A novel framework to protect animal data in a world of eco-surveillance

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Abstract

Surveillance of animal movements using electronic tags (i.e. biotelemetry) has emerged as an essential tool for both basic and applied ecological research and monitoring. Advances in animal tracking are occurring simultaneously with changes to technology, in an evolving global scientific culture that increasingly promotes data sharing and transparency. However, there is a risk that misuse of biotelemetry data could increase the vulnerability of animals to human disturbance or exploitation. For the most, part telemetry data security is not a danger to animals or their ecosystems, but for some high-risk cases, as with species' with high economic value or at-risk populations, available knowledge of their movements may promote active disturbance or worse, potential poaching. We suggest that when designing animal tracking studies it is incumbent upon scientists to consider the vulnerability of their study animals to risks arising from the implementation of the proposed program, and to take preventative measures.

Keywords: Ecology, biotelemetry, biologging, species at risk, data security, poaching, data privacy

Introduction

Large numbers of animals, from insects to whales, are now tracked using electronic tags as they move over land, through air, and in water (i.e. biotelemetry and biologging; Hussey et al. 2015; Kays et al. 2015; Wilmers et al. 2015; herein called animal tracking data). Electronic tags can transmit or log data about animal movement, imagery (i.e. from onboard cameras), or physiological state, allowing four-dimensional movement path reconstructions, sometimes in real time (Lennox et al. 2017a; Box 1). Animal tracking data have multiple applications, including documenting fundamental aspects of a species' ecology, discovering new migratory corridors or breeding sites, and remotely monitoring their environment (Raymond et al. 2014; Treasure et al. 2017; Brodie et al. 2018; Goulet et al. 2019). As a result, electronic tracking tools are now relied on for animal conservation and management efforts (Cooke 2008; Brooks et al. 2018; Crossin et al. 2018; Hays et al. 2019), for the spatial planning of human activities and infrastructure, and for improving the forecasts provided by oceanographic models (Allen and Singh 2016; McGowan et al. 2017; Lennox et al. 2018; Harcourt et al. 2019).

Many commercial industries rely on the known occurrence or availability of animals and benefit from knowledge of their movements, creating an incentive for using tracking data. For example, professional ecotourism operators are dependent upon access to their target species to satisfy their customers (e.g. Hayward et al. 2012; Fraser et al. 2014) while), commercial fishers can maximize fishing effort with improved knowledge of species distributions, and aqua/agriculturists may wish to track the presence of wild animals around their livestock. These stakeholder interests do not necessarily coincide with the primary research or conservation objectives that were the impetus for the tracking study, creating the potential for conflict (Hartter et al. 2013). The potential value of animal tracking data to conflicting parties has resulted in concerns that the data could be misused and a recognition that researchers, as stewards of their data, require information about best practice before, during, and following the implementation of an animal tracking study (Cooke et al. 2017b). Data sharing and communication are critical components of the scientific process, providing access to a wealth of knowledge that opens new and robust avenues of inquiry (Nguyen et al. 2017). Yet, sharing data openly could also increase the vulnerability of animals to disturbance through unintended data use by bad actors. Data security breaches may ultimately compromise the welfare of wild animals and the recovery of imperiled species.

Open science and communication are critical to successful research (Merton 1973), but data are sometimes embargoed to protect sensitive information (Kempner et al. 2011). With emerging concerns over the potential misuse of animal tracking data (Cooke et al. 2017b), we believe that the research community will benefit from support in decision-making and information on best practices for handling potentially sensitive animal tracking cases. We briefly discuss the potential risks that animals are exposed during tracking studies. We then review existing protocols and infrastructure within animal tracking science available to researchers for protecting sensitive data. Finally, we present decision-making tools to assist researchers to develop appropriate data management plans and if necessary, instigate mitigation measures prior to a tracking study.

Risks associated with animal tracking

The scale of tracking data misuse is presently difficult to establish, with only a cases having been reported (see Table 1; Meeuwig et al. 2015; Cooke et al. 2017b; Frey et al. 2017a). Nonetheless, it is evident there are potential problems that need to be addressed (Cooke et al. 2017b; Tulloch et al. 2018). Data can either be intercepted directly from tracking hardware by physically breaching the equipment or indirectly by reading results or accessing databases, maps, public outreach websites or published accounts of animal movements (i.e. published scientific reports and papers). Receivers provide the position of tagged individuals by detecting signals transmitted by radio, acoustic, or satellite transmitters attached to animals (Table 2). If proper security precautions are not taken, the data could be intercepted by individuals possessing compatible receivers that listen for tagged animals in a study area, or be downloaded directly from stationary receivers if they are not secured (Meeuwig et al. 2015). Indeed, it is possible for the public to purchase radio or acoustic receivers or goninometers off the shelf that can locate radio, acoustic or satellite tagged animals. Wildlife photographers could do so, bringing their own radio receivers with them to locate tagged animals (Cooke et al. 2017b). Satellite and GSM tags log data onboard and then transmit it to compatible satellites or cell phone towers, which then relay the data so that is accessible via password protected internet portals or applications. Interception of these satellite coded signals of animal movement patterns is unlikely, and only possible if an actor owns a field receiver and can actively detect the tag.

