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Review

Bio-logging and animal welfare: practical refinements

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Abstract: Although bio-logging can benefit both science and animal welfare, its application involves procedures that can cause animals pain, suffering and distress. It is essential—for both animal welfare and good science—to identify all sources of potential suffering associated with bio-logging and then to minimise suffering and improve welfare. This paper summarises key welfare concerns regarding wild animal studies, taken from a new report on refinements in bio-logging that covers both field and laboratory projects.

Many welfare concerns apply to both laboratory and field studies, but wild animals can experience additional psychological stress due to capture and handling by humans. The physiological impact of devices can also be more significant for wild animals, and opportunities to monitor instrumented wild animals following their release are greatly reduced.

The report includes recommendations that aim to reduce the impact of bio-logging on wild animals. It addresses refinements in the following areas: surgery, including pain relief; device attachment; releasing animals following surgery or attachment; device impact, including mass, shape and location; and information sharing to promote good practices in experimental protocols. All of these will help to prevent avoidable animal suffering in future projects.

key words: animal welfare, bio-logging, refinement, analgesia, ethics committees

Introduction

Telemetry and datalogging (referred to as bio-logging in this paper) are often regarded as techniques that can benefit both science and animal welfare. However, it is essential to remember that the application of bio-logging involves procedures that can cause animals pain, suffering and distress. The technique therefore needs to be refined to reduce any pain, distress and suffering, just like all other experimental procedures on living animals.

Note that refinement is defined as any measure that will improve animal welfare or reduce suffering. This does not only apply to experimental procedures, since all of an experimental animal's life events can and should be refined. These include breeding or capture, handling, transport, housing and care, identification, experimental procedures, rehoming or release to the wild and euthanasia. Furthermore, by refining animal husbandry and protocols, the science will also be improved because causing avoidable animal suffering adds another variable to the experiment and will only lead to increased noise and variance. This in turn may mean that more animals will have to be used in an experiment to gain significant differences between groups.

A series of documents setting out best practice for refining procedures and husbandry is being produced by a Joint Working Group on Refinement set up by the British Veterinary Association, Fund for the Replacement of Animals in Medical Experiments, RSPCA and Universities Federation for Animal Welfare. This paper is taken from the Group's reports on refinements in telemetry (Hawkins *et al*., 2004; Morton *et al*., 2003).

Key welfare concerns

The full report covers welfare concerns that apply to studies in both the field and the laboratory, using domesticated or wild animals, but this paper sets out some of the key sources of potential suffering that apply to field projects and wild animal studies in the laboratory (see Appendix 1 for a more comprehensive list). It is very important to choose protocols that minimise the risk of suffering in all of these areas and to be able to recognise and rapidly relieve suffering when it does occur. Many of the issues in Appendix 1 also apply to laboratory studies using domestic animals, but bio-logging projects using wild animals differ in three major ways:

1) Capture and handling by humans may cause distress to wild animals who are not habituated to humans. Restrained wild animals may lie very still and appear not to be stressed, but this behaviour, tonic immobility, should not be misinterpreted. Objective physiological measurements indicate that animals who are apparently coping well with being handled can be experiencing distress (Culik *et al*., 1990). In the case of animals undergoing invasive research, such distress will be compounded by surgical procedures.
2) The physiological impact of bio-logging devices, whether attached externally or implanted, can have far more serious implications for wild animals in the field than for laboratory animals. For example, the consequences of a reduction in the ability to forage or of increased grooming time may not be significant in laboratory animals but could be severely debilitating or fatal for free-ranging wild animals.
3) There is often little potential for monitoring instrumented wild animals following their release, or for administering antibiotics or analgesics if necessary. Animals in the field could suffer through their inability to feed, thermoregulate or defend themselves if humans are not in a position to intervene.

The rest of this paper summarises the Group's conclusions for actions that will help to refine field or wild animal studies in four areas: surgery; device attachment; device impact; and information sharing to promote best practice in experimental protocols, which will help to prevent avoidable suffering within other projects.

