Rethinking terrestrial wildlife telemetry through instrumentation without capture and handling

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ABSTRACT

Telemetry using animal-borne biologgers is central to wildlife research. Capturing and instrumenting wild animals, however, remains the most invasive, logistically challenging, and costly component of telemetry studies. This has contributed to current practice, which favors long tracking durations on few individuals, prioritizing longevity over temporal detail. While this model has yielded important insights, it also imposes ethical and scientific constraints. I argue that less invasive deployment methods could enable a complementary, lighter-touch telemetry framework. Autonomous marking approaches — first developed in the mid-1900s but now largely ignored — offer such a pathway by eliminating physical capture, restraint, and chemical immobilization. After revisiting early work on autonomous instrumentation,I present two proof-of-concept demonstrations of autonomous GPS-collaring, one in an ungulate and one in a carnivore. I discuss how such approaches could support shorter deployments, improved population coverage, and finer temporal resolution. Crucially, by reducing or eliminating capture-related disturbance, autonomous instrumentation could lessen cumulative welfare impacts and observer effects, thereby strengthening the ethical foundation and scientific validity of wildlife telemetry.

Keywords: 3Rs, animal welfare refinement, biologging deployment methods, *Cervus elaphus*, high-throughput monitoring, individual heterogeneity, self-marking systems, *Vulpes vulpes*

1 MAIN TEXT

1.1 Physical capture and handling are constraining current telemetry practice

Animal-borne telemetry and biologging have transformed wildlife biology and ecology, providing unparalleled insights into the behavior, physiology, and life histories of wild animals. Despite substantial technological advances (Williams et al., 2020; Allan et al., 2018; Wilmers et al., 2015) and the widespread use of wildlife telemetry (Kays et al., 2015, 2022; Nathan et al., 2022), the way we deploy trackers on terrestrial mammals has changed remarkably little over the six decades since its inception (Williams et al., 2020). Today's dominant telemetry model is to instrument a small subset of individuals, each for as long as possible, ideally spanning multiple life-history stages (Fig. 1a; Hebblewhite and Haydon 2010; Brown et al. 2012; Hofman et al. 2019; Manville et al. 2024). This telemetry model was partly shaped by necessity: capturing animals to attach devices is invasive, logistically difficult, and expensive (Murray and Fuller, 2000; Wilson and McMahon, 2006; Hebblewhite and Haydon, 2010; Manville et al., 2024). In addition, long-duration deployments are the obvious choice for studying rare or slow processes such as dispersal, primiparity, migration, learning, and, generally, the ontogeny of life-history processes, where extended temporal coverage is essential. Consequently, researchers aim to maximize the information obtained from each captured individual, often favoring long-term monitoring at the expense of temporal resolution and population coverage (Brown et al., 2012; Hebblewhite and Haydon, 2010). Here, I argue that an alternative, albeit complementary, telemetry model is desirable and possible: short-term high-throughput monitoring of many individuals, enabled by autonomous, low-impact biologger and tracker deployment systems that do not require physical capture, immobilization, and handling by humans.

1.1.1 Animal welfare impacts and observer effects

The process of deploying telemetry devices can cause stress, pain, and carry risks for study subjects (Soulsbury et al., 2020; Muñoz-Igualada et al., 2008; Manville et al., 2024) and in some cases for the humans involved (Manville et al., 2024). It has been suggested that capture can resemble a predatory attack, causing extreme stress levels (Wilson and McMahon, 2006). Despite decades of rapid technological advances in biologging, terrestrial wildlife telemetry has seen comparatively little refinement of capture and deployment practices. From a three-Rs perspective (Replacement, Reduction, Refinement; Russell and Burch 1959; Soulsbury et al. 2020), progress has focused primarily on device miniaturization and data yield, while the welfare effects associated with capture and handling have remained persistent concerns (Wilson and McMahon, 2006; Soulsbury et al., 2020; Zemanova, 2020; Manville et al., 2024).

Capture, handling, and long-term device wear can alter the very phenomena researchers aim to document, also referred to as the observer effect (Wilson and McMahon, 2006; Baclawski, 2018; Manville et al., 2024; Stiegler et al., 2024). Behavioral changes, physiological responses, and even fitness effects have been documented (Murray and Fuller, 2000; Bergvall et al., 2021; Becciolini et al., 2019; Mayer et al., 2021). Because telemetry data themselves are often used to evaluate these impacts on animal welfare and scientific inference, quantification is difficult and sometimes circular (Wilson and Wilson, 1989; Murray and Fuller, 2000; Milleret et al., 2021). To assess impacts and their temporal reach, researchers usually resort to documenting signs of acclimation, i.e. asymptotic patterns in certain behavioral or physiological metrics over time following capture (Trondrud et al., 2022). But even when responses appear to diminish over time (Stiegler et al., 2024), it is unclear whether study subjects fully recover and return to pre-capture baseline states or suffer lasting consequences (Bergvall et al., 2021; Becciolini et al., 2019).

