments we used the flat bottom configuration.

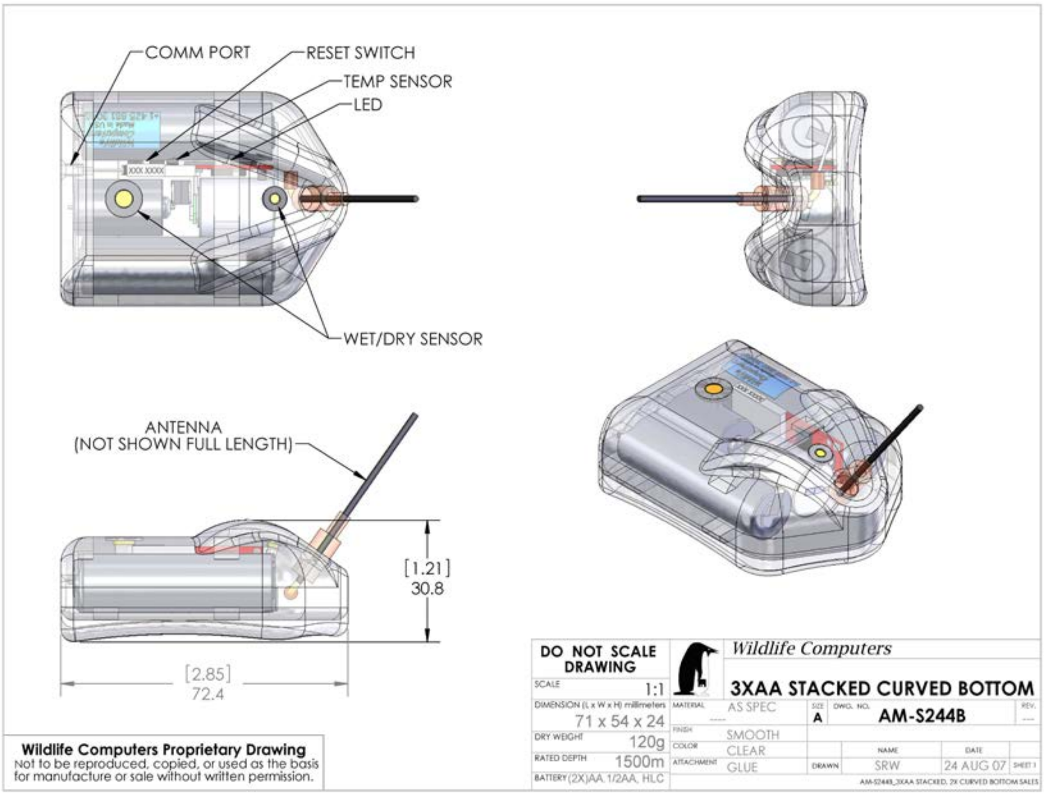

Figure 2 – Technical drawings of a curved-bottom SPOT5 tag. Courtesy of Wildlife Computers Inc. (www.wildlifecomputers.com).

Prepping of the satellite tags for deployment

The following steps were followed to prepare the tag for deployment:

- Each satellite tag was sanded on its bottom to favour gluing of the mesh.
- The wet/dry sensors of each tag were covered with electric tape, to avoid gluing them during the tag preparation and attachment to the seal. The tape was then removed at the end of the tag deployment.
- A piece of strong mesh was attached to the tag bottom, in order to increase the surface available for gluing and to favour the attachment by letting the seal fur

to pass through the mesh. The mesh was fixed to the tag using cable ties and strong fishing line, and glued to its bottom with a small quantity of cyanocrylitic glue (HotStuff Classic).

- Each tag was programmed to send a message to the satellite every 45 seconds when the seal was at the surface. Programming was carried out using the TagWare software (Wildlife Computers).
- Each tag was launched a few days before the actual deployment, to be sure that it was working properly. All tags transmitted well during the test.

Choice of the study subjects

Each subject was chosen considering the individual age and breeding history, and the contingent situation of the harem at the time of the deployment attempt. Individual information of the satellite tagged seal is summarized in Table 1.

Year	Name	Born	Age	Year of first pup	Age at first breeding	Breeding seasons	Pup sex
2009	Berta	2005	4	2009	4	1	F
2009	Wara	1999	10	2003	4	7	F
2009	Tina	2005	4	2009	4	1	M
2009	Axes	1995	14	1999	4	11	F
2009	Feta	2001	8	2005	4	5	M
2009	Paola	1997	12	2002	5	8	F
2010	Giada	2000	10	2004	4	7	M
2010	Trip	1999	11	2003	4	8	F
2010	Linda	2006	4	2010	4	1	F
2010	Bub	1998	12	2002	4	9	F
2010	Foxi	2003	7	2007	4	4	M
2010	Nove	2005	5	2009	4	2	M
2010	Olga	2001	9	2006	5	5	F
2010	Toy	2000	10	2004	4	7	M
2010	Moka	2005	5	2009	4	2	F
2010	Afa	1996	14	2000	4	11	M
2010	Hoc	2004	6	2009	5	2	M
2010	Giti	2005	5	2009	4	2	M
2011	Jise	2002	9	2006	4	6	F
2011	Lisa	2003	8	2007	4	5	M
2011	Arca	2001	10	2005	4	7	F
2011	Eux	2007	4	2011	4	1	F
2011	Das	2002	9	2006	4	6	F
2011	Xora	2006	5	2011	5	1	F

Table 1 – Individual data of the subjects. Age in years (at the time of deployment).

We choose females with the following characteristics:

- Known age (tagged as pups at SLI).
- Age between 4 and 15 years. We tried to choose females of different age classes to study the differences in feeding strategies adopted by females of different age. We excluded females older than 15 years of age because of the greater risk associated with the anaesthesia for older seals, and the greater natural mortality rate.
- Known breeding history, including age of first parturition.
- Breeding in one of the main breeding areas of SLI (east portion of the island).
- Pup at medium to late stage of development (14-20 days of age). We choose females with rather mature pups, because of the very low risk of abandonment and good chances to survive to it in the unfortunate case this would happen. At the same time, we choose females likely to remain on the island for at least a few days after the deployment, to be able to monitor their status before their return to sea.

At the time of deployment we carefully considered the position of each subject with respect to the other seals. We chose females that were on the edge of harems, to be able to safely work with them, and we examined the distribution and identity of the nearby males. We considered the distance from the water and the tide level, and we chose females on the land side of harems and as far from the water as possible, to avoid the risk of a partially anesthetized female going into the water. We also checked with binoculars the head of the subject, to avoid deployment on females with head wounds or scars, which would make the tag attachment impossible or less effective.

Median year of birth of satellite tagged females was 2002 and median age at deployment was 8.5 years (median absolute deviation = MAD = 3). Most tagged females gave birth the first time at 4 years of age, and they bred for a median of 5 seasons (MAD = 3) before being satellite tagged. Age distribution of satellite tagged females is shown in Figure 3. Females of the 4-5 age class were mostly primiparous females. The 10+ class included females 10 to 14 years old. Pups of satellite tagged females were 58.3% females.

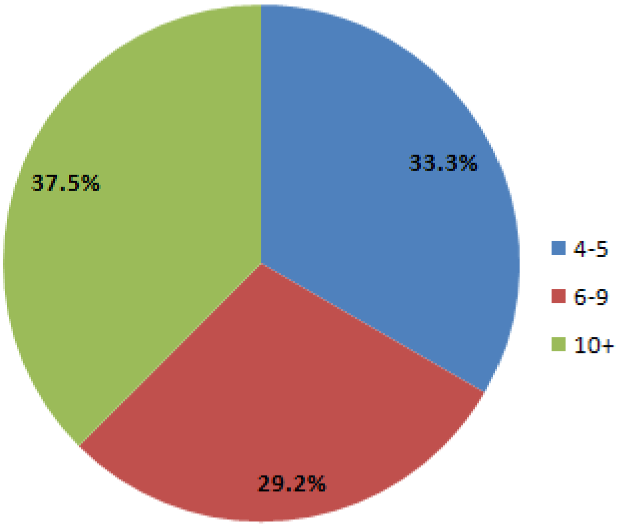

Figure 3 - Age distribution of satellite tagged females. N = 24

Year	Name	IM anaesthetic	IM quantity (mg)	IM dose (mg/Kg)	IM Atropine (ml)	IV anaesthetic	IV quantity (mg)	IV dose (mg/Kg)
2009	Berta	Zoletil 50	300	1.07	2.0	Ketamine	100	0.36
2009	Wara	Zoletil 100	480	1.00	2.0	Ketamine	300	0.63
2009	Tina	Zoletil 100	250	1.00	1.5	Ketamine	150	0.60
2009	Axes	Zoletil 100	650	1.30	2.0	None	0	0.00
2009	Feta	Zoletil 100	420	1.00	2.0	Ketamine	250	0.60
2009	Paola	Zoletil 100	500	1.00	2.0	None	0	0.00
2010	Giada	Zoletil 100	380	1.00	1.2	Zoletil 100	180	0.47
2010	Trip	Zoletil 100	300	1.03	1.2	Zoletil 100	250	0.82
2010	Linda	None	0	0.00	0.0	Zoletil 100	230	0.88
2010	Bub	Zoletil 100	450	1.00	2.0	None	0	0.00
2010	Foxi	Zoletil 100	350	1.09	2.0	None	0	0.00
2010	Nove	Zoletil 100	400	1.00	1.2	Zoletil 100	250	0.63
2010	Olga	Zoletil 100	380	1.00	2.0	Zoletil 100	150	0.39
2010	Toy	Zoletil 100	320	1.00	2.0	Zoletil 100	80	0.25
2010	Moka	Zoletil 100	300	1.03	2.0	None	0	0.00
2010	Afa	Zoletil 100	420	1.00	2.0	None	0	0.00
2010	Hoc	Zoletil 100	350	1.03	2.0	None	0	0.00
2010	Giti	Zoletil 100	280	1.00	2.0	None	0	0.00
2011	Jise	Zoletil 100	450	1.07	1.2	Zoletil 100	150	0.33
2011	Lisa	Zoletil 100	500	1.00	1.2	Zoletil 100	100	0.20
2011	Arca	Zoletil 100	380	1.09	1.2	Zoletil 100	150	0.43
2011	Eux	Zoletil 50	250	1.00	1.2	Zoletil 100	100	0.40
2011	Das	Zoletil 100	350	1.04	1.2	Zoletil 100	150	0.45
2011	Xora	Zoletil 100	270	1.08	1.2	None	0	0.00

Table 2 – Details of the anaesthetics used during the satellite tag deployments.IM: intramuscular, IV: intravenous

Weight estimate of the subjects

Each subject weight was estimated before the start of the procedure, to calculate the right amount of anaesthetic to administer. The two PIs, who have good experience of elephant seals, eyeballed a consensus weight estimate. In some cases, a weight estimate obtained by applying a photogrammetric method (Bell et al. 1997) was also available. These pre-deployment weight estimates were a good approximation of the real weight (see Results).

Recording of the procedure

One operator was in charge of timing and serially recording all the phases of the whole procedure, including the area and harem, weight estimate of the subject, drugs administered, biological samples taken, physiological parameters, behaviour of the subject and the pup, etc. These notes were used to produce a full transcript that was assembled at the end of each deployment day. Transcripts are available upon request (fil_esrg@eleseal.org).

Chemical restraint

Once the subject was chosen, we proceeded with the chemical restraint. Anaesthesia was carried out by: 1) an intramuscular (IM) injection of Zoletil 50 (50 mg/ml) or Zoletil 100 (100 mg/ml; Virbac); 2) supplementary sedation by intravenous (IV) Zoletil or ketamine (ketamine hydrochloride, 100 mg/mL, Wyeth Ketaset) if required. Zoletil is a mixture of tiletamine and zolazepam, and is the standard anaesthetic for elephant seal sedation (McMahon et al. 2000). IV sedation was used in 62.5% of the deployments. In one case, only IV sedation was used, with the subject briefly restrained by hand using a head bag. In 2009 the IV sedation was carried out with ketamine, but then we preferred to use a single anaesthetic, to simplify the procedure, and so we used Zoletil for both IM and IV. Zoletil 100 was used in 91.3% of the IM sedations (N=23) and 73.3% of the IV sedations (N=15). Details of the anaesthetics used for each subject are reported in Table 2.