Surgery

Surgical standards for wild animals, including in the field, should follow similar principles to those expected in a laboratory operating theatre with the aim of ensuring that procedures are competently carried out, that asepsis is maintained, and that pain is adequately managed in all species. Access to an adequate supply of drugs, disinfectants and sterile instruments is essential and at least one assistant is necessary to monitor anaesthesia. If all of these conditions cannot be met, surgery in the field should not be contemplated.

Surgery may not go according to plan, due to (for example) unexpected adverse effects of anaesthetics or poor technique. In such an event a contingency plan must be in place to enable a rapid decision to be made regarding whether it would be in the animal's best interests to receive veterinary treatment and then be rehabilitated and released at a later date, rehomed to a collection, or killed. It will therefore also be necessary to have the means and expertise to kill animals humanely and containers and transport suitable for moving the species in question to a suitable centre for treatment.

Competence

The quality and relevance of surgical training has a direct impact upon animal welfare. Anyone performing surgical procedures with bio-logging devices should have a sound basic training in experimental surgery before progressing to implant insertions. Advice and training in relevant surgical techniques must be obtained from veterinary surgeons and from research scientists familiar with the devices, species and procedures being employed. It is good practice to set out 'benchmarks' such as acceptable failure rates for surgeons and to allocate resources to assess them—assessment could be a function of local committees such as the UK Ethical Review Process or US Institutional Animal Care and Use Committee.

Asepsis

Strict aseptic technique is absolutely essential where chronic implantations of foreign objects are being performed. Most infections originate from the skin, so special care needs to be taken with sterilisation of implants and of the skin at the operation site. Any minor wounds found to be present should also be treated wherever possible, even if they are remote from the surgery site, to minimise the possibility of their subsequent worsening through infection or other reasons post-release. Wild animals may appear to be resilient but this may be an adaptation to hide signs of disease, pain or distress rather than a reflection of their true physical and psychological fitness or their resistance to infection.

Prophylactic antibiotics can reduce the risk of infection in free-ranging animals and should be administered wherever necessary. For example, free-ranging animals can be given long acting antibiotic preparations that last for 3 or 4 days. Specialist veterinary advice should always be sought regarding both antibiotic regimens (and analgesic protocols; see below) and appropriate programmes should be carefully planned. It is also good practice to consult zoos or other organisations concerned with keeping wild animals about antibiotics for particular species. Useful starting points on the internet are the International Veterinary Information Service (IVIS, http://www.ivis.org/), WildPro (http://www.wildlifeinformation.org/) and the Electronic Zoo (http://netvet.wustl.edu/e-zoo.htm).

Pain relief

Surgical procedures cause animals discomfort and pain, even with appropriate analgesia. Pain causes suffering and distress, slows recovery, can reduce food and water consumption, interferes with respiration and can slow healing (Flecknell, 2000). The provision of appropriate pain relief following all surgical procedures on all species is therefore absolutely essential. Despite this, analgesia is still sometimes not provided following surgery. Reasons for this and current thinking on pain management are summarised in Table 1 (simplified from Flecknell and Waterman-Pearson, 2000; see also Soulsby and Morton, 2001;

Table 1. Current thinking on post-surgical analgesia for animals.

Historical reasons for withholding analgesia	Current thinking
Pain has a protective function–if it is relieved, animals will become too active and damage incision sites.	Analgesics rarely completely relieve pain–sufficient protective function will remain to prevent damage. Alleviating pain will speed recovery of normal physiological functions.
Analgesics have side effects that may be undesirable.	Side effects can almost always be avoided or managed by choosing appropriate agents and doses or by modifying care during recovery.
There is a lack of guidance on safe doses.	More information is now available on a range of agents and doses, due to increasing concern about pain in animals.

Roughan and Flecknell, 2002).