Following study completion, animal tracking results are shared in media, reports, or journal articles, and the data commonly archived in online repositories (Roche et al. 2015; Soranno et al. 2015; Renaut et al. 2018) in compliance with commitments by many governments and research funding agencies to the FAIR (Findable, Accessible, Interoperable, Reusable;

Wilkinson et al 2016) principles for scientific data management and stewardship. Data-sharing and data-reuse accelerate the pace of scientific discovery.

Review of existing protocols and infrastructure to limit security risks

Whereas researchers are directly responsible for stewardship of their tracking data, the growth of major networks and telemetry databases are beginning to tackle issues of data curation and to provide data owners with preferred protocols for archiving potentially sensitive data. Cyberinfrastructure is available for archiving and sharing large data sets from animal tracking studies, including institutional or third party repositories such as Dryad (http://datadryad.org/) and Movebank (http://www.movebank.org/) and research networks that have data portals for archiving and sharing detection data (Table 3). We reviewed data policies from major platforms providing data archiving and sharing services where animal movement data was a focus. Although we concentrate on movement data, we include databases that provide purely location data (e.g. Global Biodiversity Information Facility [GBIF], eBird, International Union for the Conservation of Nature [IUCN]; Table 3). For example, location-based services often provide options to generalize species' locations by decreasing resolution based on the threats posed to the species (Chapman and Grafton 2008).

To respect FAIR principles, data embargoes or generalization must have an expiry date for all but the most critically sensitive species (Table 3). Campbell et al. (2015) suggested a three-year embargo on wildlife telemetry data amounting to the average lifespan of telemetry projects. Roche et al. (2014) discussed embargoes related to data archiving in the Dryad database and suggested that a five-year data embargo would be sufficient to assuage concerns of premature access by other researchers for ecology and evolution data. A review of the outcomes was recommended after five years, to determine whether the protections from the embargo were sufficient or whether an additional five-year embargo should be initiated. The Ocean Tracking Network data embargoes can be extended by the data creators, but by default are set to expire two years after the end of a tag's expected life.

Key to fair and effective protection of sensitive animal movement data is a transparent decision making process. Networks may have policies for embargoes and it is the purview of the researcher to request an embargo where perceived necessary. It is unclear how frequently such individual requests are denied, although the IMOS policy explicitly states that publication priority or commercial interests are insufficient grounds to grant an embargo (Table 3). Best practices advised by the GBIF are to determine whether the species is exposed to anthropogenic stressors, whether it is sensitive to those stressors, and whether those stressors would be exacerbated by the release of location data.

Implementing data protections for responsible telemetry

Given situations where risks to animals are possible, data transmitted or logged by electronic tags should be protected so their data cannot be immediately decoded and identify an animal's position. Manufacturers of transmitters must have secure software options available to provide protection from attempts to intercept data by third parties. For sensitive studies, metadata should be restricted so even if a transmitter signal is intercepted it does not provide the identity of the animal (i.e. the species). This could be further accomplished by encrypting signals before the receiver decodes them, which would be more efficient than attempting to limit access to equipment, as the latter may not be feasible. In many extant systems, a connection between a computer and a receiver or logger is sufficient to successfully offload data with no security protocols limiting who may access the data. When the risk of physically breaching receivers, loggers, or repositories that contain sensitive animal position data is perceived, the data may be strongly encrypted to ensure they are uninterpretable without a compatible key. Raw data could be encrypted whether stored on receivers or uplinked from satellites to online accounts as an additional layer of security. Live data streaming services (e.g. Keating et al. 1991) only release transmission data from compatible UHF tags to account-holders; however, goninometers can make it possible for third parties to locate satellite tagged individuals (e.g. equipped with SPOTs) or recover satellite tags in the ocean (PSATs) and then directly offload the data without data security protocols.

We emphasise that, as a rule, researchers should strive to make their tracking data open and available where possible. The information often has immense value to multiple parties including, for example, informing the general public as well as serving the needs of the scientists and managers who directly undertake the research. Stakeholder identification and consultation are therefore essential in developing animal tracking studies to ensure the socioeconomic context of the animal tracking is well understood. Stakeholder consultation also allows the researchers to ascertain the level of risk prior to implementing a study, because researchers may be naïve to other group perspectives in a study system. By default, researchers should be expected to upload tracking data without restrictions or generalization in the context of it being shared openly and freely. We suggest that the use or request of embargos should include a risk assessment (Box 2), and we present a template here (Box 2; Figure 1). Embargos should have the option for renewal depending upon the sensitivity of the study, and we provide an avenue by which to consider this (Figure 1).

Discussion

Data management plans provide an effective tool for scientists using telemetry to proactively address concerns about data misuse and provide transparency about embargoes, if necessary (Michener 2015). Funding agencies such as the Australian Research Council, UK Research Councils, National Science Foundation (USA), NASA, and others require data management plans from scientists so that expectations are clear to all parties about the ultimate fate of the data. Although they may need to be flexible as conditions change over the course of a multi-year study, data management plans assist in managing expectations of funding agencies and often satisfy publishing outlets that require data to be made open-access. The long-term fate of data requires a broader discussion about the ownership and power of attorney over data to ensure that researchers are not solely responsible for making decisions about its fate. In the future it may be useful to establish "treaties" or other international agreements when tracking "sensitive" species and for which one might anticipate conflict. We are unaware of any such agreements at present.