For the IM sedation, we used the dose of 1 mg/kg intramuscularly as per Baker et al 1990. An average of 1.6 ml atropine sulphate (0.600 mg/mL, Atrocare) was also included in the initial dose to prevent excess secretions in the respiratory tract and salivation (Woods et al 1994). The drugs were drawn into a 20 ml syringe already partially filled with physiological solution through a 3 m extension tubing (Ryding 1982). A 9 cm long spinal needle was fitted at the end of the tubing. The subject was approached from the front by one experienced operator to attract its attention, while another operator approached it from the back and placed the needle in the lumbar muscles. The reaction of the subjects to this injection was always moderate. The second operator waited for the seal to become quite again, checked that the needle was placed in the right position and at the right depths (the needle needs to pass through the blubber layer to actually reach the underlying muscle), and injected the whole content of the syringe (anaesthetics plus physiological solution).

After IM injection the level of sedation was checked, initially after 5 minutes and then every 3 minutes, until the sedation was deep enough to permit the tag deployment. Sedation level was checked by touching the back, flank and finally head and nostrils of the subject, and judging its response. Sedation was considered satisfactory when the subject was not able to raise its head under stimulation.

If the plane of anaesthesia was considered not enough to carry on the procedure, see below), ketamine (2009) or Zoletil (2010-2011) was injected intravenously through the extradural vein. The site to access the vein was searched by palpation, firstly locating the hips, then placing the hands on the spine at the hips level and moving frontward about 15-20 cm, and then looking for an inter-vertebral space. A 9 cm spinal needle was inserted into the vein, and left in place, ready to be used to inject anaesthetic if/when needed. IV anaesthetic was administered either before the start of the actual tag gluing, or throughout the procedure, whenever was considered necessary to increase the level of sedation. IV anaesthetic administration was attempted even if the level of sedation after IM injection was very low. The reaction at the back of the subject was much reduced even in case of very low sedation, and it was possible in partially sedated subjects, and in very lightly sedated one, in this case with the help of manual restraint of the subject using a head bag (see Appendix 1).

Isolation of the subject and work area preparation
Once the subject reached the right level of sedation, we isolated it and its pup from other seals, to maximize the safety of both the subject and the operators. If the subject was totally isolated from other seals, we simply checked that no seals approached it during the procedure, being ready to stop approaching seals using a tarpaulin. If the subject was partially isolated, with only few seals close by, we gently moved those seals back from the subject using a tarpaulin. If the subject was on the edge of a harem, we gently moved back the animals closer to the subject with the tarpaulin and we then placed one or two cars between the subject and the harem to improve isolation and guarantee a safe follow up of the procedure. The main risk for the sedated female is a mating attempt by a harem holder or a peripheral male. The harem holder tried to approach the sedated female in just one of the 24 deployments, but he was driven away using a tarpaulin and was not able to reach the subject.

Morphological measurements
As soon as the subject reached the desired level of sedation, we proceeded to measure length, width and girth of the subject, both directly and by means of the photogrammetric method mentioned above (section on weight estimation). Straight nose to tail and nose to fore flipper attachment length was measured using a surveying pole lying on the side of the animal, while curvilinear nose to tail length (dorsal standard length) was measured using a flexible measuring tape. The girth was measured just behind the flippers and was done by wrapping a piece of string around the seal and then measuring the string. Lateral and frontal pictures of the seal, with the surveying pole included in the frame as a scale, were taken to estimate photogrammetric length, side area, and girth perimeter and area. Weight was later estimated both from the direct measurements and from the photogrammetric ones, using conversion equations from Bell et al. (1999).

Blood sampling and IV access maintenance
Blood samples were taken from the extradural vein, using the same access eventually used for IV administration of anaesthetic. As soon as the sedation level was good, we collected blood samples to study:

- hormone levels in whole blood spotted on filter paper and in serum
- gene expression in the Major Histocompatibility complex (MHC), the area of genome related to immunity and resistance to pathogens; in this case, white blood cells are separated from the blood, and RNA is extracted from them

- haematology, blood chemistry and coagulation

Blood sampling was carried on using a sequence of appropriate Vacutainers (Becton Dickinson), and took less than one minute to be completed. The needle used for IV access was a spinal needle (9 cm long; BD Spinal Needle 18G 3 1/2"), fitted with an insert that can be placed inside the needle hole. The needle was inserted in the extradural vein and left in place during the whole procedure, to be able to administer IV anaesthetic as needed. We made sure that the needle was always clear from clotted blood by washing it with physiological solution after each blood sampling, and by closing it with the needle insert.

After collection, blood samples were processed and shipped to the Veterinary Services for haematology analysis and to King Edward Memorial Hospital for biochemistry and coagulation analysis. Results of the analysis are currently being incorporated in a manuscript about blood reference values that is in preparation.

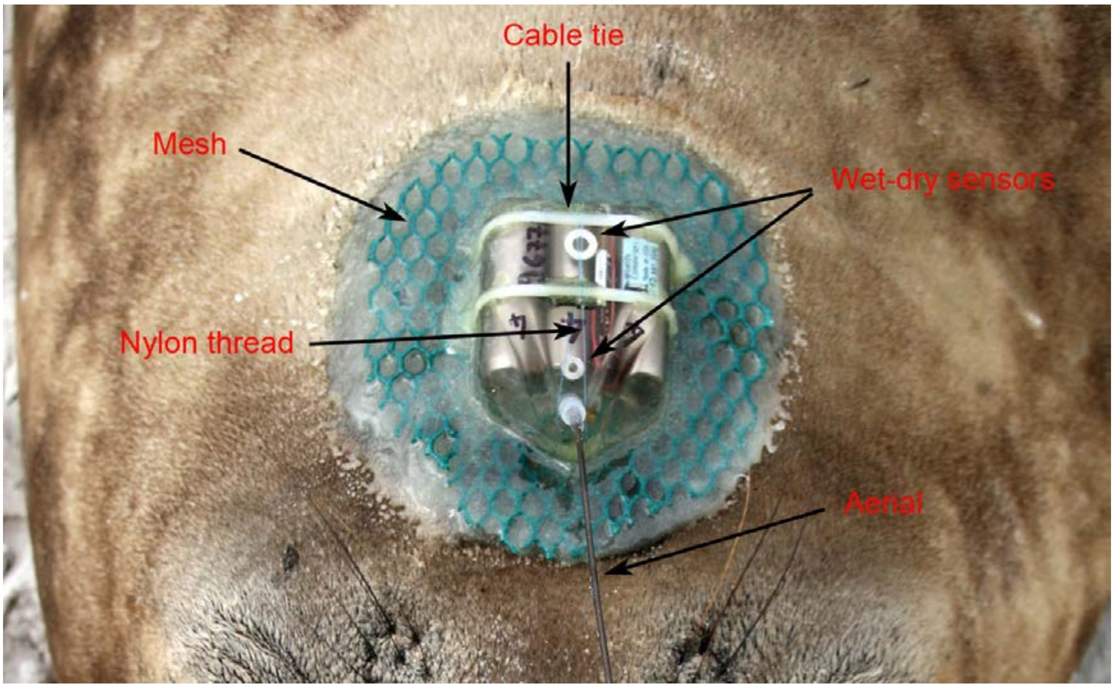

Figure 4 – The SPOT5 tag glued on the head of female Axes.
Wet/dry sensors permit to optimize the data collection because the tag transmits only when the subject is on the surface, prolonging the batteries life.

Attachment of the satellite tag

The tag was glued on the head of the subject (Figure 4) using a fast setting (5 minutes) two components epoxy glue (Loctite Epoxy Professional in 79.2% of deployments, Devcon 5 minutes Epoxy in the other deployments). The procedure was the following:

- A towel, kept in place by a cylindrical rice bag, was placed over the subject eyes to darken the immediate environment and to protect the eyes from any glue that might have felt from the tag attachment and from blowing sand. In lightly sedated subjects (or towards the end of the procedure of some of them, when they were approaching the recovery from sedation), the towel was often not well tolerated, as was obvious from their attempt to move the head and shake it away. In those cases, we removed the towel and just protected the eyes with the hands during the gluing.

- The head of the subject was carefully inspected to detect any recent scar or old wound, which could lead to a poor attachment of the instrument.
- The head was brushed to remove sand, then cleaned with acetone to remove dirt and grease from the fur, and finally dried with compressed air.
- Epoxy glue was prepared by mixing the two components.
- The exact site for tag attachment was chosen, and a thin layer of epoxy was applied to the bottom of the tag which was placed over attachment site to leave an imprint and then removed.
- A thick layer of epoxy (enough to cover the fur texture) was then applied to the fur where the imprint was left and on the bottom of the tag; at this point the tag was applied in its final location, and more glue was applied over its edge and over the mesh, through the fur.
- The glue was “worked” with wooden sticks to avoid leaking from the tag until it started to settle (as indicated by the formation of filaments)
- After full setting, the tape covering the wet/dry sensors was removed.

After the first deployments, the glue was pre-heated to allow easier mixing and application which can be difficult in cold climate

Other biological samples collection
Once the satellite tag was attached we collected other biological samples, including:

- One nasal, one buccal and one rectal swab, to be used to investigate a range of pathogens
- A faecal sample, if possible, to study pathogens
- One skin sample, to be used for DNA extraction and genetic studies, and for stable isotopes analysis (SIA)
- One whisker, to be used for SIA
- A sample of fur, to be used for SIA

Permanent and temporary mark checking
Dye marks on back and sides of the subject were checked, and were applied/refreshed if not well visible. Rear flipper cattle tags were checked and recorded, and new tag was applied if necessary. Each seal had one tag on each rear flipper at the end of the deployment. We used a nylon moulded tag, the Jumbo Rototags (Dalton).

Pup monitoring and managing
The pup identity (flipper tag) was recorded. During the whole procedure, we checked that the pup was not going too far from the mother, or too close to the operators. This was done by simply standing in front of the pup and directing its movements if needed, using a tarpaulin if necessary. An operator was dedicated to this task for most of the time of the deployment.

Physiological parameters monitoring
During the whole procedure we tried to monitor the physiological parameters of the subjects, including heart rate, respiratory rate, rectal temperature, gum refill time, palpebral response, and assessed level of chemical restraint as often as possible. This monitoring was not regular, due to the different level of restraint of different subjects and to the necessity for operators to carry out other duties. Notwithstanding this, we always constantly monitored the breathing and heart beat rate, which can be seen by

eye and are the first and most important indicators of the actual status of the anesthetized subject.

We defined a period of more than 1 minute with no breath as apnoea. Rectal temperature was monitored using a digital thermometer and a rectal probe in some subjects. We also checked the rear flippers temperature by hand and placed cool packs on them to avoid any risk of hyperthermia, if they became unusually warm, which could be a sign of increased body temperature,.

Emergency procedures

The main risk of anaesthesia in elephant seals is prolonged apnoea (cessation of breathing). Elephant seals are used to deep dive, they can hold their breath for more than an hour, and they normally go through regular periods of apnoea when on land. There are reported cases of prolonged periods of apnoea (up to approx 45 minutes) during anaesthesia, which didn't lead to fatality or problems to the seals. Notwithstanding this, it is suggested to avoid apnoea during anaesthesia, both because apnoea may cause a decrease in blood flow and hence a slower effect of anaesthetics, and to reduce to a minimum the chance of a complete cessation of breathing. We were ready to stimulate breathing following these protocols:

- If a subject is not breathing for a minute, the first operation is the physical stimulation, achieved by first lifting its head and then vigorously scratching the throat by hand
- If physical stimulation is not working the following step is to lightly pinch the bottom of the nostrils with a needle, to stimulate pain receptors and induce breathing
- Shaking or rocking an anesthetized seal have been showed to might be effective in taking it out of apnoea
- If these simple physical manipulations are not effective and apnoea is prolonged, resuscitation procedures and equipment is available to follow up

For resuscitation procedures, we had available: 1) endotracheal tubes of various sizes for intubation and forced ventilation, 2) the respiratory stimulant doxepram (suggested dose 2mg/kg, Woods et al 1996), 3) adrenaline (no published dose for elephant seals), and 4) atropine (no published dose for elephant seals).

There were no problems during the deployments, so no emergency procedure was required. Out of 24 deployments we applied mechanical stimulation to avoid prolonged apnoea in three cases. Resuscitation procedures were never required.

End of the procedure

Once all the steps described above were terminated, we removed the IV needle, disinfected the site of both IM and IV injections with Savlon, moved all the materials away from the subject, removed the cars (if they were placed), checked that pup was close to the mother and stepped back from the subject. If the subject was still at a relatively high level of sedation, its respiration rate was checked until it started to move spontaneously.

Follow up

One operator was left observing the seal after deployment for 1 to 2 hours, until full recovery. The tagged females were then visited at least two times per day (usually more) until departure to sea. All the tagged females apart from Berta were also intensively observed because they were included in a study of female parental investment.