Post-surgical pain also affects a wide variety of physiological parameters in an unpredictable manner, which may have a significant impact on the validity of any experimental results. For example, sympathetic nervous system activation affects virtually all cardiovascular parameters and depresses gastrointestinal motility. It is also possible that renal and hepatic functions may be compromised *via* decreased water and food intake respectively. Respiratory function may be impaired by restricted breathing if there is thoracic pain, or by hyperventilation due to non-thoracic pain. Skeletal pain can restrict mobility, thus reducing food and water intake and depress appetite *per se* (see Flecknell and Waterman-Pearson, 2000).

New developments in pain management:

It is absolutely essential for the researcher and attending veterinarian to keep up with developments in pain management. This includes the introduction of new agents and current thinking on the most effective way to use all agents. Analgesia for wild species can be problematic; for example, opioids may be sedatives and little is known about potential adverse effects of Non-Steroidal Anti-Inflammatory Drugs (NSAIDs) on wild species. This should be addressed by thoroughly and continually researching new developments in analgesia protocols for wild animals, not by denying these animals pain relief. Again, IVIS, WildPro and the Electronic Zoo are valuable resources in this respect.

Timing—pre-emptive analgesia:

Even where appropriate anaesthesia is used, surgical pain can alter neurones in the central nervous system such that the injured site and adjacent sites become more sensitive following recovery (hyperalgesia) and even non-painful stimuli can become painful (allodynia) (Livingston and Chambers, 2000). This central sensitisation (or 'wind-up') should be prevented by administering analgesia before any incisions are made—so-called "pre-emptive analgesia"—as well as post-surgery (Dobromylskyj *et al.*, 2000). If this protocol is not followed, established pain can only be controlled, which is more difficult to achieve. Note that additional medication will still be required post-operatively, although post-operative pain will be reduced and easier to control due to the pre-emptive analgesia. Another benefit of pre-emptive analgesia is that it may result in a reduction in the dose of anaesthetic drugs required, which reduces the risk to the animal (see Dobromylskyj *et al.*, 2000).

Using different analgesics—multimodal pain therapy:

The clinical pain experienced by an animal involves many different pathways, mechanisms and transmitter systems, and so the use of a single class of analgesic is often not sufficient to control pain, even when it is administered pre-emptively. 'Multimodal pain therapy', using two or more different agents that act on different parts of the pain system, is now known to relieve discomfort and pain far more effectively. Another benefit of this approach is that it helps to overcome problems associated with differing speeds of action of different agents (Dobromylskyj *et al.*, 2000). For example, an opioid (*e.g.* Buprenorphine) and an NSAID are often used in combination to reduce post-surgical pain to an extent that would not be possible using either drug alone. Opioids act by limiting the input of nociceptive information into the central nervous system (CNS), thereby reducing central hypersensitivity, whereas NSAIDs act peripherally to decrease inflammation, limiting the nociceptive stimulation entering the CNS. In addition, NSAIDs act centrally to limit central changes induced by nociceptive information that does get through. For further information and examples of perioperative analgesic protocols, see Dobromylskyj *et al.*, (2000).

Release following surgery

The health of wild animals can deteriorate very rapidly in captivity if their essential needs cannot be met; there is a balance between releasing animals before they have lost condition and holding them for long enough to ensure that they have fully recovered from implantation. If animals are likely to lose condition quickly, it may be necessary to release them relatively soon. This should be of concern and such projects should not be carried out without compelling scientific justification. In these cases, animals should be released at the point of capture in favourable environmental conditions after very carefully checking that:

(i) a full recovery has been made from anaesthesia;
(ii) there are no signs of bleeding, haemorrhage or haematoma;
(iii) no injuries were caused during capture or handling, *e.g.* broken limbs in small birds;
(iv) analgesics and antibiotics have been administered as appropriate; and
(v) the animal is not in shock or pain. Behavioural and physiological indicators of shock and pain in the species should be thoroughly researched and a checklist should be prepared for field use. If necessary, a veterinarian or other relevant expert should accompany the investigator to assist with assessing animals.