We expect that in the near future real-time animal tracking data will be of even greater value in ways previously unforeseen (Box 1). Initiatives pursuing the vision of bringing real-time animal data to the public and beyond the traditional research sphere include the sensor network in a wetland area (Li et al. 2015), augmented reality in daily life (https://www.internetofelephants.com), and efforts to merge human data with animal data (Frey et al. 2017b). These varied initiatives using animal movement data collected with telemetry require consideration of how best to protect the data from misuse when they become widely available rapidly and automatically. To protect sensitive data from fraud and misuse, stronger organizational or technical measures must be taken than those currently used with near real-time or archived data. In principle, the same protective measures can be applied as are used for other types of sensitive data, such as financial or personal data. Drawing on the experiences of others working in data management and data mining with sensitive personal data, we provide some technical approaches that could be used to protect real-time animal data from misuse. Possible approaches include data blurring (reduce location accuracy), noise addition (add location errors), differential privacy (add randomness), data aggregation (share habitat instead of location), data hiding (share altitude but hide latitude/longitude), homomorphic encryption (analyze on encrypted data), and multiparty computation (jointly analyze while keeping data private). However, all the popular anonymization and pseudonymization approaches used with human data are less useful in this context because the identity of an animal is rarely important, i.e. with rare exceptions its identity does not need to be protected.

As the number of instruments used to track animals increase and become progressively more complex, central monitoring of the devices will be necessary. Oceanographic buoys are presently monitored by a central registry JCOMMOPS (https://www.jcommops.org/board) and can alert research and government bodies when instruments cross boundaries. Animals making similar movements, and in certain instances collecting similar oceanographic data, may soon require this type of international organizational framework to avoid having instrumented animals confused as "spies" that are carrying out illicit surveillance (http://www.imr.no/en/hi/news/2019/may/beluga-whale-with-harness). International cooperation bringing tracking communities together will empower researchers with standards and expectations of data management, sharing, protection.

Conclusion

Maps and visualizations of animal movement are probably the most compelling deliverables from scientific research on animal movement (Demšar et al. 2015) and sharing fascinating animal movement information should be encouraged to facilitate understanding and engagement with research. We strongly support safe promulgation of animal telemetry data but with consideration and recognition of potentials risk to the studied species and the environment they inhabit. The presented framework will encourage researchers to share their research while protecting their study systems (Bickford et al. 2012; Cooke et al. 2017a). Specifically, data-protection principles can be applied regardless of the technology used and the animal observed. These principles are presented because we suggest that the larger scope of the problem is still emerging and not completely understood. At the time of writing, relatively few animal tracking projects are predicted to be deemed high risk and require data security. Even for rare species, or those at high risk, the animals may be inaccessible to potential poachers or the species may be highly mobile and therefore the data does not provide relevant information with which to find them (e.g. whales; Wade et al. 2006). However, the risk of animal tracking data getting into the wrong hands remains highest *in situ*. Direct interception of tracking signals is the point at which animals are most likely to be harassed or harvested. Risk assessment prior to implementing a study can help reduce or eliminate this risk and provide avenues for data to be shared in a safe and timely fashion.

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References

Allen AM, Singh NJ. 2016. Linking movement ecology with wildlife management and conservation. Frontiers in Ecology and Evolution 3: 155.

Bennett JR, Maloney R, Possingham HP. 2015. Biodiversity gains from efficient use of private sponsorship for flagship species conservation. Proceedings of the Royal Society of London B: Biological Sciences 282: 20142693.

Bickford D, Posa MRC, Qie L, Cmpos-Arceiz A, Kudavidange EP. 2012. Science communication for biodiversity conservation. Biological Conservation 151: 74-76.

Brodie S, Lédée EJ, Heupel MR, Babcock RC, Campbell HA, Gledhill DC, Hoenner X, Huveneers C, Jaine FR, Simpfendorfer CA, Taylor MD, Udyawer V, Harcourt RG. 2018. Continental-scale animal tracking reveals functional movement classes across marine taxa. Scientific Reports 8: 3717.

Brooks JL, Chapman JM, Barkley AN, Kessel ST, Hussey NE, Hinch SG, Patterson DA, Hedges KJ, Cooke SJ, Fisk AT, Gruber SH, Nguyen VM. 2018. Biotelemetry informing management: case studies exploring successful integration of biotelemetry data into fisheries and habitat management. Canadian Journal of Fisheries and Aquatic Sciences: 1-15.

Goulet, P., Guinet, C., Swift, R., Madsen, P. T., & Johnson, M. (2019). A miniature biomimetic sonar and movement tag to study the biotic environment and predator-prey interactions in aquatic animals. Deep Sea Research Part I: Oceanographic Research Papers, 148, 1-11.