Collection of ARGOS data

Due to logistical constraints of our Internet access we were not able to have position data updated in real time. Therefore, we opted for the data to be transmitted by email once per day using the ARGOS tabular format, which includes not only information about each position, but also diagnostic information that permits to evaluate the performance of the tag. Twenty-three of the deployed tags transmitted for the full permanence at sea of the subjects, from the day of departure to the day of return to land for the moult. One tag did not transmit any useful information; it was the tag deployed on female Paola in 2009. Paola was observed the last time on 10/11/2009 in the evening. The day after, she was not on land anymore, but the weaned pup was observed as expected near the harem. The tags transmitted fine in the days after the deployment when Paola was still on land, so a failure of the tag is unlikely. We concluded that Paola left on the 10th of November during the night and that, either, the tag was damaged during the departure, possibly by a male trying to mate, or Paola herself was attacked and killed by orcas upon return to sea. These are the most likely explanation of the lack of transmissions from the tag. Paola did not return to SLI the following year, so the killer whales explanation is the most likely one.

Data processing

In 2009 and 2010, the Argos services provided raw location obtained by least squares fitting. Then,a new algorith based on Kalman filter was adopted. This new algorithm offers numerous inprovements over the last squares algorithm, permitting to greatly incresse the number of valid locations, in particular for difficult platforms like elephant sealsTherefore, the 2011 data was generated directly by Kalman filtering, and the 2009 and 2010 were re-processed with the new alogorithm.

The raw ARGOS data files were processed using a set of custom scripts written in Revolution 4 software (Runtime, www.runrev.com) to: 1) exclude low quality class positions; 2) exclude unreasonable positions that are completely off scale; 3) filter out positions that imply a too high travel speed; 4) assemble data by individuals, including only the filtered data; 5) calculate simple statistics about position, distance and speed; 6) link to GlobalMapper software (version 10, www.globalmapper.com) to plot individual tracks, together with the coast outline and a gridded bathymetry (GEBCO, http://www.gebco.net/); 7) plot the tracks in Google Earth.

The Argos service calculates the location of the tag and gives a quality score, called “location class”, to each position (Argos user manual, http://www.argos-system.org/manual/). Different location classes require a different number of transmissions (called “messages”) for the location estimation, and have different precisions (Table 3). Transmissions can be received only when the tag aerial is above the sea surface. Seals usually stay at the surface for rather short times, so it is intrinsically difficult to obtain high quality locations, and most locations obtained are A or B class. These locations need to be retained in the analysis to have a suitable sample size (Freitas et al. 2008). Therefore, we excluded just Z class locations and filtered the remaining locations. we used an algorithm similar to the one developed by McConnell et al. (1992), that recursively filter out consecutive positions that would imply a too high travel speed. The maximum allowed speed was 3.0 m/sec (Campagna et al. 2006).

Data analysis

Data was imported in ArcGIS 10, (ESRI, www.esri.com), to merge the individual tracks not only with topographic and bathymetric data but also with environmental data (sea surface temperature, productivity) obtained from public access online sources (NASA OceanColor Web, http://oceancolor.gsfc.nasa.gov/). Background GIS data and specific GIS data about offshore oil exploration was downloaded from the FIG Department of Mineral Resources (http://www.falklands-oil.com/). In the future, we plan to correlate individual tracks with environmental features (Campagna et al 2006) and traits of the individual life history, using a spatial regression approach (Bini et al 2009). All quantitative analysis have been carried out in Stata (version 12, Stata Corporation, www.stata.com).

LC	Error (m)	Messages
3	<250m	4+
2	>250,<=500	4+
1	>500,<=1500	4+
0	> 1500	4+
A	Not estimated	3
B	Not estimated	2
Z	Invalid location	

Table 3 – Argos location quality classes. LC = location class; Error = expected error of the location; Messages = number of successful transmission required.

Year	ID	SBL (cm)	Girth (cm)	Weigth (kg)
2009	AXES	293	213	537
2009	BERT	254	160	287
2009	FETA	271	192	416
2009	PAOLA	287	192	423
2009	TINA	246	159	274
2009	WARA			
2010	AFA	298	193	438
2010	BUB	297		481
2010	FOXI	274	168	334
2010	GIADA	294	196	488
2010	GITI	253	160	277
2010	HOC	289	188	395
2010	LINDA	252	164	269
2010	MOKA	262	162	316
2010	NOVE		197	
2010	OLGA	292	192	457
2010	TOY	274	180	393
2010	TRIP	277		366
2011	ARCA	294	176	399
2011	DAS	279	197	430
2011	EUX	251	151	264
2011	JISE	292		498
2011	LISA	310	220	
2011	XORA	258	170	311

Table 4 – Summary of measurements of the satellite tagged females. SBL = standard body length, obtained by direct measurement, Girth = girth length, obtained by direct measurement, Weight = body weight estimate obtained by photogrammetry.

Results

Morphometrics of the satellite tagged females

The main measurements obtained are summarized in Table 4. We obtained a measure of the standard body length for 22 females and of the girth length for 20. We also obtained an estimate of the body weight by using photogrammetry for 21 females. For only one of the females, Wara, we obtained no measurement. Mean standard body length was 277.1 cm (SD = 18.86, CV = 0.0680), mean girth length was 181.5 cm (SD = 19.31, CV = 0.1064), and mean estimated weight was 387.4 kg (SD = 84.60, CV = 0.2184). The weight estimated before the deployment and used to calculate the anaesthetic dose was slightly lower that the weight estimated by photogrammetry (mean difference = -37 kg). In just three cases the initial estimate of the weight was higher than the photogrammetric weight, and in two of these cases the difference was lower than 5 kg.

Performance of the satellite tags and quality of fixes

Over the three years of the study, the tracking of the 23 individuals generated a total of 772 daily location files, containing 130601 unfiltered positions (31670 in 2009, 74024 in 2010, and 24907 in 2011). As expected, in the raw data the majority of locations had a A or B location class (59.2% of the locations), while 26.3% of the locations belonged to the 0-3 classes (that have an estimate of location error) and 17.9% of the locations were invalid. This is a common situation with elephant seals, which spend a very short time at the surface between consecutive dives. Location classes distribution in the raw data is shown in Figure 5.

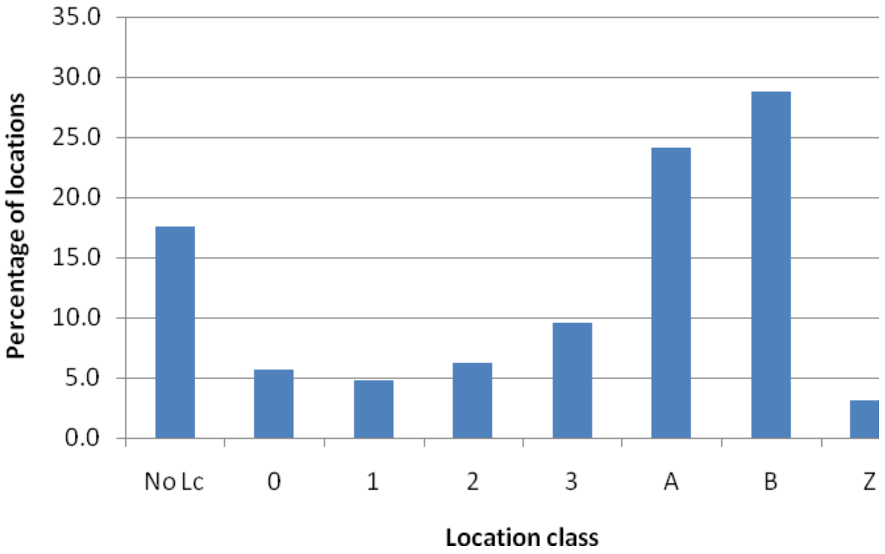

Figure 5 – Distribution of location class in the raw (not filtered) data.

The distribution of the location class of the filtered data was different from the distribution of the location class of the raw data, even after exclusion of the locations with no class and of the Z class locations (Exact log-likelihood ratio test; P = 0.0001). In particular, the B class location were more represented (51.5% vs 36.6%) and the 0-3 classes were less represented.

ID	N pos.	No LC	0	1	2	3	A	B	Z	A+B	0-3
AXES	10295	11.75	14.39	8.80	10.69	18.13	19.52	13.96	2.76	33.48	52.01
BERT	3654	34.24	1.01	8.57	12.26	19.81	7.42	16.37	0.33	23.79	41.65
FETA	4326	28.66	2.70	4.07	6.61	11.00	18.79	25.50	2.66	44.29	24.38
TINA	3837	25.88	2.89	5.21	8.05	11.10	17.51	27.29	2.06	44.80	27.25
WARA	7249	25.07	3.66	4.80	7.42	12.93	21.29	22.61	2.23	43.90	28.81
AFA	5084	21.07	2.75	3.17	4.76	7.67	28.89	27.01	4.68	55.90	18.35
BUB	8146	18.27	7.37	3.70	3.42	3.84	30.57	28.06	4.78	58.63	18.33
FOXI	5438	23.89	3.97	2.43	2.37	2.19	25.98	34.37	4.80	60.35	10.96
GIADA	5511	10.85	15.3	8.93	6.53	9.71	26.86	15.64	6.19	42.50	40.47
GITI	6915	20.81	2.30	2.10	5.81	11.54	26.97	27.53	2.94	54.50	21.75
HOC	5228	18.09	4.00	6.18	5.70	5.36	30.83	25.67	4.17	56.50	21.24
LINDA	7279	18.85	3.41	2.73	5.76	8.05	25.68	32.60	2.93	58.28	19.95
MOKA	6557	14.99	5.73	4.70	5.86	7.58	33.22	23.50	4.42	56.72	23.87
NOVE	5277	24.73	5.14	4.45	8.58	8.41	20.05	25.07	3.56	45.12	26.58
OLGA	4784	19.73	13.48	7.07	3.68	5.75	24.83	21.20	4.26	46.03	29.98
TOY	7946	26.03	1.20	2.13	3.52	7.09	22.80	33.79	3.45	56.59	13.94
TRIP	5323	22.47	6.84	4.11	5.52	8.47	20.72	29.10	2.76	49.82	24.94
ARCA	3621	0.77	7.37	6.35	5.00	7.15	29.16	43.33	0.86	72.49	25.87
DAS	5171	0.79	4.10	4.14	6.09	11.14	30.57	42.22	0.95	72.79	25.47
EUX	6232	0.66	0.69	2.28	4.78	6.26	18.79	62.77	3.77	81.56	14.01
JISE	3794	1.50	5.09	6.67	8.17	20.53	21.40	36.19	0.45	57.59	40.46
LISA	5114	1.10	9.17	7.33	7.70	12.22	29.62	32.15	0.70	61.77	36.42
XORA	2865	1.33	2.72	6.77	9.77	12.22	17.14	49.01	1.05	66.15	31.48
Mean	5636.78	16.15	5.45	5.07	6.44	9.92	23.85	30.21	2.90	54.07	26.88
SD	1751.14	10.50	4.14	2.19	2.41	4.70	6.05	11.20	1.63	12.94	10.01
CV	0.3107	0.6500	0.7606	0.4307	0.3747	0.4741	0.2535	0.3706	0.5618	0.2394	0.3725

Table 5 – Distribution of location class (%) in the raw data. No LC: pos. without location class.

ID	N pos	0	1	2	3	A	B	A+B	0-3
AXES	1284	12.46	11.92	12.31	20.72	20.17	22.43	42.6	57.41
BERT	344	1.74	11.34	14.83	22.97	12.79	36.34	49.13	50.88
FETA	414	3.38	5.56	7.73	12.8	20.77	49.76	70.53	29.47
TINA	437	2.06	6.64	8.01	10.53	22.43	50.34	72.77	27.24
WARA	770	4.29	7.79	13.25	19.22	20.78	34.68	55.46	44.55
AFA	357	4.48	3.08	5.32	7.84	34.73	44.54	79.27	20.72
BUB	378	12.70	5.82	2.12	1.59	36.77	41.01	77.78	22.23
FOXI	398	3.27	1.51	2.51	3.27	33.67	55.78	89.45	10.56
GIADA	477	18.87	8.60	2.31	3.14	40.25	26.83	67.08	32.92
GITI	494	1.42	1.62	1.01	0.81	36.84	58.30	95.14	4.86
HOC	457	4.81	4.81	2.41	1.53	41.58	44.86	86.44	13.56
LINDA	602	2.99	2.82	3.49	5.32	31.40	53.99	85.39	14.62
MOKA	413	7.75	3.63	5.57	6.05	39.71	37.29	77.00	23.00
NOVE	285	3.86	4.21	3.86	4.91	33.33	49.82	83.15	16.84
OLGA	379	13.98	8.71	2.11	1.06	35.36	38.79	74.15	25.86
TOY	348	2.59	0.86	0.00	1.15	31.32	64.08	95.40	4.60
TRIP	369	7.32	3.25	3.25	1.90	30.89	53.39	84.28	15.72
ARCA	698	5.01	3.30	2.15	1.29	26.65	61.60	88.25	11.75
DAS	1046	3.06	1.91	2.01	2.68	27.44	62.91	90.35	9.66
EUX	1218	0.33	0.57	0.66	0.33	15.85	82.27	98.12	1.89
JISE	585	4.44	4.44	2.91	4.44	19.66	64.10	83.76	16.23
LISA	839	7.51	5.72	2.03	1.67	30.15	52.92	83.07	16.93
XORA	530	1.51	1.51	2.08	1.13	12.45	81.32	93.77	6.23
Mean	570.52	5.64	4.77	4.43	5.93	28.48	50.75	79.23	20.77
SD	282.20	4.70	3.20	4.10	6.77	8.81	15.06	14.57	14.57
CV	0.4946	0.8321	0.6708	0.9249	1.1419	0.3092	0.2967	0.1839	0.7015

Table 6 – Distribution of location class (%) in the filtered data.