There are, however, other conditions that will affect the balance relating to when an animal should be released. For example, an incubating bird may be released onto her nest while still under the influence of the anaesthesia. S/he can then recover in familiar surroundings and is less likely to desert the nest. If animals can be held for longer periods (*e.g.* days), clinical signs that should be monitored before release include signs of infection such as raised temperature, haematological changes, superficial or other injuries, appetite and eliminatory behaviour. In general, normal circadian rhythms should have been re-established and individuals prepared to feed in captive conditions should be taking appropriate amounts of food and water. It is essential to monitor the fate of released animals as far as possible and to assess times and possible causes of morbidity and death so that they can be related to surgical or attachment protocols and used to refine them as appropriate (*e.g.* Mulcahy and Esler, 1999).

Attachment

Judgement as to the most appropriate attachment method that will cause least discomfort or distress should be made on a case-by-case basis, which will necessitate a comprehensive literature search (see Kenward, 2001) and consultation with experts in the field.

There are a number of methods used to fix transmitters or data loggers to animals in the field, including collars, pendants or necklaces, neck bands, backpacks and harnesses, leg bands, tail or patagial mounts (Anderka and Angehrn, 1992; Gaunt and Oring, 1999; Kenward, 2001; Redfern and Clark, 2001). Glue, tape such as Tesa™ tape (Beiersdorf WG; *e.g.* see http://www.penguins.org.au/04/andre/content.asp?page=9; Wilson and Wilson, 1989; Wilson *et al*., 1997) sutures and bolts (for carapaces) are also used to attach devices; glue is suitable for short-term projects whereas sutures are generally used for studies on rapidly growing juvenile birds where the use of glue is not possible. The sutures gradually pull through the skin as the bird grows, but this method is not to be recommended unless there are no other attachment techniques and there is strong scientific justification for the study. Sutures should never be used to attach devices to mammals. Harpoons are used to fix devices to the fins or blubber of cetaceans or the muscle of large fish. External attachment techniques for fish frequently involve suturing through skin and muscle and analgesia for fish is poorly understood, which is a cause for concern. It is essential to consult organisations such as Concerted Action for Tagging of Fishes (http://www.hafro.is/catag/) for information on current refinements in field fish bio-logging and tagging.

The colour of external components including harnesses, devices and markers should be considered very carefully for studies involving wild animals, in case they affect social status or attract the attention of predators or prey (Keinath and Musick, 1993; Cuthill *et al*., 1997; Gaunt and Oring, 1999; Redfern and Clark, 2001). Red components or identification tags should not generally be used, as they may be mistaken for blood by conspecifics or predators. The likely impact of different colours should be researched for each species.

It is essential that harnesses will eventually become detached from wild animals. Even where datalogging devices need to be retrieved so that data can be obtained, there will need to be a "failsafe" in place so that the harness will eventually become detached if the animal is not recaptured after a predetermined length of time. One way to achieve this is to use harnesses made from biodegradable materials that will permit the harness to fall off after an appropriate period, *e.g.* by using magnesium components or adjacent links of aluminium and stainless steel in a marine environment (Kenward, 2001). Another safety option is a 'one break—all release' mechanism so that harnesses are not left hanging from the animal. The most desirable system would be a time-release mechanism (Kenward, 2001) and the availability of such equipment should be researched when designing harnesses.

Release following external device attachment

Animals are usually released immediately after devices have been attached to them. Points (iii) and (v) relating to surgery also apply in such cases; so does point (i) if it has been necessary to anaesthetise or sedate the animal to fit the device. Also note that immobilising drugs will inevitably have side-effects that may not always be predictable in wild animals (*e.g.* Alibhai *et al.*, 2001). Every care must be taken to ensure as far as possible that the method of attachment will not abrade skin, scales, fur or feathers (Gedir, 2001). Research will also be necessary to find out whether external devices are unsuitable for some species and/or behaviours.

The physical impact of devices

Attaching or implanting devices to animals will always have an impact on physiology or behaviour, and this can be significant (Culik and Wilson, 1991; Vaughan and Morgan, 1992; Wilson and Culik, 1992; Ropert-Coudert *et al.*, 2000). However, only 10% of marked-animal studies published in major journals in 1995 included evidence that tag impact had been considered (Murray and Fuller, 2000). There are three main device design criteria that need to be reviewed; mass, shape and location.