Chapman AD, Grafton O. 2008. Guide to best practices for generalising sensitive psecies-occurrence data, version 1.0. Copenhagen: Global Biodiversity Information Facility, 27 pp. ISBN: 87-92020-06-2. Available at: https://www.gbif.org/document/80512

Cooke SJ. 2008. Biotelemetry and biologging in endangered species research and animal conservation: relevance to regional, national, and IUCN Red List threat assessments. Endangered Species Research 4: 165-185.

Cooke SJ, Gallagher AJ, Sopinka NM, Nguyen VM, Skubel RA, Hammerschlag N, Danylchuk AJ. 2017a. Considerations for effective science communication. FACETS 2: 233-248.

Cooke SJ, Nguyen VM, Kessel ST, Hussey NE, Young N, Ford AT. 2017b. Troubling issues at the frontier of animal tracking for conservation and management. Conservation Biology 31: 1205-1207.

Demšar U, Buchin K, Cagnacci F, Safi K, Speckmann B, Van de Weghe N, Weiskopf D, Weibel R. 2015. Analysis and visualisation of movement: an interdisciplinary review. Movement Ecology 3: 5.

Fraser EJ, Macdonald DW, Bryce R, Lambin X. 2014. Controlling invasive species by empowering environmental stakeholders: ecotourism boat operators as potential guardians of wildlife against the invasive American mink. Oryx 48: 605-612.

Frey RM, Hardjono T, Smith C, Erhardt K, Pentland AS. 2017a. Secure sharing of geospatial wildlife data. In Proceedings of the Fourth International ACM Workshop on Managing and Mining Enriched Geo-Spatial Data. ACM.

Frey RM, Miller GA, Ilic A, Fleisch E, Pentland A. 2017b. Wild animals in daily life. In Proceedings of the Thirty Eighth International Conference on Information Systems.

Fuller MR, Fuller TK. 2012. Radio-telemetry equipment and applications for carnivores. Carnivore ecology and conservation: A handbook of techniques Oxford University Press.

Hartter J, Ryan Sj, MacKenzie CA, Parker JN, Strasser CA. 2013. Spatially explicit data: stewardship and ethical challenges in science. PLoS Biology 11: e1001634.

Harcourt, R. et al. 2019. Animal-Borne Telemetry: an integral component of the ocean observing toolkit. Frontiers in Marine Science. 6: 326

Hays GC, Bailey H, Bograd SJ, Bowen WD, Campagna C, Carmichael RH, Casale P, Chiaradia A, Costa DP, Cuevas E, de Bruyn PJN, Dias MP, Duarte CM, Dunn DC, Dutton PH, Esteban N, Friedlaender A, Goetz KT, Godley BJ, Halpin PN, Hamann M, Hammerschlag N, Harcourt R, Harrison A-L, Hazen EL, Heupel MR, Hoyt E, Humphries NE, Kot CY, Lea JSE, Marsh H, Maxwell SM, McMahon CR, Notarbartolo di Sciara G, Palacios DM, Phillips RA, Righton D, Schofield G, Seminoff JA, Simpfendorfer CA, Sims DW, Takahashi A, Tetley MJ, Thums M, Trathan PN, Villegas-Amtmann S, Wells RS, Whiting SD, Wildermann NE, Sequeira AMM. 2019. Translating marine animal tracking data into conservation policy and management. Trends in Ecology and Evolution https://doi.org/10.1016/j.tree.2019.01.009

Hayward MW, Somers MJ, Kerley GIH, Perrin MR, Bester MN, Dalerum F, Do Linh San E, Hoffman LC, Marhsal JP, Mills MGL, Nel JAJ, Owen-Smith N. 2012. Animal ethics and ecotourism. South African Journal of Wildlife Research 42: 3-5.

Hussey, N., et al. 2015. Aquatic animal telemetry: a panoramic window into the underwater world. Science 348: 1255642.

Jacques CN, Van Deelen TR, Hall Jr WH, Martin KJ, Vercauteren KC. 2011. Evaluating how hunters see and react to telemetry collars on white-tailed deer. The Journal of Wildlife Management 75: 221-231.

Kays R, Crofoot MC, Jetz W, Wikelski M. 2015. Terrestrial animal tracking as an eye on life and planet. Science 348: aaa2478.

Keating KA, Brewster WG, Key CH. 1991. Satellite telemetry: performance of animal-tracking systems. The Journal of Wildlife Management 55: 160-171.

Kempner J, Merz JF, Bosk CL. 2011. Forbidden knowledge: Public controversy and the production of nonknowledge. Sociological Forum 26: 475-500.

Kessel ST Hussey NE, Crawford RE, Yurkowski DJ, Webber DM, Dick TA, Fisk AT. 2017. First documented large-scale horizontal movements of individual Arctic cod (*Boreogadus saida*). Canadian Journal of Fisheries and Aquatic Sciences 74: 292-296.

Lennox RJ, et al. 2017. Envisioning the future of aquatic animal tracking: technology, science, and application. BioScience 67: 884-896.