There was a large variation in the number and quality of the locations collected for the different females, both in the raw data (Table 5) and in the filtered data (Table 6), possibly due to the different movement patterns of the different females, and/or different satellite coverage. Notwithstanding this, enough filtered locations were collected for all females.

General foraging strategies

Of the 23 satellite tagged females, 78.3% (95% CI = 57.3-91.0) foraged close (< 400 km) to their breeding colony, 69.6% (47.1-86.8) foraged in an area south west of the Falklands, 87.0% (68.3-96.4) foraged on the continental shelf, and 69.6 % (47.1-86.8) had most fixes concentrated in a small area. The combination of these four qualitative features was the most common overall foraging strategy, adopted by 47.8% of the females (Table 7).Sample tracks of two females foraging very close to Sea Lion Island are shown in Figure 6. Sample tracks of the three females foraging very far from Sea Lion island are shown in Figure 7. A combined map of the tracks of the three years of study is shown in Figure 8. Year specific maps are presented in Appendix 2.

ID	Distance	Shelf	Area	Direction
BERT	Close	On	Large	South west
WARA	Far	Off	Large	South west
TINA	Close	On	Small	South west
AXES	Close	On	Small	South
FETA	Far	Off	Large	South west
GIADA	Close	On	Large	North
TRIP	Close	On	Small	South west
LINDA	Close	On	Large	North
BUB	Far	On	Small	South west
FOXI	Close	On	Small	South west
NOVE	Close	On	Small	South west
OLGA	Close	On	Small	South
TOY	Far	On	Small	South
MOKA	Close	On	Small	South west
AFA	Close	On	Small	South west
HOC	Close	On	Large	North
GITI	Close	On	Small	South west
JISE	Close	On	Small	South west
LISA	Close	On	Small	South west
ARCA	Close	On	Small	South west
EUX	Far	Off	Large	South west
DAS	Close	On	Small	South west
XORA	Close	On	Small	South

Table 7 – Summary of the qualitative aspects of the foraging pattern of the satellite tagged females. Distance: distance from Sea Lion Island (close: <= 400 km); Shelf: foraging on or off the continental shelf; Area: foraging in small (concentrated) area or over a long loop; Direction: main direction of the movements respect to Sea Lion Island.

Time spent at sea and survival

Females spent at sea a mean of 69.7 days between the end of the breeding haul out and the start of the moult haul out (SD = 9.3, CV = 0.13). There was a gradual decrease in the mean time spent at sea, from 76.8 days (SD = 10.2, CV = 0.13) in 2009, to 69.9 days (SD = 7.1, CV = 0.10) in 2010, to 63.5 day (SD = 9.3, CV = 0.15) in 2011. The decrease trend was statistically significant (Rank test for trend: z = -2.67, P = 0.007).

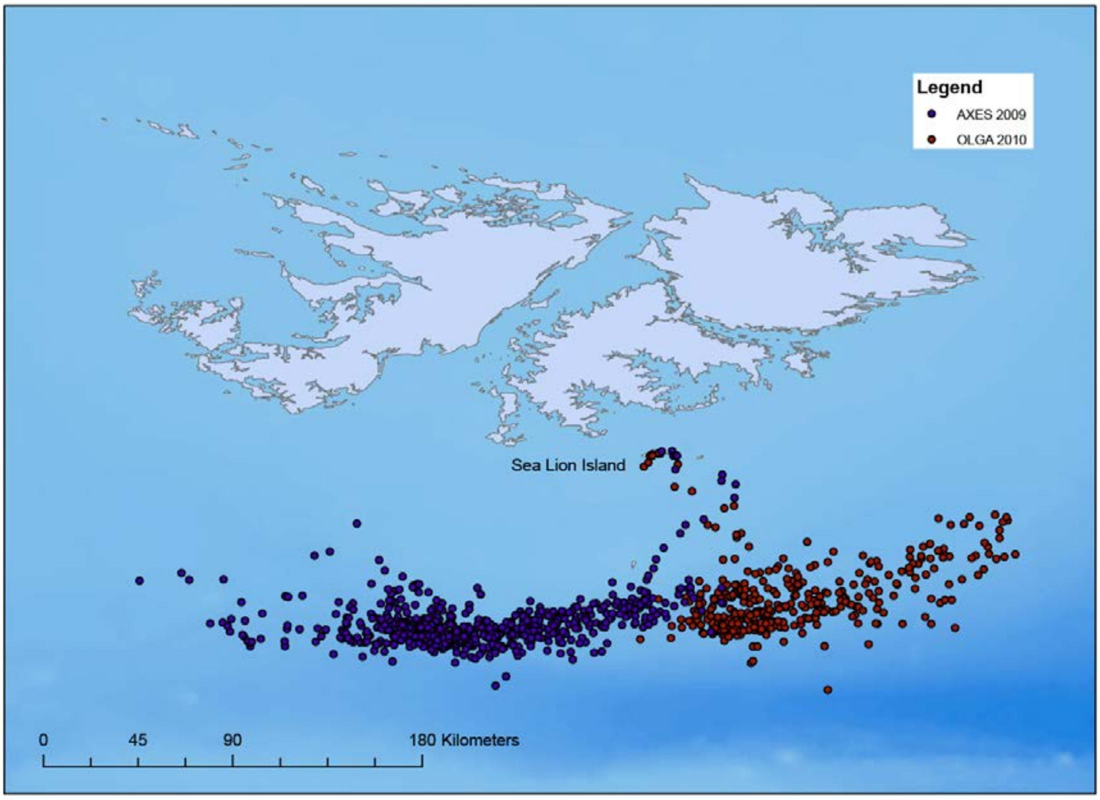

Figure 8 – Sample tracks of two females foraging close to Sea Lion island.

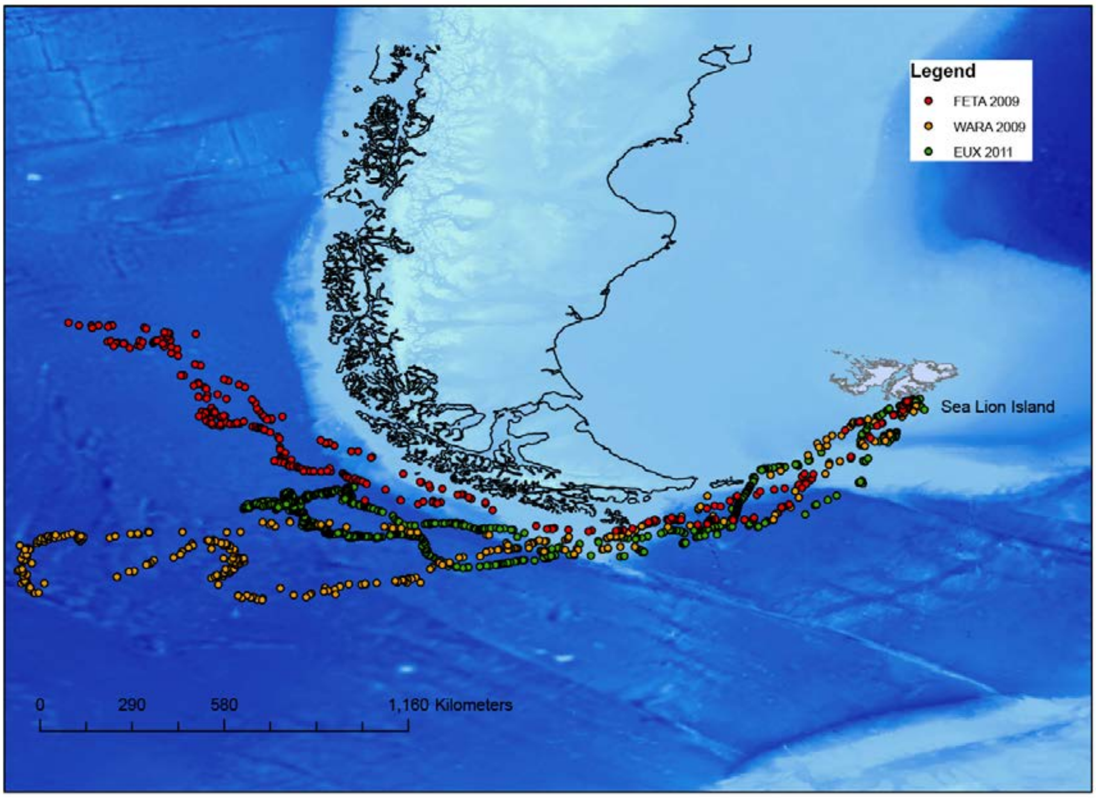

Figure 9 – Sample tracks of three females foraging far from Sea Lion island.

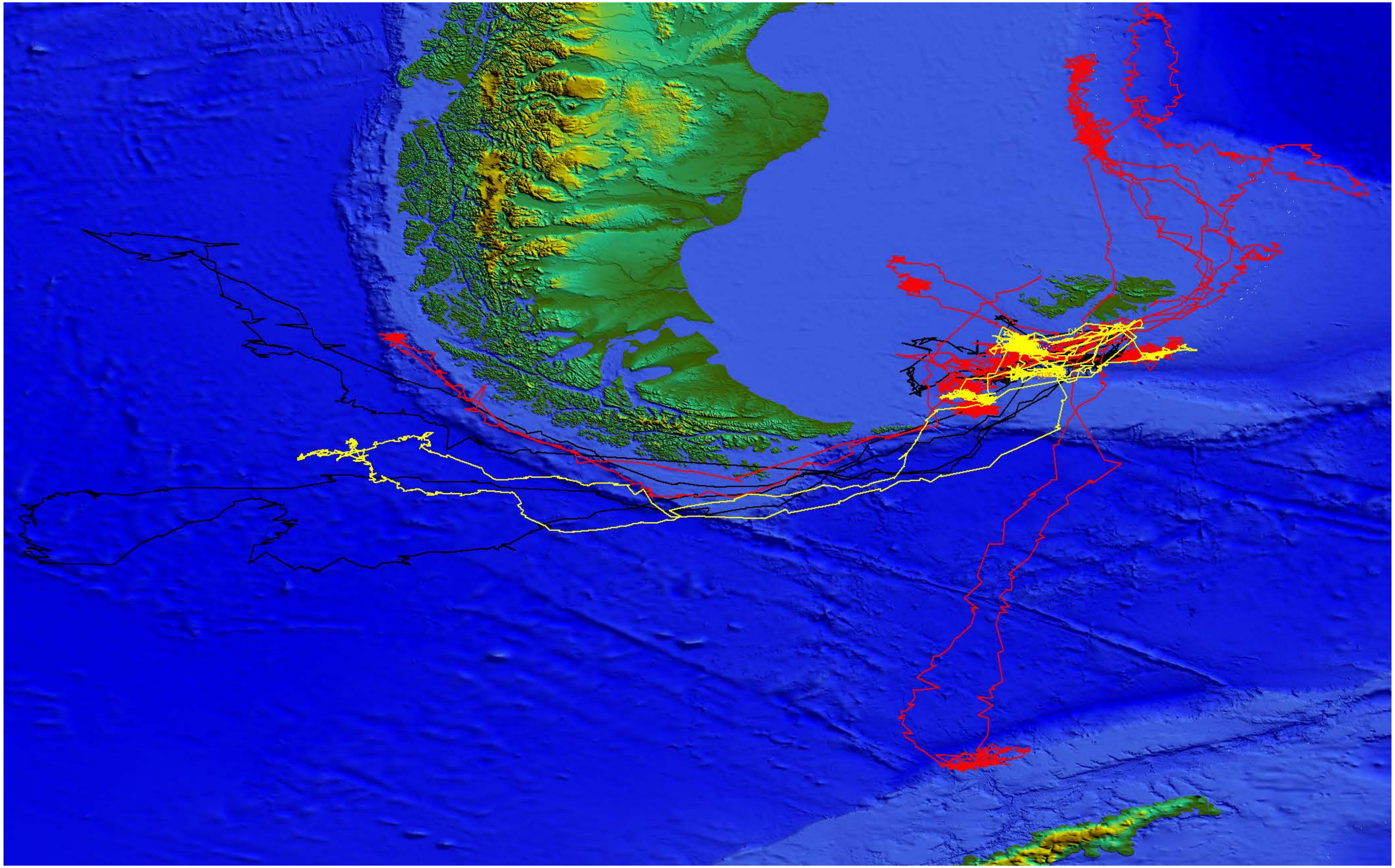

Figure 10 – Map of the tracks of the tagged females by year. Black: 2009, red: 2010, yellow: 2011

All females survived until the moulting season following the deployment. Of the 17 females tagged in 2009 and 2010, 76.5% (95% CI = 51.1- 91.5) survived to the following breeding season. All the survived females gave birth and successfully weaned a pup which weight was within the normal range observed at SLI. Of the 23 satellite tagged females, 47.8% returned to Sea Lion island to moult, 30.4% went to Sea Lion Easterly, and one to Whisky island. The remaining four females went to moult away from the Sea Lion group, three on islets close to the south coast of East Falklands, and one in the north of the islands, on the South Fur islet (Jason group).All together, almost all females moulted at SLI or close.