1.1.2 Small population coverage and low temporal grain

While individual time series may be long under the prevailing telemetry model, population coverage is usually low, and data are collected infrequently to preserve battery life (Cushman, 2010; Brown et al., 2012). When only a few individuals are tracked — whether due to welfare concerns, logistical constraints, or cost — the resulting sample often fails to capture the spatial, temporal, and behavioral variability present in the population (Lamb et al., 2023). This limits or biases population-level inference and hampers attempts to account for individual differences which are increasingly recognized as critical for understanding ecological processes (Roberts et al., 2018). Analyses of telemetry sampling design show that large numbers of individuals (often 80–150 or more Roberts et al. 2018) are required to approximate population-level patterns and reduce bias, far exceeding sample sizes in most studies (Roberts et al., 2018; Lamb et al., 2023). Invasive methods may also unintentionally select for individuals that are easier to capture or less sensitive to disturbance (Lamb et al., 2023), further biasing inference.

Long but infrequent sampling fails to capture brief but ecologically critical events, such as intra- and interspecific interactions, responses to disturbances or mitigation measures, and other transient behaviors and phenomena. These events require dense sampling, not sparse data stretched over long intervals (Cushman, 2010; Brown et al., 2012; Bischof et al., 2019; Forrest et al., 2022). A mismatch between ecological process rates and telemetry sampling frequency limits our ability to study transient behaviors (Nathan et al., 2022). Although power efficiency and battery capacity have improved substantially, and technical solutions exist (Brown et al., 2012; Bischof et al., 2019; Tallian et al., 2023; Nathan et al., 2022), most telemetry studies still follow the traditional low-frequency and long-duration model.

1.2 A lighter-touch telemetry model enabled by low-impact instrumentation

The need to physically capture animals for attaching devices has constrained telemetry applications since the 1960s. Low-impact instrumentation methods that bypass physical capture and immobilization would offer a pathway toward a different model: shorter deployments across a larger sample of the population, allowing high-throughput data collection and broader, yet detailed, ecological inference. Crucially, removing the need for physical capture, immobilization, and handling by humans could reduce the individual and cumulative animal welfare impacts (Fig. 1b). This is not a case of wishful thinking; the methods and technology to accomplish this are already within our reach.

1.2.1 Autonomous marking in wildlife research

Documented efforts to develop marking systems that bypass physical capture date back to the 1950s. Observations of accidental marking of game birds and other animals along a trap-line in the Soviet Union led Romanov (1956) to propose the first