Lennox RJ, Alós J, Arlinghaus R, Horodysky A, Klefoth T, Monk CT, Cooke SJ. 2017. What makes fish vulnerable to capture by hooks? A conceptual framework and a review of key determinants. Fish and Fisheries 18: 986-1010.

Lennox RJ, Engler-Palma C, Kowarski K, Filous A, Whitlock R, Cooke SJ, Auger-Méthé M. In Press. Optimizing marine spatial plans with animal tracking data. Canadian Journal of Fisheries and Aquatic Sciences 00: 00-00.

Li Q, Dublon G, Mayton B, Paradiso JA. 2015. MarshVis: Visualizing real-time and historical ecological data from a wireless sensor network. IEEE VIS Arts Program (VISAP).

Lindenmayer D, Scheele B. 2017. Do not publish. Science 356: 800-801.

McGowan J, et al. 2017. Integrating research using animal-borne telemetry with the needs of conservation management. Journal of Applied Ecology 54: 423-429.

Meeuwig J, Harcourt R, Whoriskey F. 2015. When science places threatened species at risk. Conservation Letters 8: 151-152.

Merton RK. 1973. The Normative Structure of Science. Pages 267-278 in Merton RK, ed. The Sociology of Science. University of Chicago Press.

Michener WK. 2015. Ecological data sharing. Ecological Informatics 29: 33-44.

Muehlenbein MP, Ancrenaz M, Sakong R, Ambu L, Pral S, Fuller G, Raghanti MA. 2012. Ape conservation physiology: fecal glucocorticoid responses in wild *Pongo pygmaeus morio* following human visitation. PLoS One 7: e33357.

Nguyen VM, Brooks J, Young N, Lennox RJ, Haddaway N, Whoriskey FG, Harcourt R, Cooke SJ. 2017. To share or not to share in the emerging era of big data: perspectives from fish telemetry researchers on data sharing. Canadian Journal of Fisheries and Aquatic Sciences 74: 1260-1274.

Pschera, A. 2016. Animal Internet: Nature and the Digital Revolution, New Vessel Press.

Raymond B, et al. 2014. Important marine habitat off East Antarctica revealed by two decades of multi-species predator tracking. Ecography 37: 001-009

Renaut S, Budden AE, Gravel D, Poisot T, Peres-Neto P. 2018. Management, archiving, and sharing for biologists and the role of research institutions in the technology-oriented age. BioScience 68: biy038.

Roche DG, Kruuk LE, Lanfear R, Binning SA. 2015. Public data archiving in ecology and evolution: how well are we doing? PLoS Biol 13: e1002295.

Runge MC, Converse SJ, Lyons JE. 2011. Which uncertainty? Using expert elicitation and expected value of information to design an adaptive program. Biological Conservation 144: 1214-1223.

Sequeira AM, et al. 2018. Convergence of marine megafauna movement patterns in coastal and open oceans. Proceedings of the National Academy of Sciences 115: 201716137.

Soranno PA, Cheruvelil KS, Elliott KC, Montgomery GM. 2015. It's good to share: why environmental scientists' ethics are out of date. BioScience 65: 69-73.

Stuart BL, Rhodin AG, Grismer LL, Hansel T. 2006. Scientific description can imperil species. Science 312: 1137-1137.

Tulloch AI, et al. (2018). A decision tree for assessing the risks and benefits of publishing biodiversity data. Nature Ecology and Evolution 2: 1209-1217.

VanWey LK, Rindfuss RR, Gutmann MP, Entwisle B, Balk DL. 2005. Confidentiality and spatially explicit data: Concerns and challenges. Proceedings of the National Academy of Sciences 102: 15337-15342.

Wall J, Wittemyer G, Klinkenberg B, Douglas-Hamilton I. 2014. Novel opportunities for wildlife conservation and research with real-time monitoring. Ecological Applications 24: 593-601.

Weinberg BD, Milne GR, andonova YG, Hajjat F. 2015. Internet of Things: Convenience vs. privacy and secrecy. Business Horizons, 58(6), 615-624.

Wilmers CC, Nickel B, Bryce CM, Smith JA, Wheat RE, Yovovich V. 2015. The golden age of bio-logging: how animal-borne sensors are advancing the frontiers of ecology. Ecology 96: 1741-1753.

Young N, Corriveau M, Nguyen VM, Cooke SJ, Hinch SG. 2018. Embracing disruptive new science? Biotelemetry meets co-management in Canada’s Fraser River. Fisheries 43: 51-60.

Tables

Table 1. Examples of how animal tracking data could be misused, exposing tagged animals (and populations containing tagged individuals) to disturbance and/or exploitation. Examples are hypothetical but are representative of possible scenarios in which security could be breached. For documented cases of animal tracking data misuse, see Meeuwig et al. 2015; Cooke et al. 2017b; Frey et al. 2017a.