Year	ID	N fixes	Mean dist.	SD dist.	Max dist.	Max dist. SLI	Cum. dist.
2009	AXES	1284	8.24	7.93	48.42	160.82	6086.01
2009	BERT	344	11.32	15.61	133.54	362.29	2164.42
2009	FETA	414	17.42	29.87	422.94	1664.65	5647.36
2009	TINA	437	9.75	9.69	62.45	280.73	3229.01
2009	WARA	770	12.99	16.55	131.75	1690.71	5872.40
2010	AFA	342	11.22	10.18	84.69	335.83	3434.42
2010	BUB	403	13.34	15.65	131.33	1146.46	5125.92
2010	FOXI	395	9.26	7.68	55.05	316.52	3507.14
2010	GIADA	493	9.96	9.12	87.98	613.24	4495.28
2010	GITI	511	8.48	7.10	56.29	316.05	4107.92
2010	HOC	476	12.25	10.96	86.01	696.73	5508.99
2010	LINDA	627	10.66	11.28	148.08	832.89	5840.59
2010	MOKA	420	9.18	8.89	100.5	402.14	3410.82
2010	NOVE	298	16.54	15.17	94.91	349.83	4585.74
2010	OLGA	389	10.47	8.55	44.89	122.06	3887.58
2010	TOY	372	13.89	15.2	152.27	1154.87	5029.65
2010	TRIP	386	9.99	8.48	53.41	209.90	3598.92
2011	ARCA	698	5.54	4.99	38.17	193.26	2973.57
2011	DAS	1046	4.46	5.49	88.21	207.83	3201.15
2011	EUX	1218	5.58	8.38	113.55	1274.4	5016.59
2011	JISE	585	5.39	5.63	53.38	214.80	2157.19
2011	LISA	839	4.70	5.79	64.07	325.89	2852.01
2011	XORA	530	5.14	5.88	63.01	198.91	1902.71

Table 8 – Summary statistics of the distance travelled (calculated on filtered fixes). Mean dist., SD dist. and Max dist.: mean, standard deviation and maximum of the distance between consecutive fixes. Max dist. SLI: maximum distance from Sea Lion Island. Cum. dist.: cumulative distance (all fixes). All distances in km.

Distance travelled

There was a large variation in the distance statistics of the different females (Table 8). The maximum distance from SLI ranged from 122 to 402 km (mean = 266.5, SD = 84.2) in the 15 females that went south or south west and remained close to the Falklands, from 613 to 833 km (mean = 714.3, SD = 110.9) in the 3 females that went north, and from 1146 to 1691 km (mean = 1386.2, SD = 271.0) in the 5 females that went far from the Falklands. The trend of increase of the maximum distance in the three group was significant (Rank test for trend: z = 3.91, P = 0.0001).

Year	**ID**	**N**	**Mean**	**SD**	**CV**	**Median**	**MAD**	**Min**
2009	AXES	649	-556.2	143.2	-0.2574	-574	66	-1266.00
2009	BERT	166	-366.7	181.0	-0.4934	-385.5	105.5	-664.00
2009	FETA	284	-3020.4	1570.8	-0.5200	-3951.5	169	-4386.00
2009	TINA	320	-631.2	183.0	-0.2899	-638	48	-1439.00
2009	WARA	371	-3442.6	1818.1	-0.5281	-4393	448	-5816.00
2010	AFA	290	-353.0	120.1	-0.3402	-367	59.5	-683.00
2010	BUB	375	-735.2	577.3	-0.7852	-528	285	-3473.00
2010	FOXI	367	-328.3	132.9	-0.4047	-305	86	-874.00
2010	GIADA	459	-594.1	211.0	-0.3552	-651	69	-1148.00
2010	GITI	491	-455.9	94.6	-0.2075	-479	26	-645.00
2010	HOC	445	-675.9	198.6	-0.2938	-732	52	-1289.00
2010	LINDA	582	-1563.2	1182.7	-0.7565	-1385.5	980	-5252.00
2010	MOKA	384	-160.3	70.4	-0.4388	-159.5	18.5	-508.00
2010	NOVE	263	-413.4	117.2	-0.2835	-432	56	-626.00
2010	OLGA	369	-556.8	160.5	-0.2883	-557	49	-1989.00
2010	TOY	345	-1978.4	1385.9	-0.7005	-1651	1152	-4705.00
2010	TRIP	360	-412.9	98.7	-0.2391	-419	33.5	-681.00
2011	ARCA	677	-399.2	81.5	-0.2041	-413	29	-544.00
2011	DAS	998	-352.3	68.8	-0.1952	-359	9	-453.00
2011	EUX	1211	-3542.5	1253.2	-0.3537	-4071	159	-4730.00
2011	JISE	573	-644.7	276.9	-0.4295	-737	116	-1170.00
2011	LISA	829	-347.4	126.6	-0.3643	-300	50	-733.00
2011	XORA	514	-755.3	274.2	-0.3630	-716	136	-1515.00

Table 9 – Summary statistics of the depth of the water along the female tracks. N: number of fixes, SD: standard deviation, CV; coefficient of variation, MAD: median absolute deviation.

Depth of the water

Statistics about the depth of the water along the female tracks are presented in Table 9. The median depth ranged from -159.5 m to -4393 m. Most females travelled over rather shallow waters, with 78.3 % of the females travelling over waters with a median depth lower than 800 m. Only 3 females spent the most of the time over waters with depth of 4000 m or more. The median depth of waters was lower for the 2009 tracks (mean = -1988.4 m) that for the 2011 (-1099.3) and 2010 (-638.8).

Foraging areas

Summary statistics of the foraging areas of the 17 females that foraged in a concentrated area are summarized in Table 10 (females foraging over long loops are not included). Fixes were projected on UTM zone 20 (12 female) or UTM zone 21 (1 female) as appropriate. Four females had foraging spanning two UTM zones (20 and 21), and, therefore, their fixes were projected on the South America Albers projection (that was chosen because preserve areas).

Year	ID	Perimeter	Area	Projection
2009	AXES	412.0	7834.0	Albers
2009	TINA	334.4	5406.0	UTM 20
2010	AFA	216.6	2974.1	UTM 20
2010	FOXI	183.7	2308.4	UTM 20
2010	GIADA	511.7	11959.7	Albers
2010	GITI	200.2	2648.4	UTM 20
2010	HOC	665.6	15365.1	Albers
2010	MOKA	265.7	4345.9	UTM 20
2010	NOVE	563.1	15497.2	UTM 20
2010	OLGA	294.3	5496.0	UTM 21
2010	TOY	269.5	4317.5	UTM 20
2010	TRIP	246.6	3639.1	UTM 20
2011	ARCA	205.1	2778.4	UTM 20
2011	DAS	257.0	4593.0	UTM 20
2011	JISE	291.2	5406.7	UTM 20
2011	LISA	208.2	2432.4	UTM 20
2011	XORA	658.5	12069.1	Albers

Table 10 – Summary statistics of foraging areas. Perimeter in km, area in square km.

Overlap with exclusive economic zones (EEZ) and oil exploration blocks

Considering all filtered fixes, 56.5% of the females (N=23) had 50% or more fixes within the Falklands EEZ, and 34.8% had all fixes within it (Figure 10). Four females had 50% or more fixed within the Argentine EEZ, and two females within the Chile EEZ. Overall, a mean of 59.5% of the fixes (SD = 38.5%) of each female was within the Falklands EEZ. Considering only the female that had a concentrated foraging area (N=17), and excluding the females that foraged over long loops, 82.3% of the females had the whole foraging area within either the Falklands or the Argentine EEZ. 64.7% of the females had most of the foraging area (70% or more of the fixes) within the

Falklands EEZ, and 47.1% had the whole foraging area within it. Overall, 63.2% of the fixes of females with a concentrated foraging area were within the Falkland EEZ. A summary of the overlap between female fixes and the exclusive economic zones is presented in Table 11.

Year	ID	Falklands	Argentina	Chile	EEZ	Non EEZ
2009	AXES	100.0	0.0	0.0	100.0	0.0
2009	BERT	63.9	36.1	0.0	100.0	0.0
2009	FETA	8.4	15.0	69.3	92.7	7.3
2009	TINA	84.7	15.3	0.0	100.0	0.0
2009	WARA	11.3	8.9	30.6	50.8	49.2
2010	AFA	30.8	69.2	0.0	100.0	0.0
2010	BUB	19.8	27.2	52.9	100.0	0.0
2010	FOXI	20.4	79.6	0.0	100.0	0.0
2010	GIADA	80.1	0.0	0.0	80.1	19.9
2010	GITI	27.5	72.5	0.0	100.0	0.0
2010	HOC	44.9	0.0	0.0	44.9	55.1
2010	LINDA	60.0	0.0	0.0	60.0	40.0
2010	MOKA	100.0	0.0	0.0	100.0	0.0
2010	NOVE	87.4	12.6	0.0	100.0	0.0
2010	OLGA	100.0	0.0	0.0	100.0	0.0
2010	TOY	12.4	8.3	0.0	20.7	79.3
2010	TRIP	100.0	0.0	0.0	100.0	0.0
2011	ARCA	100.0	0.0	0.0	100.0	0.0
2011	DAS	100.0	0.0	0.0	100.0	0.0
2011	EUX	7.1	12.2	80.7	100.0	0.0
2011	JISE	100.0	0.0	0.0	100.0	0.0
2011	LISA	8.9	91.1	0.0	100.0	0.0
2011	XORA	100.0	0.0	0.0	100.0	0.0

Table 11 – Summary of the overlap between filtered female fixes and the exclusive economic zones of the Falkland islands, Argentine, and Chile. All values are percentages.

There was a modest overlap between female tracks and oil exploration licensed blocks. Only three out of the 23 females had an overlap greater than 10% and only one greater that 50%; 47.8% of the females had no overlap at all. The average overlap was 4.38% (SD = 11.77). Most overlapped fixes were within the blocks of just one operator, FOGL (96.1% of the overlapped fixes).