Mass

Adding extra mass to animals' bodies can have a significant physiological impact and cause discomfort and distress, particularly in small individuals (Baumans *et al.*, 2001). Mechanical loading may contribute to the regulation of body mass in some circumstances; in deer mice (*Peromyscus maniculatus*) there is a significant and sustained loss of tissue mass that varies directly with the mass of the implant (Adams *et al.*, 2001). The health and welfare implications of such a mass loss are not known, but it is important to note that adding extra mass can have a significant impact on the whole animal and could, in some species, alter the 'set point' for body mass in the long term. It is especially important to be aware of this when using wild animals, particularly in the field.

It is also important to consider the effects of the mass of a device on the energy costs of travel (*e.g.* Ropert-Coudert *et al.*, 2000). It can be calculated (see Calder, 1984) that the extra travel cost of having to carry around a device weighing 10% of body weight would be about 6% in mammals and 7.5% in birds. Using estimates of the distances travelled daily, it is possible to calculate the likely increment in daily energy requirement associated with transport of devices of known mass (see Croll *et al.*, 1992). This will help to predict possible impact on foraging time, but there are likely to be other biological implications for the animal, for example reduced food delivery to young (Murray and Fuller, 2000). Such considerations are relevant to the assessment of the welfare impact of bio-logging equipment used in wild animals in the field (*e.g.* Culik and Wilson, 1991).

Behaviour and adaptations to significant life events such as breeding should be taken fully into account. For example, some species of sea bird rapidly lose body mass after their chicks have hatched, in what is believed to be an adjustment to optimise flight efficiency (Croll *et al.*, 1991; and Gaston and Perin, 1993). Implanting a data logger could, in some cases, replace a significant proportion of body mass that had been lost for an adaptive purpose. Further tissue mass may be lost to compensate for this, which could impact on the ability of birds to rear their chicks and also affect the scientific value of any data obtained.

Shape

Even when the relative mass of a device may not cause discomfort or pain *per se*, trauma, abrasion or prevention of normal function can occur if the device is of an inappropriate shape or incorrectly fitted (*e.g.* see Gedir, 2001). The length of devices may be an issue in adult animals such as rodents or marmosets who curl up to sleep, and it is also essential to avoid placing pressure on the bladder, liver or diaphragm when animals assume resting or sleeping postures. Where external devices will be attached to running, flying or diving animals, it is essential to minimise drag. This includes reducing the frontal area of the device, streamlining its shape and ensuring that it is attached in an appropriate location so as to smoothly extend the contours of the animal (see Obrecht *et al.*, 1988; Bannasch *et al.*, 1994). It is especially important to consult with experts and to search the literature for guidance on device shape and dimensions.

Location

The optimal location of the body of a device varies according to the type of device, parameter measured and the study species. The primary factor to be borne in mind is the extra weight which may lead to discomfort and also pressurise adjacent tissue. If this is skin, the pressure may cause abrasion, pressure sores or necrosis. If the device is in or near the gut, pressure may cause an obstruction or perforation of the bowel (*e.g.* Broadhurst *et al.*, 1996). Devices placed in the peritoneal cavity have also been known to pass into the gut lumen and be passed out of the animal *per rectum* (AJ Webb, pers. obs. in the pig). It is thus advisable to secure devices within the abdominal cavity by anchoring them to the flank wall. Pressure applied to the peritoneum can be very painful, so the risk of this should be minimised by anchoring devices to the parietal (not visceral) peritoneum. Many devices are designed to be implanted subcutaneously in rodents, but this location is not suitable for some larger animals, *e.g.* some non-human primates, as seromas and sinuses can form.

In all cases, the device should be 'balanced' in the animal as much as possible as a unilateral load can lead to device slippage and postural problems. Both normal and postoperative behaviour of animals should be taken into consideration, including lying positions and scratching and grooming actions. Devices should be unaffected by limb movement during locomotion and should not restrict it. Thought should be given to the animals' centre of gravity when walking, running, flying, swimming or diving, if and how this moves location, and how devices can be positioned so as to minimise impact on the animal's posture and equilibrium (Obrecht *et al.*, 1988; Bannasch *et al.*, 1994). Careful observation of animals, a literature search and consultation with colleagues may all be necessary to position devices correctly.