Data source	Example of misuse	Possible preventative measures
Transmissions from animal tag actively accessed by public to locate animal	Photographer acquires tracking hardware to locate and follow tagged animals and disturbs/harms them while trying to obtain pictures	• Manufacturer encrypts transmitted data • Manufacturers of tags could be required to pass an independent security review and their tag make / model be openly listed as assessed & assured to follow best practices •
Public acquires positional data from published maps or databases of animal distributions; Journal	Occurrences used by poacher to target the animal	• Journal has policies in place recognising the need to restrict access to sensitive information about animal distributions • Decrease resolution of images and maps

articles or public reports showing maps of rare species		
Access to information request filed by citizen for data from publicly funded study	Poachers access data to illegally harvest animals	• Government regulations limit the accessibility of animal movement data to the public or punish misuse of the information • Database has embargoes to restrict availability of certain sensitive data
Public purchases tags for vigilantism	Pastoralists trap and fit radio collars to Judas animals to find and eradicate what they perceive to be colonies of nuisance species	• This would violate the requirement of a scientific collection permit instituted by most governments; requirement of relevant ACC documents for equipment purchase
Government uses tag data to target 'problematic' individuals	Tag data provided by researchers is used to track 'problematic' animals to define movement corridors or target individuals for culling	• Memorandum of understanding with researcher • Legislated protection through animal ethics authority

Biomimetic sonar tags scanning prey fields in front of predatory marine animals	Tags deployed to sample marine biological data could be intercepted for finding fisheries resources or misinterpreted as surveillance/spying equipment	• Data encryption onboard tags • International agreements regarding jurisdiction and sampling opportunities for scientific research

Table 2. Telemetry tag technologies used to generate animal movement data on air, land and in water. Different tags have unique benefits and drawbacks that researchers must consider when designing a study. One key consideration is the potential for direct misuse by data poachers (i.e. signal interception). All technologies have equal vulnerability to indirect misuse (i.e. viewing of data archived in open databases or visualised on published maps).

Telemetry Technology	Brief Description	Vulnerability to Direct Misuse
Passive integrated transponders (PIT tags)	Small radio frequency identification (RFID) tags with a unique ID code that can be deciphered by an electronic reader generally only from very short distances (<1m). For example, in aquatic environments, battery-powered cables can be laid across a riverbed to monitor the passage of tagged fish	Low; Inexpensive technology (~cost of a receiver) and limited range of receivers to detect tags.
Radio transmitters	Implantable or attachable devices that send signals across various radio frequencies,	High; Receivers require modest investment ($500-$1000) and location methods are simple;

	typically detected from 100's or 1000's of m distance.	enthusiasts may locate radio tagged animals by intercepting signals that are not encrypted.
Acoustic transmitters	Implantable or attachable infrasonic tags for aquatic research whose unique sequence of transmissions is decoded by a hydrophone receiver	High; Receivers are inexpensive (~$2000 each) and easy to use, requiring little pre-existing knowledge; no data encryption
Satellite beacons	Attachable devices that record location Doppler or GPS and transmit results through satellite, cell phone, or ad hoc networks.	Low; Tags are high cost and transmissions can be difficult to intercept. Digital databases where transmissions are stored are usually password protected, requiring approval to gain access. Goninometers to locate satellite tags are expensive and would be difficult to use without knowledge of where the tag popped off, but could be used to find animals with tags (e.g polar bears).

Geolocation loggers	Implantable or attachable devices measuring environmental variables (e.g. ambient light, depth, temperature) to estimate the position of the tag	Low; Requires interception of the physical tag itself to offload data, at which point the animal would have already been captured or have moved away from the location (i.e. for tags that pop-off after a predetermined period of time). Location quality is poor and methods to estimate it from sensor data are complicated.
Biomimetic sonar tags	Attachable devices used to scan prey fields available to aquatic animals	High; sonar used by these tags could be misinterpreted as surveillance/spying equipment if detected by certain stakeholders.

Table 3. A summary of biodiversity databases that contain animal tracking information and their policies regarding sensitive data. We provide a description of the database and its services (i.e. scope), a summary of their stated policy to researchers with sensitive data, information about who decides whether to protect data, and links that can be followed for more information. Note that all links were current as of July 2019.

Data sharing service	Description	Policy for sensitive data	How decision is made	Relevant links
OTN	An international network for archiving detection data from animals tracked in aquatic environments	Optional per-animal embargo based on a two-year period following the end of electronic tag life. Embargoes may be waived at any time by the original data collectors. Rights to data citation and collaboration are retained by	Extensions and exceptions to existing embargoes are reviewed and approved by a scientific advisory committee composed of subject matter experts and data managers.	https://members.oceantrack.org/data/policies/otn-data-policy-2018.pdf

		researchers producing and inputting data.		
IMOS	An Australian national ocean observing system that includes physical and biological observations. Includes two animal telemetry streams, satellite tagging and acoustic tracking. The latter is a	By default all IMOS are openly available under a Creative Commons licence and for satellite tagging they are released in real time. Acoustic data released upon entry of receiver download metadata into the national database. Researchers may request animal-specific embargoes for sensitive acoustic data or full project-wide protection in extraordinary circumstances. Embargoes are granted for three years, with	For the acoustic stream a data committee composed of subject matter experts and data managers reviews applications from researchers to either embargo or protect their detection data. Embargoes are primarily granted to students to allow sufficient time to publish their results before making data publicly available. Applications for protected status require formal justification (e.g. endangered species attracting	http://imos.org.au/fileadmin/user_upload/shared/IMOS%20General/Framework_Policy/2016_May_update/4.2_IMOS_Data_Policy_May16_Final_14062016.pdf