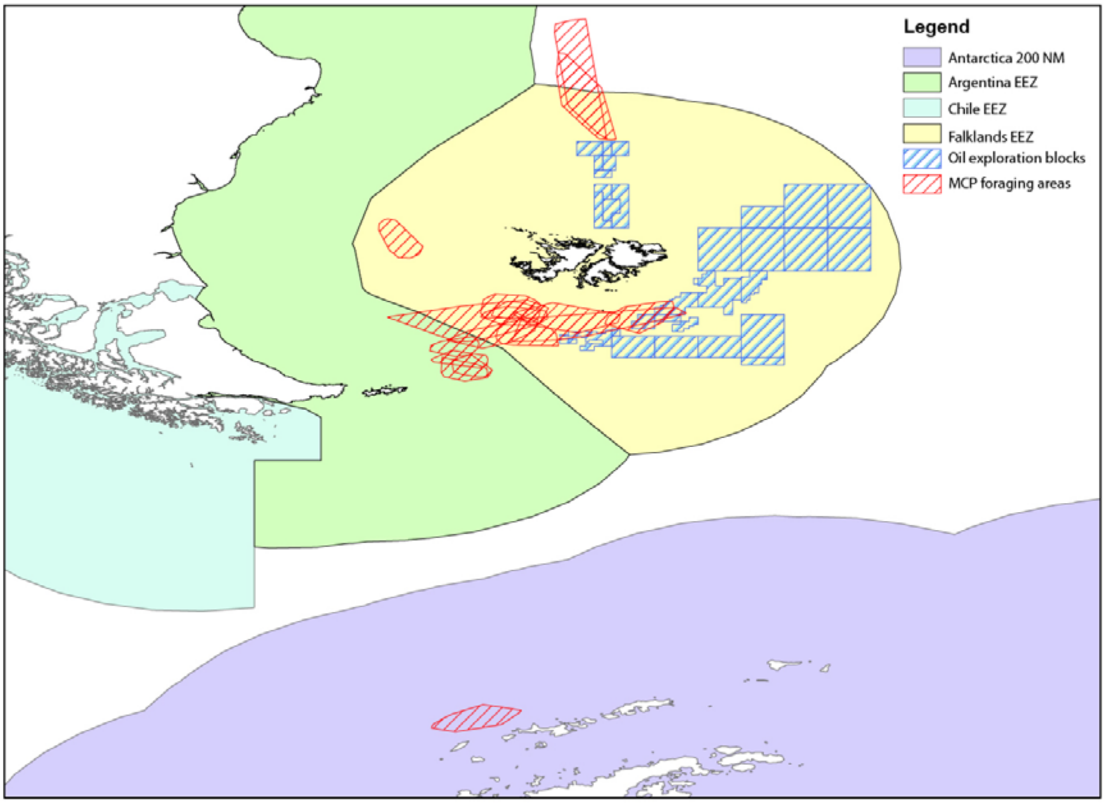

Figure 10 – Overlap between the elephant seal foraging areas and the Exclusive Economic Zone of the Falkland Islands and Argentina. The map includes all females that forage in concentrated areas close to the Falklands. Hatched red polygons: minimum convex polygon of the putative foraging fixes. Hatched blue polygons: oil exploration blocks. The 200 nautical miles zone off the coast of Antarctica is also shown

Discussion

Movements at sea of tagged females

Prior to the 2009 deployment of satellite tags, there was scanty information about movements at sea and foraging areas of elephant seals of SLI. Basically, the available information came from two sources: 1) re-sights of cattle tags that we place in the interdigital membrane of the rear flippers of each pup; 2) the track of a SLI breeding female, born in 2001 and named Aqua, that was fitted with a satellite tag during the moult at Livingston Island, in the South Shetlands, by a team of the University of California Santa Cruz led by professor Dan Costa (Mike Fedak, pers. comm.). Most re-sights of our flipper tags, belonging to individuals of all sex and age classes, were of moulting animals and came from the far south (South Shetlands, King George Island, Antarctic Peninsula, and South Georgia). Aqua's pattern of movements at sea was well defined: she was satellite tagged at Livingston Island; after the moult she left the island, foraged close to it for the whole post-moulting period; then she returned straight way to Sea Lion Island to give birth (Luis Huckstadt, UCSC, pers. comm.).

All together, based on the cattle re-sights and Aqua's track, SLI seals were expected to go mostly south and forage very far from the Falklands, towards the Drake Passage and the Antarctic Peninsula: "This data suggests that elephant seals that breed at sites to the south of the Falkland Islands are most likely foraging to the south, including the Drake Passage and Antarctic waters. Thus conservation efforts in the Falkland Islands may ultimately play only a small part in achieving the international goal of securing long term survival of the Falkland Islands population." (Falkland Islands Species Action Plan for Seals and Sea Lions 2008 – 2018, p. 9)".

The tracks of the 23 females that we satellite tagged were very different from this expectation, and cast some doubts about the representativeness of Aqua's movement patterns, and about the above statement of the Action Plan for Seals. Females showed three very different foraging strategies, with most of them remaining close to the Falklands and foraging on the south or south west, some moving very far to the Pacific Ocean or towards the Antarctic Peninsula, and some moving to the north of the Falklands at intermediate distance. The observed tracks have various interesting implications, general and applied:

- Feeding areas of SLI females seem to be quite different from the ones used by seals of other populations of the South Georgia stock (McConnell and Fedak 1996; Campagna et al. 1999, Campagna et al. 2006).
- There is a large variation in movement patterns of different females, which seems to be somehow related to the age class of the female, but with a lot of individual variation.
- The difference in both the location of the fixes and the depth of the waters in the fixes areas, points to a difference in the diving pattern and diet between females.
- The majority of females remain close to the Falklands, and this means that the potential interaction with human activities (e.g., fisheries) may be greater than expected; in particular, these females may have diets that partially overlap with commercially exploited species.
- Some females foraged close to offshore oil exploration blocks; it's interesting to note that elephant seals are not mentioned in the "BHP Billiton final non technical summary" on environmental impact assessment, and in the "Review of the Environmental Impact Statement produced by BHP Billiton Petroleum (Falklands) Corporation for offshore drilling" (both accessed from http://www.falklands-oil.com/); although very few locations were actually in the blocks area, some female foraged very close or close to the blocks, and even females that moved to the Pacific Ocean passed through some of the blocks.
- The proximity of the foraging areas of most females to the Falklands coast seems to greatly increase the responsibility of the Falklands authorities, and the role of them in ensuring the persistence of the SLI population.
- The fact that some females move in water close to the Falklands increases the interest in using seals as environmental samplers of oceanographic data that can be of local applied value (e.g., fisheries management).
- The fact that some females move in water of the Pacific Ocean probably not used by seals of other populations under study increases the interest in using SLI seals as environmental samplers for the collection of oceanographic data in deep water areas, difficult and expensive to survey with other approaches (see SEaOS, http://biology.st-andrews.ac.uk/seaos/).

Advantages and disadvantages of Sea Lion Island as a site for a large scale study

SLI proved to be a very good place for the deployment of satellite tags on southern elephant seals. The seals are much accustomed to human presence, and are very tame. Population density is rather low, there is plenty of breeding space and, therefore, harems are rather small and not crowded, reducing the risks of negative interference between the subjects and other seals during the deployment. The logistics is easy, and seals breed on sandy beaches that are very accessible. The presence of a previous long term study provides a strong background of information about each seal, and this greatly helps in choosing the subjects. SLI was the only notable population of the South Georgia stock in which no tracking-at-sea project was carried out, so there is a quite strong reason to fill the gap.

A potential negative aspect of SLI is that it is mostly a wildlife tourism place, internationally noted, and very important for the Falklands tourism business (Sea Lion Lodge, www.sealionisland.com). This is a main concern for us, because we wish to avoid any direct or indirect negative effect of the research on the local tourism business. We think that the research on elephant seals, and the satellite tracking project in particular, should be considered more as an asset, than a risk, for the lodge business. We had no direct complaints about the deployment of satellite tags, nor were complaints reported to the Lodge Manager. On the contrary, we had some enthusiastic reactions from visitors of the island and guests of the lodge, when they observed us working on the beach, when we gave talks to the lodge guests, and when we presented the satellite deployment project in Stanley. Controversies about research on wildlife are often the results of lack of information (Jabour Green and Bradshaw 2004), and can be solved by a better and deeper interaction between researchers, administrators, and the general public. During the next field work seasons we plan to intensify this aspect by giving more lectures in the lodge, and also by offering guided walks to explain elephant seals biology straight on the beaches.

Effectiveness of the chemical restraint procedure

We are satisfied of the result of the chemical restraint. In all cases we were able to successfully restrain the subject and achieve a level of sedation sufficient to deploy the satellite tags. Moreover, we usually were also able to carry out the other procedures (measuring, sampling, marking), and in just a few cases some steps of the full handling protocol were avoided. All subjects successfully recovered, and resumed their normal activity. The weight estimated before the deployment was slightly lower that the weight estimated by photogrammetry. This means that we actually administered a lower dose of anaesthetic, and this increased the safety margin of the procedure. We had three classes of problems:

- *Reaction of the harem holder*. In one case we tried a deployment but we were not able to get access to the female because of the aggressive reaction of the harem holder. This was surely an unusual event, because elephant seal males at SLI, and in particular main breeding males that hold harems, usually don’t take much care of what humans do; the problem can be avoided with a better choice of the subject, and avoiding harems in which the holder is known to be particularly reactive
- *Wrong IM injection*. In some cases the initial IM injection was not effective, because the subject became aware of the presence of the operator, the injection was not done in the correct location and with the correct needle placing, and no (or a too small amount) of anaesthetic was injected; having to handle wild animals, in a complex social setting, the risk of missing the IM inject looks unavoidable
- *Insufficient IM sedation*. During some deployments, the initial sedation by intramuscular injection was not very effective, and the female was not enough sedated to permit access to the extradural vein and further administration of anaesthetic. The problem was solved by placing a head bag on the female, getting access to the extradural vein, and giving extra anaesthetic. Although the placing of the head bag

may look somehow dangerous for the operator, the situation is under full control, and the risk for the operator is modest, due to the limited capability of elephant seals to bite by turning on the back. In fact, in some cases, we placed the head bag without any previous IM injection, and give the anaesthetic in the extradural vein only. This approach may offer the advantage of a more accurate control of the level of sedation from the very beginning (see also McMahon et al. 2000).

Monitoring of the subject

Although the monitoring of the subject was good enough to prevent any problem (constant monitoring of vital signs), we were not able to regularly collect all physiological parameters due to practical constraints. In the future, we plan to improve the monitoring, not only to be better able to respond to problems, but also to collect data for further analysis. This would be particularly useful if a large sample of individuals will be chemically restrained.

Attachment of the tags

We have reconsidered the choice to use curved bottom SPOT5 tags. Due to the large size of the head of female elephant seals, the part of head surface that is used to glue the tag is really not very curved. On the other hand, the gluing of the mesh to the tag is more difficult with a curved bottom tag, and produces plies in the mesh that make the gluing of the tag-mesh assemblage to the seal more difficult. A curved bottom tag would be, on the contrary, better suited to smaller animals with a smaller head. Therefore, in 2010 and 2011 we used flat bottom tags.

From our recent experience of gluing of instruments on elephant seals in Baja California (Mexico), we were expecting that the main problem during the deployment was the leakage of the glue that tends to produce a “pancake” effect. On the contrary, at SLI the main problem with the gluing, that became apparent during the first deployment, was that the two components of the epoxy glue were very hard due to the low temperature and, therefore, the mixing of them was difficult. This problem was solved by pre-heating the two components, using a small box containing hot water bottles. All tags deployed remained in place for the whole length of the transmission life, so the glues that we used were quite effective, but this aspect requires investigation, because there are no guidelines about the choice of the glue in the literature.

Performance of the tags

Although one of the 24 tags that we deployed stopped transmitting, the performance of the other ones was good, and we received enough fixes to determine the movements at sea with quite good accuracy. The analysis of fixes dispersion, and the fitting to them of feeding range models, will permit a good estimation of feeding areas. Notwithstanding this, there is room for improvement. One option would be to obtain some tags with onboard GPS. This kind of tags, fitted with the Fastloc algorithm that permits a very fast acquisition of the first GPS position, seem to give much better precision in the location than plain Argos location (Costa el at. 2010). Unfortunately, these tags are 3 times more expensive than the SPOT5 model. In the meanwhile, CLS, the company managing the Argos System, updated the protocol used to calculate Argos locations from satellite messages, and the new protocol, based on Kalman filters produced a great improvement in the number of usable locations, and in the precision of locations (Argos Flash no. 19, available from www.argos-system.org). An advantage of the new algorithm is that precision is estimated also for A and B location classes, that are the most frequent in elephant seal studies.

Additional data
When handling animals, and when using chemical restrain in particular, it is imperative to optimize the costs/benefits balance. One way to improve the balance is to collect extra data and samples during the deployment operation. During this study we collected morphometric measures and various samples, including blood, but not all measures/samples were collected in all cases. A better standardization of the procedure, and an improvement in the team capabilities, should let us collect all the data and measurements during all deployments.

Impact of the deployment on the subject and on other seals
The evaluation of the effect of invasive research procedures on the subject is a very complex matter, as it is a complex matter the evaluation of any perturbation of wildlife produced by any human activity (Tarlow and Blumstein 2007). Therefore, firm conclusions and guidelines are usually lacking. Luckily, the southern elephant seal is an exception, because there is an extensive literature on the matter. The published studies show that this species is quite resistant to human activities at large (Burton and Van Den Hoff 2002) and to research activities in particular (Engelhard et al. 2002a), it permits to apply a safe chemical restraint protocol (McMahon et al 2000), shows a low or moderate response to chemical anaesthesia (Engelhard et al. 2002b), and may be subject to invasive approaches without suffering medium or long term costs (McMahon et al. 2005). We are very interested in the matter, and in the recent past we compared cortisol (a hormone associated to stress) between resting weanlings and handled weanlings (subject to weighing and measuring before blood sampling), and we found no significant differences (manuscript in prep.).