Sharing information about best practice in bio-logging studies

It is part of the researcher's responsibility towards experimental animals to evaluate and effectively communicate any information related to refinement so that other workers can minimise animal suffering and improve welfare. In particular, all surgical, anaesthetic, analgesic and antibiotic regimens should be correlated with available information about post-release morbidity and mortality rates and disseminated to others in the field (Mulcahy and Esler, 1999). There are a number of suitable forums for this, *e.g.* the Forum on Wildlife Telemetry (http://www.npwrc.usgs.gov/resource/tools/telemtry/telemtry.htm) or the International Society for Biotelemetry (http://baby.indstate.edu/isb/frames/). Refinements in both procedures and husbandry should also be included in the materials and methods sections of scientific papers, posters and talks and should not be marginalised or segregated (Appendix 2 lists details that should be included in methods sections).

It is sometimes believed that journal editors would refuse to include more information on refinement due to lack of space or because it is not the convention. This should not stop those using animals from making a case for including more detail on ethical, scientific and welfare grounds. Information on husbandry and care can also often be summarised so that length is not an issue (GV-SOLAS, 1985; Morton, 1992; Smith *et al*., 1997). Details of refinements should be included in paper titles and abstracts wherever possible, and attention should be drawn to this by using relevant keywords such as refinement, reduction, analgesia or enrichment. This will encourage database compilers to use keywords indicating that the paper includes information that will enable others to refine experimental protocols and/or husbandry.

Conclusion

This paper provides a brief overview of refinement measures that can help researchers, veterinarians and others involved in bio-logging studies to reduce the impact of their research on animals. These issues are covered in greater depth in the full Joint Working Group on Refinement reports (Hawkins *et al*., 2004; Morton *et al*., 2003). The Group hopes that its report will be useful not only to those using bio-logging for the first time, but also to those with more experience who want to ensure that they are doing everything possible to minimise harms and improve animal welfare.

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References

Adams, C.S., Korytko, A.I. and Blank, J.L. (2001): A novel mechanism of body mass regulation. J. Exp. Biol., **204**, 1729–1734.

Alibhai, S.K., Jewell, Z.C., and Towindo, S.S. (2001): Effects of immobilization on fertility in female black rhino (*Diceros bicornis*). J. Zool. London, **253**, 333–345.

Anderka, F.W. and Angehrn, P. (1992): Transmitter attachment methods. Wildlife Telemetry: Remote Monitoring and Tracking of Animals, ed. by I.G. Priede and S.M. Swift. Chichester, Ellis Horwood, 135–146.

Bannasch, R., Wilson, R.P. and Culik, B. (1994): Hydrodynamic aspects of design and attachment of a back-mounted device in penguins. J. Exp. Biol., **194**, 83–96.

Baumans, V., Bouwknecht, J.A., Boere, H., Kramer, K., van Lith, H.A., van de Weerd, H.A. and van Herck, H. (2001): Intra-abdominal transmitter implantation in mice: effects on behaviour and body weight. Anim. Welfare, **10**, 291–302.

Broadhurst, P.A., Sayer, J. and Nathan, A.W. (1996): Migration of an implantable cardioverter-defibrillator generator into the small bowel. Heart, **75**, 368.

Calder, W.A. III (1984): Size, Function and Life History. Cambridge, Harvard Univ. Press, 448 p.

Croll, D.A., Gaston, A.J. and Noble, D.G. (1991): Adaptive loss of mass in thick-billed murres. Condor, **93**, 496–502.

Croll, D.A., Gaston, A.J., Burger, A.E. and Konnoff, D. (1992): Foraging behaviour and physiological adaptation for diving in thick-billed murres. Ecology, **73**, 344–356.