	network that archives detection data from animals tracked in aquatic environments around Australia	possibility of extension upon application.	controversial public interest), with protecting commercial interests and/or publishing priority considered insufficient rationales.	
FACT	A regional network for archiving animal detection data in the Gulf of Mexico, Florida, Georgia, the Carolinas, and The Bahamas	Collaborators may request that data be restricted access from other users with embargos preferably expiring after four years. Data may ultimately be released in part or after modification rather than in their entirety at the discretion of the PI.	Collaborators are entitled to request an embargo from the database.	http://secoora.org/wp-content/uploads/2018/07/FACT_user_agreement_and_data_policy_2018.pdf

GBIF	An open database for researchers and citizen scientists to share information about animal sightings	Information holders must determine the level of sensitivity of their study species and choose to restrict data or generalize the spatial accuracy of data uploaded to the database. Dates for reviewing the sensitivity of the data must be provided at the discretion of the uploader.	The information holder makes the request.	https://www.gbif.org/document/80512
IUCN	An international institution focused on status evaluation and range mapping of species at risk	Endangered or critically endangered species, those that are threatened by trade or have economic value, or whose locations are not well known can have data withheld, with no limitations.	IUCN SSC Red List Authority must make the case for protecting sensitive location data	Annex 7: https://www.iucnredlist.org/resources/rules-of-procedure
MOTUS	A network for sharing radio	Data for species at risk shared as normal, with option for delayed	PI must contact Bird Studies Canada prior to uploading data	https://motus.org/wp-content/uploads/2016/0

	telemetry data, mostly collected from birds, within the research community.	sharing (embargo) in exceptional circumstances that will be considered case by case.	with rationale for restricting the data and proposed embargo period	1/MotusCollaborationPolicy.January2016.pdf
Movebank	An international network for archiving animal tracking data	Data on Movebank cannot be restricted, but researchers can upload it without publishing it to make it available to collaborators. Data can easily be embargoed until publication but longer embargoes are considered case by case	Embargoes are discussed directly with Movebank by contacting support	https://www.movebank.org/node/2220#embargoes
Dryad	An international online data repository for all scientific data	One year embargoes can be requested in special circumstances and longer ones may be granted if the journal editor agrees. Data will	Journal editors must grant permission to embargo data submitted to Dryad	http://datadryad.org/pages/faq

		still be uploaded and a data file will be visible but the details will not be available and the file cannot be downloaded until the embargo expires.		
eBird	An international online database for bird observations	Data for sensitive species can be hidden from the public or appear at poor resolution (e.g. grid cell resolution within 400 km^2) or regionally resolution.	Sensitive species are recommended by partners or published sources and are generally also listed as species at risk by IUCN.	https://help.ebird.org/customer/portal/articles/2885265

Boxes

Box 1. Types of animal location and movement data collected by tracking studies in relation to potential threats (e.g., poaching, harassing) of telemetered animals, and security measures that should be considered depending on whether the species is valued, vulnerable, visible, and/or fragile.

Real-time data: Data on animal location can be immediately available to investigators by manual tracking or via automatic uplink from tags or receivers to databases. Direct interception of tag transmissions by outside parties or sharing real-time data on social media or websites could severely imperil tagged animals that are valuable and vulnerable.
Near real-time data: Data offloaded from receivers that log proximate tags (e.g., PIT tags, acoustic tags) and remotely-downloaded GPS units provide insight into recent (but not current) tagged animal location/activity within a detection radius (usually < 100 m). Interception of receivers and data offloading with compatible software by outside parties can provide last-known locations of tagged animals in an area that could be misused.
Archived data: Data archived in open databases or published as maps in scientific papers or reports can provide general characteristics on individual or population locations and movement patterns. There are varying degrees of security issues on archived data: databases or publications can be publicly available/open access or can be protected (e.g., by a password), or data