During our deployments, all females successfully recovered from the chemical sedation, weaned the pup, and returned to sea. We received transmissions from 23 of the females during the whole period spent at sea before the moult. Paula stopped transmitting, but after deployment and before the stop of the transmission she remained on land various days, showing the usual breeding pattern of any other female. All together, we have no indications of an adverse effect of the deployment on the welfare of the subjects, and of their pups. After the deployment, all females retuned to land for the moult, and about 75% of them returned the following breeding season, showing a normal breeding pattern. This survival rate is higher than the average females survival rate between breeding seasons.

There were no indications of any adverse effects on the nearby seals in the cases in which the deployment was done on a harem female (22 out of 23). At time of deployment most females of the harems had rather large pups. After deployment, there was no abrupt reduction in the number of females of the harem, and no increase in the rate of pup separation/abandonment, or mortality of the pups.

Perspectives for the future

The deployment of the satellite tags was smooth, no adverse effects were observed for the females or their pups, the reaction of the general public to the deployment was positive, and the data obtained is very interesting, although it should be considered preliminary due to the small sample size. SLI seems to be an ideal place for the deployment, due to the tameness of the seals, the easy logistics, and the very large database of information about the life history of the study subjects. Altogether, the 2009-2011 deployments were successful. Our goal is to carry on, and possibly expand the project. A larger sample size is required to firmly establish the feeding areas of females, better tags with more data collection capabilities can be used, and individuals of other sex/age classes should be instrumented. We have one year left in our current research licence, and we plan to use the available slots to deploy 12 more tags in the 2012 breeding season.

In the meanwhile, we are looking for extra funding to be able to deploy more complex (and expensive) tags that have internal memory, so, if the tag can be recovered, high resolution data can be downloaded from the tag itself, while only low resolution data is relayed to the Argos system, due to the constraints in bandwidth of transmissions. Moreover, tags can be fitted with a large array of sensors to collect information not only about the animal, but also about the environment. Sensors permit to record data about diving depth, speed, and direction, temperature, and light level. Our priority for future seasons is to get tags with pressure sensors, to be able to study diving profiles of the tracked seals. The data available before the deployments of our satellite tags was indicating that breeding females do not come back to SLI for moulting, being usually re-sighted elsewhere and, hence, are not good subjects for the deployment of tags with archival capabilities. The results of the deployments, on the contrary, suggest that females might come back to SLI or the nearby islets to moult. This may permit the downloading of data from the internal memory of the tags.

Two possible developments may produce interesting improvements of the project: 1) we are currently developing a project using stable isotopes to study foraging patterns and diet; the stable isotopes approach and satellite tracking approach nicely complement one each other; 2) new logging devices currently under development have wireless communication and, therefore, may permit the downloading of sensors data from the tagged females upon their return to SLI without any further needing to restrain the animal; therefore, the downloading of data from the tag can be possibly operated by laypeople (eg., Sea Lion Lodge staff people) without the needing to have a research team on SLI at the time of return for the moult; this new logging devices may include GPS for accurate positioning, and sensors for the recording of temperature, depth, speed and direction.

Acknowledgments

We would like to thank the Environmental Planning Department of FIG (represented along the years by Miss Dominique Giudicelli, Miss Helen Otley and, now, by Mr,. Nick Rendell) and the Environmental Committee for approving our long term research licence, and the specific licence for the satellite tags deployment. We would like to thank the Falkland Islands Development Corporation for permitting us to carry out our research on elephant seals at Sea Lion Island. We would like to thank Sea Lion Island Ltd for letting us access the facilities of the SLI settlement and for providing accommodation to the research team at discounted rate. Very special thanks are due to Jenny Luxton for her kind help and support, for her positive attitude towards our research and for the capability shown in managing the interaction between researchers and visitors of Sea Lion Island. We would like to thank the Sea Lion Lodge staff for the help provided throughout the research.

This project to track at sea the elephant seals of Sea Lion Island is dedicated to the memory of David Gray. We love to think that he would have had a great pleasure in seeing the tracks of the seals of his island out there in the big ocean.

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Appendices

1 – Annotated pictures of the deployment procedure

2 – Supplementary maps

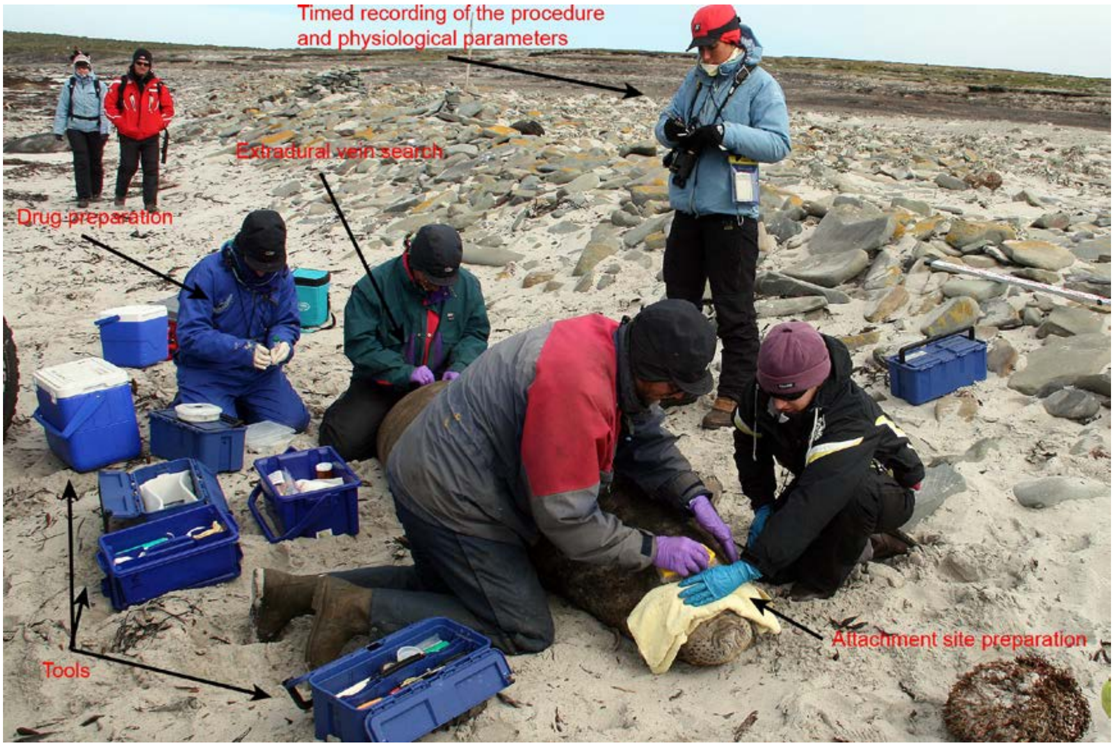
Appendix 1 – Annotated pictures of the deployment procedure

Intramuscular injection. Initial chemical restraint is obtained by intramuscular injection of the anesthetic using a 9 cm long epidural needle fitted on a 3 m extension tube.

Check of sedation. The level of sedation is assessed by gently stimulating the subject, starting from the rear flipper and going towards the head up to the nostrils.

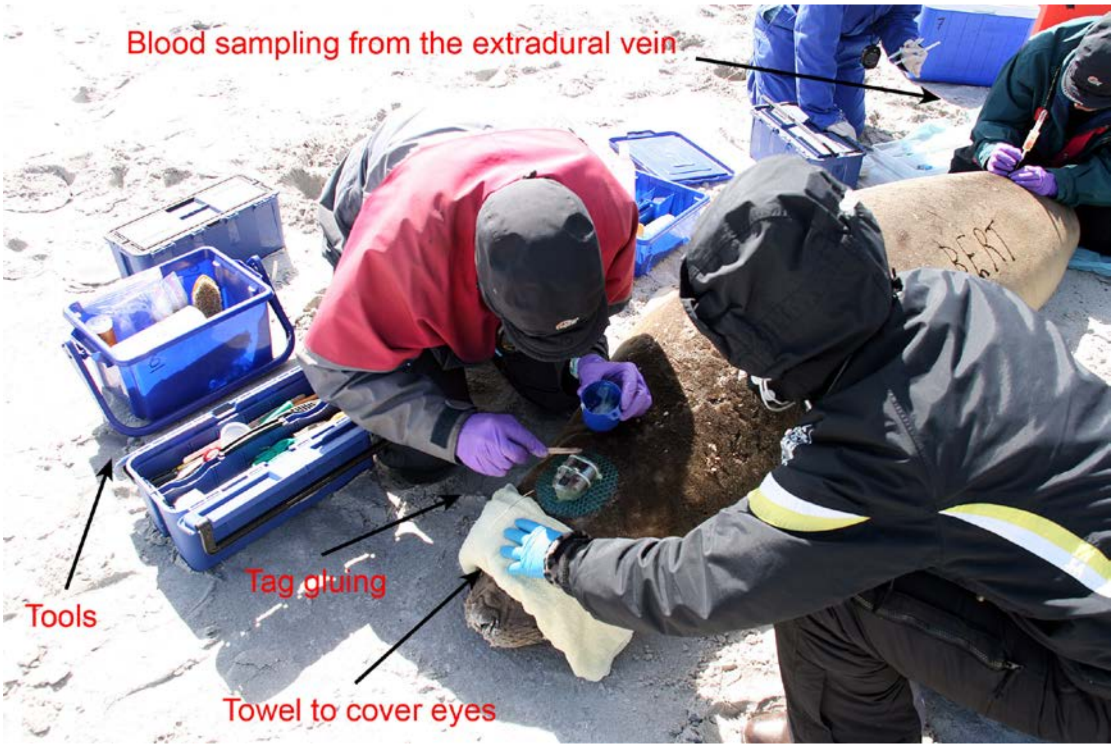
Head bag. Due to the insufficient IM sedation a head bag is placed on the subject head, to permit access to the extradural vein and IV sedation.

Measurement of the subject. A picture of the side of the animal is taken with a calibrated survey pole in the frame, to obtain an estimate of length and weight.



The working area. Preparation of the area for gluing in the front, and placement of the epidural needle in the back. A couple of lodge guest is approaching the working area from the rear left.

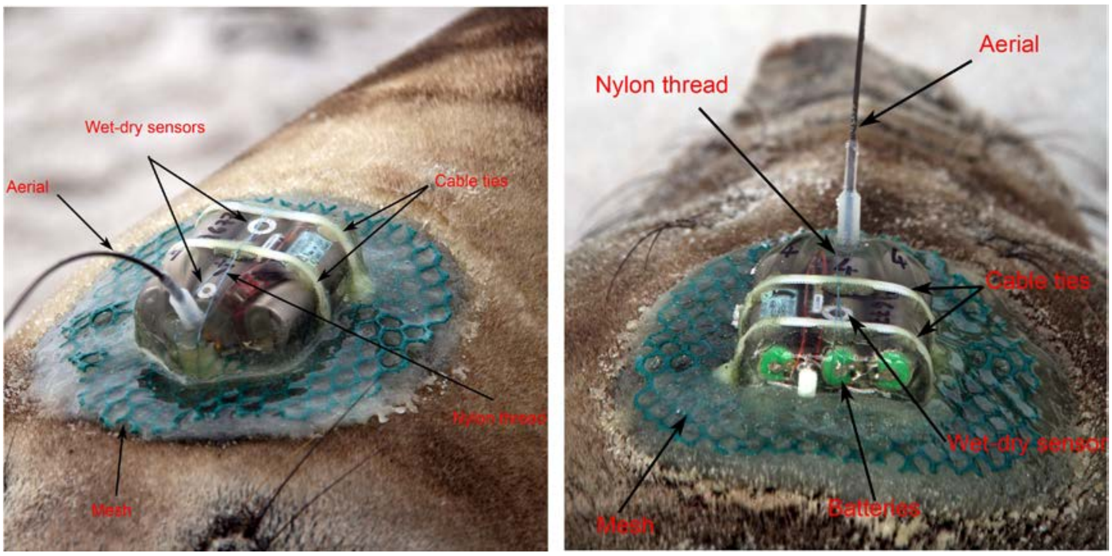
Intravenous injection. The level of sedation is controlled by giving doses of anesthetic in the extradural vein, using a 9 cm long epidural needle, which is left in place for the whole length of the procedure.



Gluing of the tag and blood sampling. The tag is glued to the head of the seal. In the meanwhile, blood samples are taken by using vacutainers and the epidural needle that was already put in place (and that is kept in place for the whole procedure).

Blood sampling. Blood is drawn from the extradural vein using a vacutainer. The epidural needle is kept in place for the whole length of the procedure, to permit the injection of extra anesthetics if required, and to permit the serial sampling of blood (heamatology, biochemistry, coagulation, hormones).