Culik, B. and Wilson, R.P. (1991): Swimming energetics and performance of instrumented Adélie penguins (*Pygoscelis adeliae*). J. Exp. Biol., **158**, 355–368.

Culik, B., Adelung, D. and Woakes, A.J. (1990): The effect of disturbance on the heart rate and behaviour of Adélie penguins (*Pygoscelis adeliae*) during the breeding season. Antarctic Ecosystems, Ecological Change and Conservation, ed. by K.R. Kerry and G. Hempel. Berlin, Springer, 177–182.

Cuthill, I.C., Hunt, S., Cleary, C. and Clark, C. (1997): Colour bands, dominance, and body mass regulation in male zebra finches (*Taenopygia guttata*). Proc. R. Soc. London, Ser. B, Biol. Sci., **264**, 1093–1099.

Dobromylskyj, P., Flecknell, P.A., Lascelles, B.D., Livingston, A., Taylor, P. and Waterman-Pearson, A. (2000): Management of postoperative and other acute pain. Pain Management in Animals, ed. by P.A. Flecknell and A. Waterman-Pearson. London, W.B. Saunders, 81–145.

Flecknell, P.A. (2000): Animal pain–an introduction. Pain Management in Animals, ed. by P.A. Flecknell and A. Waterman-Pearson. London, W.B. Saunders, 1–7.

Flecknell, P.A. and Waterman-Pearson, A., ed. (2000): Pain Management in Animals. London, W.B. Saunders, 184 p.

Gaston, A.J. and Perin, S. (1993): Loss of mass in breeding Brünnich's guillemot *Uria lomvia* is triggered by hatching. Ibis, **135**, 472–475.

Gaunt, A.S. and Oring, L.W. (1999): Guidelines to the Use of Wild Birds in Research, 2nd ed. Winfield, Kansas, American Ornithologists' Union. http://nmnhwww.si.edu/BIRDNET/GuideToUse/

Gedir, J.V. (2001): A non-invasive system for remotely monitoring heart rate in free-ranging ungulates. Anim. Welfare, **10**, 81–89.

GV-SOLAS Working Committee for the Biological Characterisation of Laboratory Animals (1985): Guidelines for specification of animals and husbandry methods when reporting the results of animal experiments. Lab. Anim., **19**, 106–108.

Hawkins, P., Morton, D.B., Bevan, R., Heath, K., Kirkwood, J., Pearce, P., Scott, E., Whelan, G. and Webb, A. (2004): Husbandry refinements for rats, mice, dogs and non-human primates used in telemetry procedures. Seventh report of the BVA(AWF)/FRAME/RSPCA/UFAW Joint Working Group on Refinement, Part B. Lab. Anim., **38**, 1-10.

Keinath, J.A. and Musick. J.A. (1993): Movements and diving behaviour of a leatherback turtle, *Dermochelys coriacea*. Copeia, **1993(4)**, 1010–1017.

Kenward, R.E. (2001): A Manual for Wildlife Radio Tagging. London, Academic Press, 350 p.

Livingston, A. and Chambers, P. (2000): The physiology of pain. Pain Management in Animals, ed. by P.A. Flecknell and A. Waterman-Pearson. London, W.B. Saunders, 9–19.

Morton, D.B. (1992): A fair press for animals. New Scientist, **1816**, 28–30.

Morton, D.B., Hawkins, P., Bevan, R., Heath, K., Kirkwood, J., Pearce, P., Scott, E., Whelan, G. and Webb, A. (2003): Refinements in telemetry procedures. Seventh report of the BVA(AWF)/FRAME/RSPCA/UFAW Joint Working Group on Refinement, Part A. Lab. Anim., **37**, 261-299.

Mulcahy, D.M. and Esler, D. (1999): Surgical and immediate postrelease mortality of harlequin ducks (*Histrionicus histrionicus*) implanted with abdominal radio transmitters with percutaneous antennae. J. Zoo Wildl., Med., **30**, 397–401.

Murray, D.L. and Fuller, M.R. (2000): A critical review of the effects of marking on the biology of vertebrates. Research Techniques in Animal Ecology, Controversies and Consequences, ed. by L. Boitani and T. Fuller. New York, Columbia University Press, 15–64.