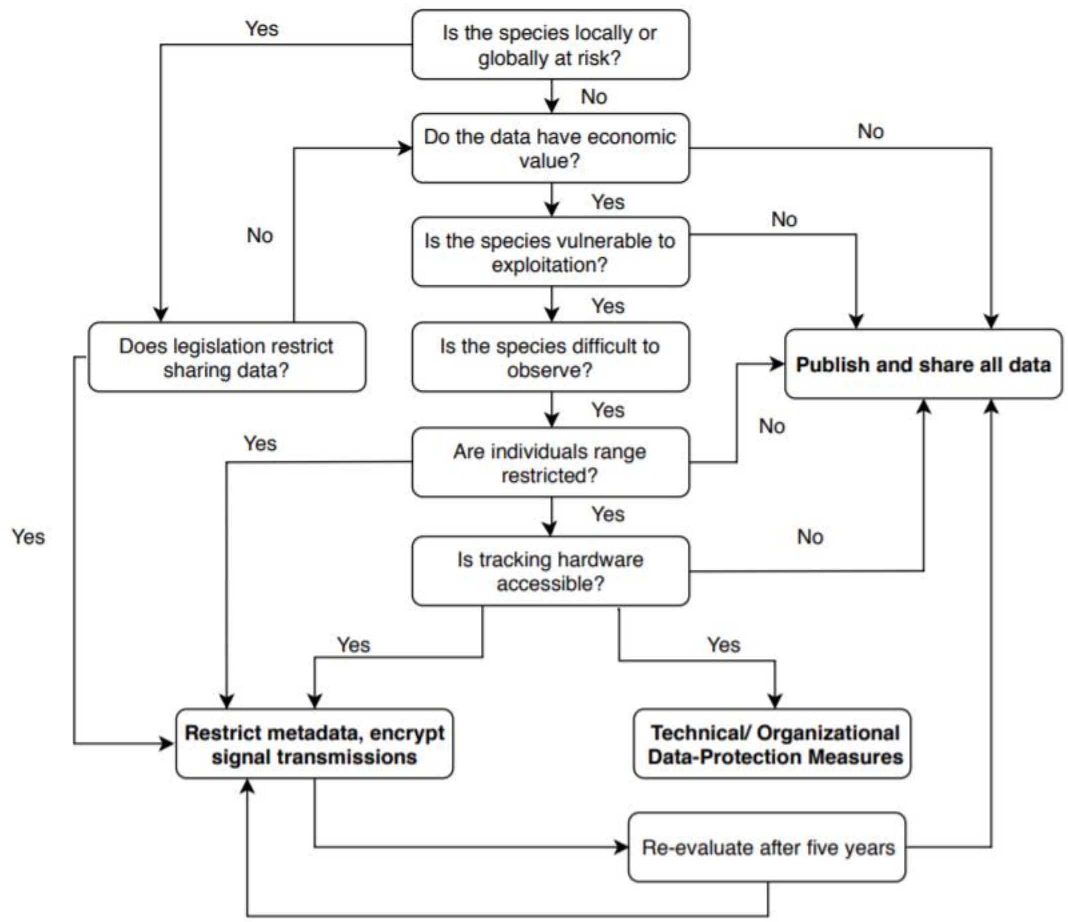
release can be embargoed for a specified period (governed by an approved data management plan), depending on the associated magnitude of risk to the study animal or to the study itself.

Box 2. Questions proposed for assessing study design and data management by researchers undertaking a study on animals with electronic tags. Presented as a flow chart in Figure 1.

1. Is my focal species listed as threatened or special concern by local or global agencies? Note a single species can be threatened at one locale but abundant at another
2. Is my species of high monetary value? Specify whether commercial or through illegal sale.
3. Is my study site easily accessible, ie vulnerable to interception of real-time tracking data by third parties?
4. Is my study site a high-risk site for animal disturbance due to poaching or ecotourism activity?
5. Is the technology widely used and therefore access to receivers to detect tags is easy?
6. Have all relevant stakeholders with vested interests in the study species been identified?
7. What is the role of stakeholders with regard to the tagged species; can these be evaluated during and after implementation?
8. Which stakeholders should be contacted regarding the local cultural and economic importance of the animals
9. What details will be provided to selected stakeholders (e.g. metadata, tag ID, radio tag frequencies)?
10. How will access to the tracking data impact the vulnerability of tagged or untagged individuals to anthropogenic disturbance? Assess the risk dependent on species, location, type of technology, questions addressed in the study (i.e. identifying aggregation sites – are individuals gregarious or solitary either seasonally or year long?: What are the consequences of poaching are lower if species is solitary rather than gregarious?)

11. Will sharing the data increase the vulnerability of the study species to disturbance?
12. Would a temporary embargo or spatial jittering of the movement patterns solve potential issues with data sharing?
13. Is it justifiable that data should never be released publicly, including through social media, in maps printed in journal articles, or in publicly-accessible databases?

Figures



Is the species locally or globally at risk?
Yes
No
Do the data have economic value?
No
Yes
Is the species vulnerable to exploitation?
No
No
Yes
Does legislation restrict sharing data?
Is the species difficult to observe?
Publish and share all data
Yes
Yes
No
Are individuals range restricted?
Yes
Yes
No
Is tracking hardware accessible?
Yes
Yes
Restrict metadata, encrypt signal transmissions
Technical/ Organizational Data-Protection Measures
Re-evaluate after five years

Figure 1. Recognizing and mitigating potential data security challenges is difficult; we present this flow chart based on questions in Box 2 to identify key questions researchers pose before implementing a tracking project. For data that might be vulnerable to direct interception by poachers using tracking technology, metadata should be protected and signal transmissions encrypted to limit the ability for poachers to identify individuals. For species vulnerable to poaching by indirect interception of data in publications, databases, or maps, data can be embargoed with an option to renew the embargo. However, we believe there are great benefits to sharing data and that whenever possible data should be shared and communicated to stakeholders through establishing clear data agreements. Researchers with effective data management plans and journals/databases with clear rules for data embargos will facilitate effective data sharing and scientific communication.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