Gluing of the tag. Close up of the gluing procedure. The operator is working the glue around the tag and in the mesh using a tongue depressor.



The glued tag. Close up of the tag from the side (left) and from the back (right). The picture shows the wet/dry sensors that are used to limit the transmissions of the tag messages to the satellite to the times when the seal is at the surface.

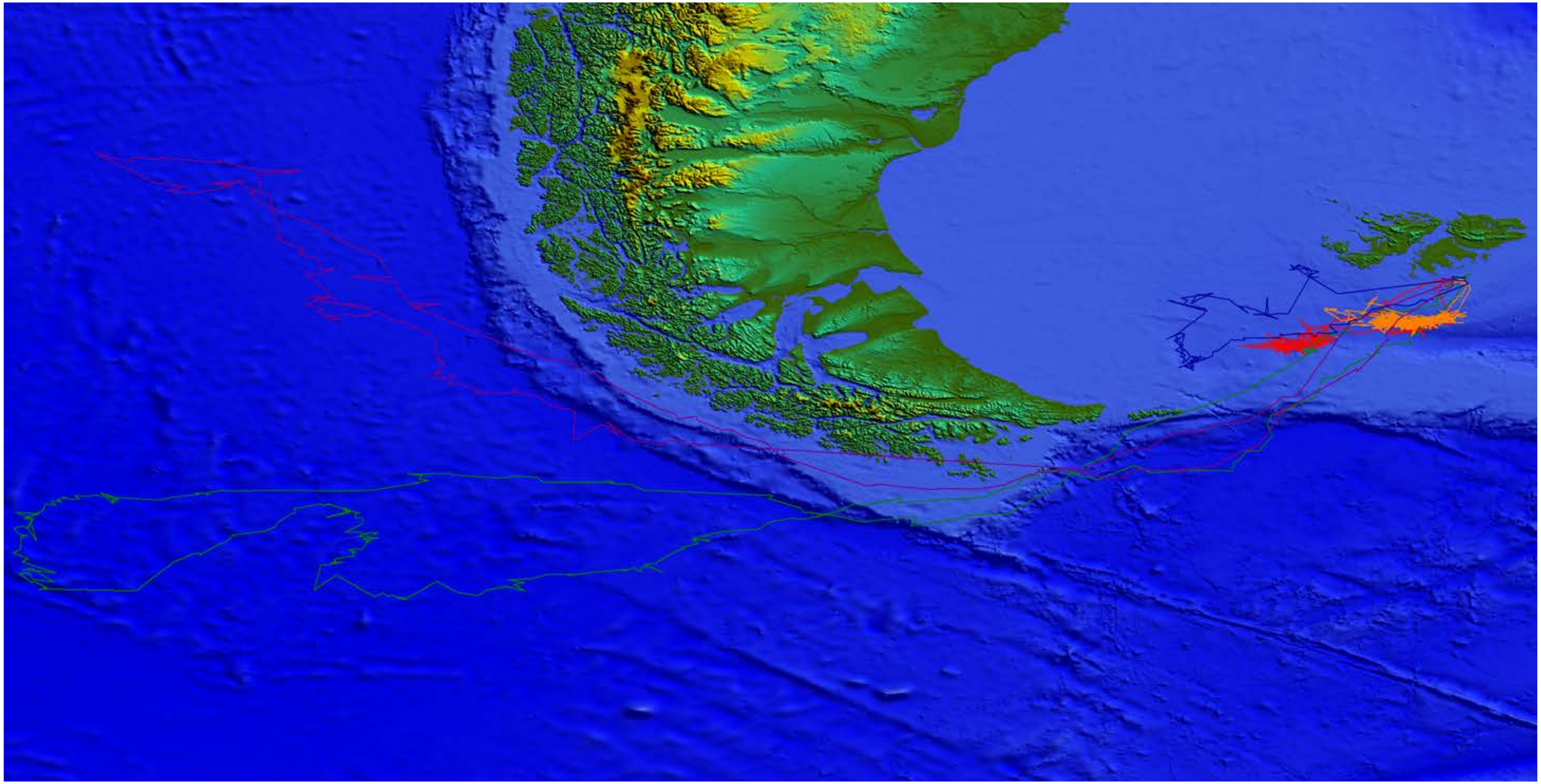
Monitoring of the subject during the deployment. An experienced operator controls the rhythm of breathing, to avoid the subject to fall into deep apnoea.

Monitoring of the subject during the deployment. A digital thermometer fitted with a rectal temperature probe is used to monitor the temperature of the subject, and to avoid the risk of hyperthermia.

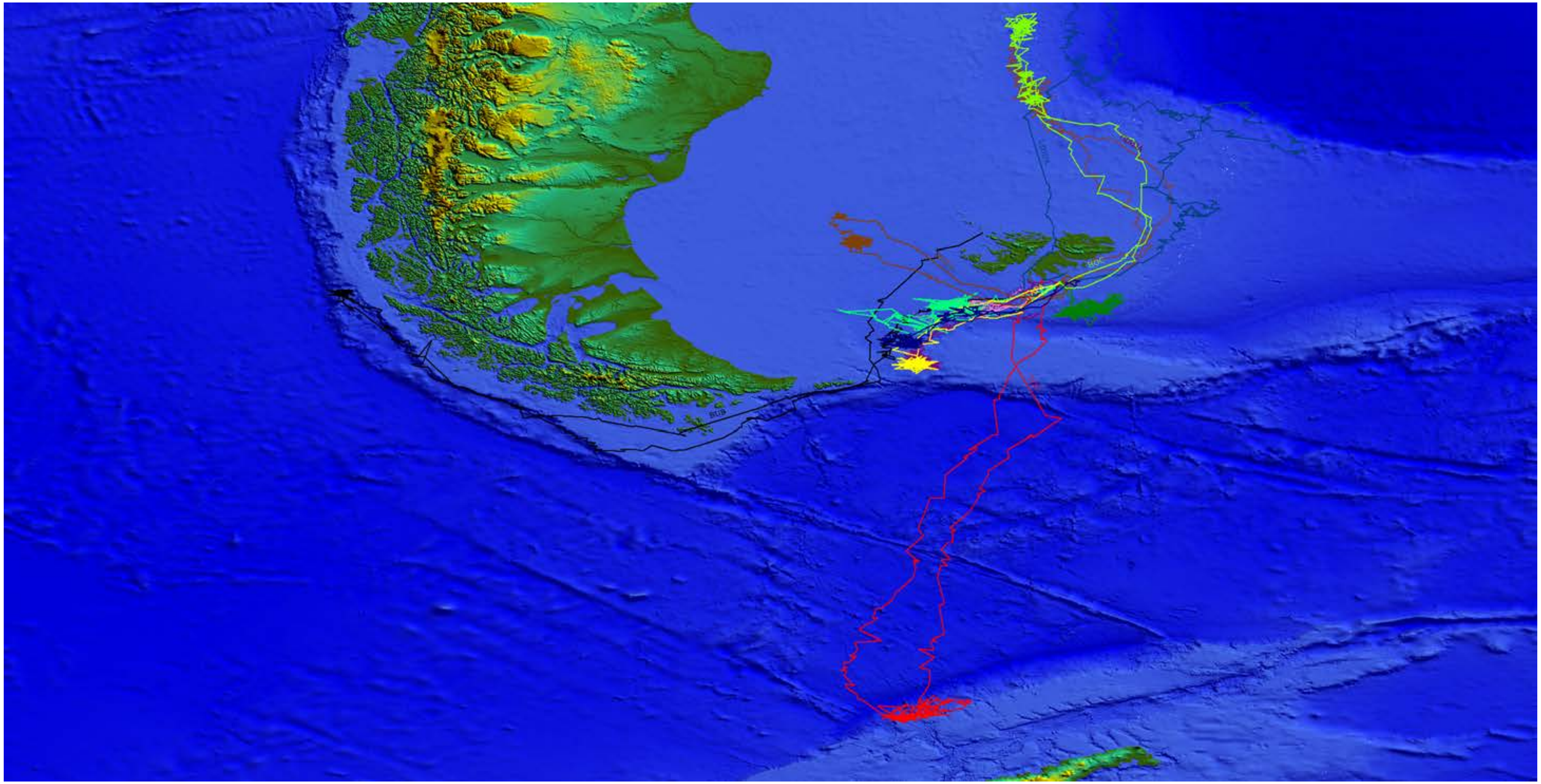
Mechanical stimulation of the subject. To speed up recovery, Axes is stimulated by one of the operator to improve post sedation recovery (lifting of the head, stimulation of the nostrils and rubbing of the throat)

Monitoring of the subject after the deployment. After the deployment one operator regularly checks the recovery of the subject, and another operator keep a full record of the female and pup behavior. Monitoring is carried out for up to two hours, depending on the speed of subject recovery

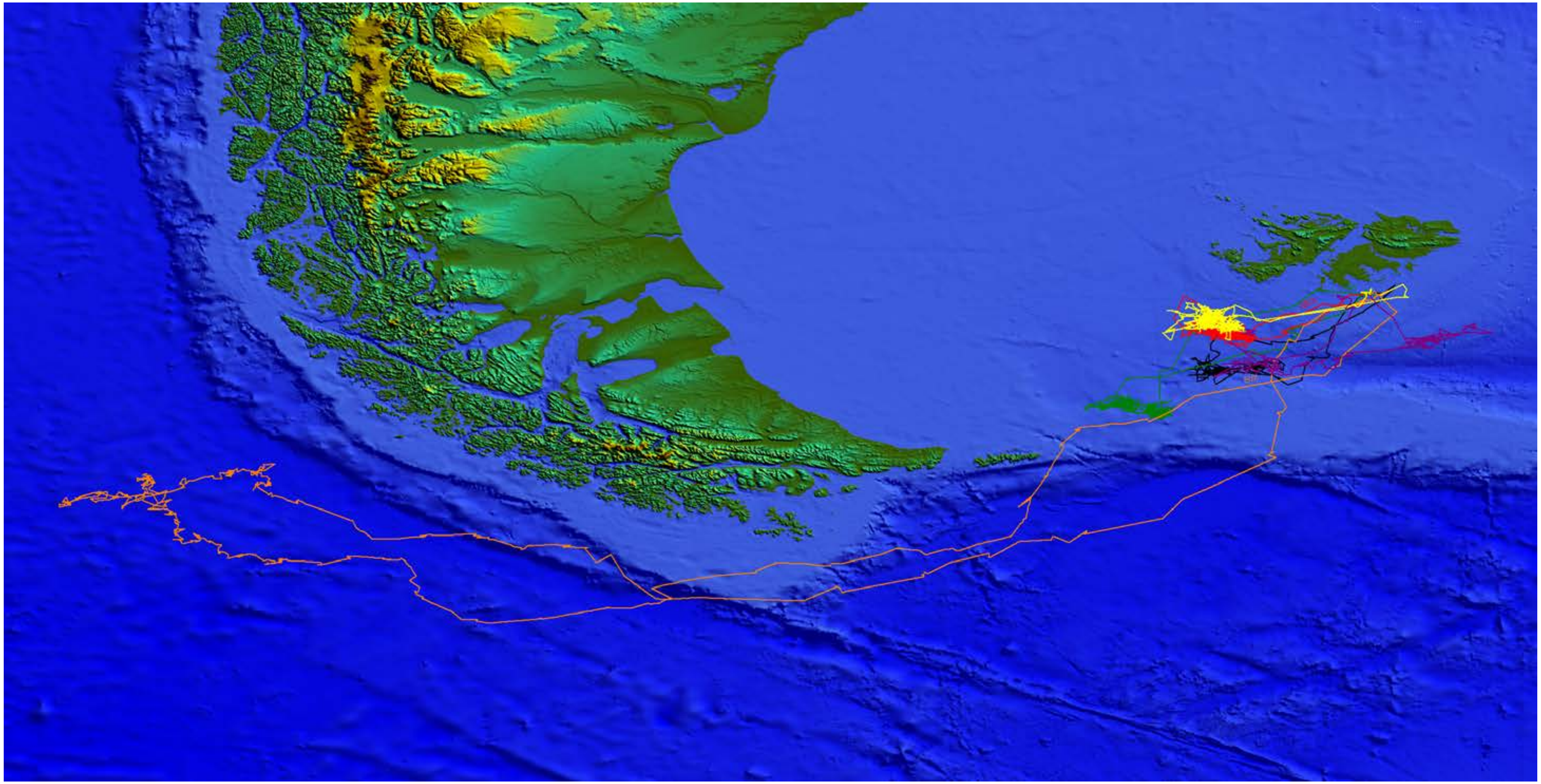
Appendix 2 - Supplementary maps



Map of individual tracks of the 2009 breeding season



Map of individual tracks of the 2010 breeding season



Map of individual tracks of the 2011 breeding season