Obrecht III, H.H., Pennycuick, C.J. and Fuller, M.R. (1988): Wind tunnel experiments to assess the effect of back-mounted radio transmitters on bird body drag. J. Exp. Biol., **135**, 265–273.

Redfern, C.P.F. and Clark, J.A. (2001): Ringers' Manual. Thetford, British Trust for Ornithology, 270 p.

Ropert-Coudert, Y., Bost, C.-A., Handrich, Y., Bevan, R., Butler, P.J., Woakes, A.J. and Le Maho, Y. (2000): Impact of externally-attached loggers on the diving behaviour of the king penguin. Physiol. Biochem. Zool., **74**, 438–444.

Roughan, J.V. and Flecknell, P.A. (2002): Buprenorphine: a reappraisal of its antinociceptive effects and therapeutic use in alleviating post-operative pain in animals. Lab. Anim., **36**, 322–343.

Smith, J.A., Birke, L. and Sadler, D. (1997): Reporting animal use in scientific papers. Lab. Anim., **31**, 312–317.

Soulsby, L. and Morton, D.B. (2001): Pain, Its Nature and Management in Man and Animals. London, Royal Society of Medicine Press, 122 p.

Vaughan, M.R. and Morgan, J.T. (1992): Effect of radio transmitter packages on wild turkey (*Meleagris gallopavo*) roosting behaviour. Wildlife Telemetry: Remote Monitoring and Tracking of Animals. Chichester, Ellis Horwood Ltd., 628–632.

Wilson, R.P. and Culik, B.M. (1992): Packages on penguins and device-induced data. Wildlife Telemetry, Remote Monitoring and Tracking of Animals. Chichester , Ellis Horwood Ltd., 573–580.

Wilson, R.P. and Wilson, M.-P.T.J. (1989): Tape: a package-attachment technique for penguins. Wildl. Soc. Bull., **17**, 77–79.

Wilson, R.P., Putz, K., Peters, G., Culik, B., Scolaro, J.A., Charrassin, J.B. and Ropert-Coudert, Y. (1997): Long-term attachment of transmitting and recording devices to penguins and other seabirds. Wildl. Soc. Bull., **25**, 101–106.

Appendix 1. Potential sources of discomfort, pain, suffering and distress associated with bio-logging in wild animals.

- Psychological stress due to human interference with habitat (*e.g.* studies involving recording vocalisations, video monitoring, removal of faeces)
- Possibly higher levels of stress and distress due to unfamiliarity with humans
- Capture, handling, restraint, injury
- Confinement
- Transport
- Impeded movement, skin/fur/feather abrasion from harnesses, jackets and poorly placed devices
- Anaesthesia or sedation, surgical stress, recovery from sedation or anaesthesia
- Post-surgical pain and discomfort
- Chronic post-operative discomfort and pain due to presence of the device (*e.g.* due to mass, dimensions or location)
- Wound breakdown
- Chronic adhesions; inflammatory lesions; seroma
- Physiological stress and disturbance of energy balance due to the extra load imposed on the animal
- Marking (including altered behaviour of conspecifics towards animal)
- Disruption of colonies of social species—both those under study and others
- Increased risk of predation, reduced ability to catch prey
- Potential to lose condition while in captivity

Appendix 2. Details that should be included in methods sections of biotelemetry papers, posters and talks.

- Age, mass and sex of animals
- Husbandry and care, including environmental stimulation
- Selection of animals and training if appropriate
- Duration of preoperative monitoring and variables used; preparation for surgery
- Anaesthesia
- Pain management: pre-emptive analgesia; post-operative analgesia; doses and duration; how duration was decided
- How pain and distress were recognised; clinical signs denoting specific actions; frequency of monitoring
- Prophylactic antibiotics
- Device mass, dimensions and shape
- Surgical techniques; device location
- Success rate
- Assessment of the impact of the device on the animal, especially for wild animals
- Any technical problems and how they were solved