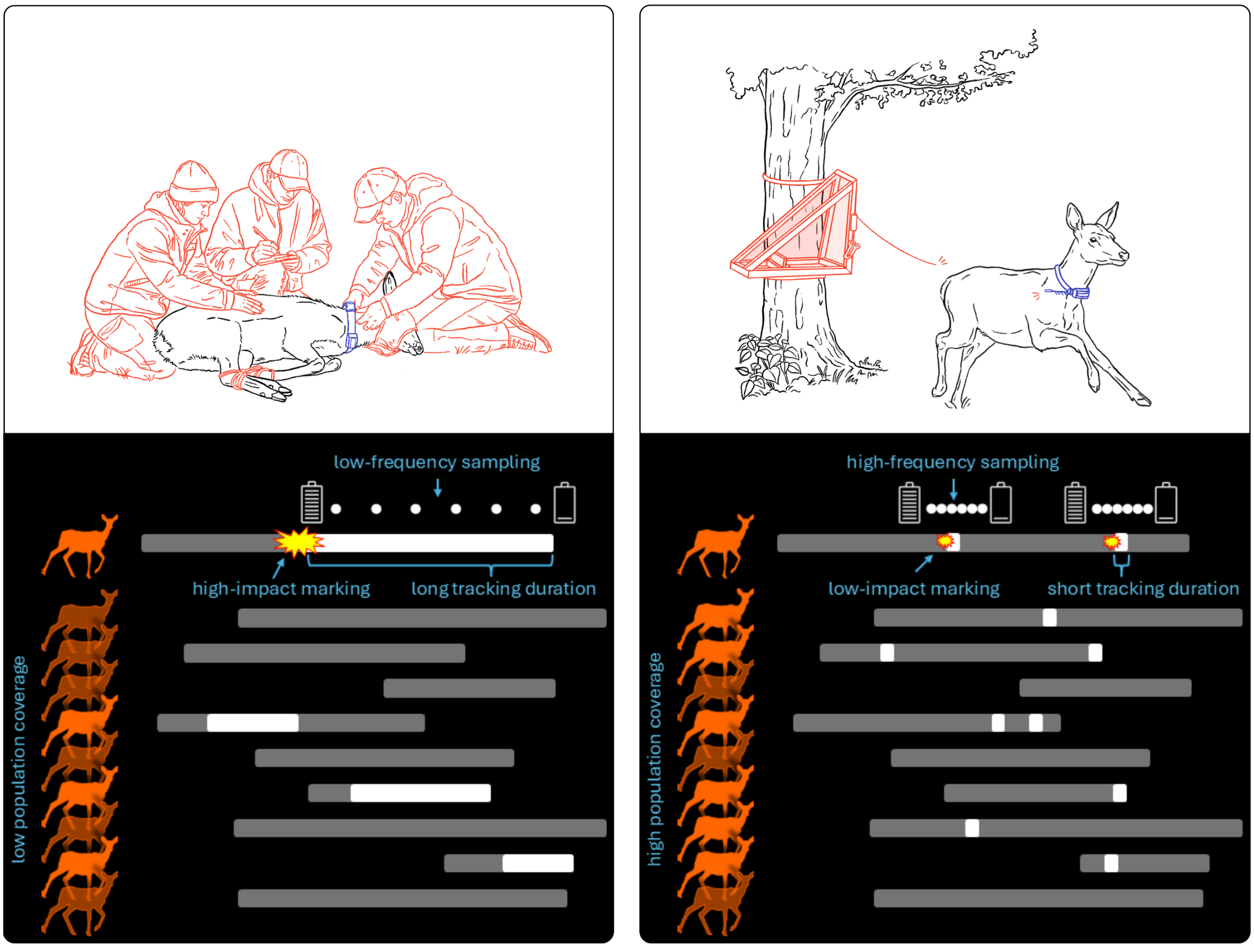

Figure 1. Visualization of two paradigms of telemetry study design: longevity (left) vs high-throughput (right). Under the longevity paradigm, a small proportion of individuals (lives from birth to death shown as horizontal bars) are instrumented but each is tracked for an extended period (white portion of each bar), ideally until death. Data collected by each device are spread over the duration of the tracking period and are collected with low frequency (low temporal grain, indicated by infrequent points). Impacts (lightning bolt) of physical capture, immobilization, and handling (top left) are initially high. Under the high-throughput paradigm, more animals are instrumented, and potentially repeatedly, but each animal is only tracked for a short time. Released from battery limitations, data can be collected at a higher frequency. Instrumentation is less invasive (top right) as it does not require physical capture, immobilization, and handling. The high-throughput paradigm results in greater coverage of the population and environmental contexts, as well as finer-grain data that is able to capture ephemeral yet important ecological events and processes. Line drawings by O. S. Bru.

self-marking application. Romanov's and most subsequent designs consisted of some type of snare with an integrated neckband, a locking mechanism, and a break-away to allow the band to separate from the anchored end of the snare (Verme, 1962; Keith, 1965; Taylor and Magnussen, 1965; Ahlén, 1965; Siglin, 1966). These self-collaring snares were typically set along animal trails in what are sometimes referred to as walk-through or trail sets. Tags or flashers were integrated into the neck band to allow individual or site-specific identification during subsequent sightings and dead recoveries. In at least one case, bells were included to allow detection of autonomously tagged ungulates (Mule deer, *Odocoileus hemionus*, Siglin 1966). The 1960s and 70s saw several applications of self-collaring aimed at ungulates in New Zealand (Taylor, 1969; Clarke and Henderson, 1978), North America (Verme, 1962; Siglin, 1966; Davidson, 1979), and Europe (Ahlén, 1965), sometimes involving hundreds of animals. I provide a summary of scientific articles and reports describing autonomous marking applications (including less common alternatives to the self-collaring snare design) in the Supplementary Information (Tables S1 and S2).

Investigators using autonomous methods to deploy visual identification tags on free-ranging animals relied on sightings, physical recaptures, or hunter-killed animals to recover tags and access the associated information about individual movement distances or survival. But the author of the very first description and test of a self-marking snare already pointed out the potential for integrating a remote tracking device (Romanov, 1956). It nevertheless took nearly nearly 50 years before the first study developed and tested a self-collaring snare with an integrated VHF transmitter (Kirchoff and White, 2002). Advances in tracking, biologging, automatization, and surveillance technology have prompted further innovation in the deployment of remote instrumentation with tracking devices (Crouchley et al., 2011; Bishop et al., 2019) – including the clever use of biomimicry (Wilson et al., 2025). Yet, despite its apparent potential, the autonomous deployment of biologging devices has yet to enter mainstream animal-borne biologging.

1.2.2 Proof-of-concept demonstrations of autonomous instrumentation

Autonomous instrumentation offers a pathway toward a fundamentally different model of wildlife telemetry, in which capture and deployment are decoupled from direct human–animal interaction. Because this approach may be unfamiliar to many readers, and to complement the drawings in Figures 1 and 2, I include two short videos from my own research documenting autonomous GPS collar deployment in an ungulate (red deer *Cervus elaphus*, Supplementary Video S1) and a carnivore (red fox *Vulpes vulpes*, Supplementary Video S2). These cases are not intended as an exhaustive validation but as concrete examples demonstrating feasibility across taxa that differ markedly in ecology, morphology, and behavior. Detailed technical descriptions, experimental design considerations, deployment procedures, and quantitative performance results will be reported in a subsequent publication.

Building on existing designs for autonomous marking (Taylor, 1969; Kirchoff and White, 2002), I developed a system that consists of a self-collaring snare integrated with a GPS unit (or other tracking and biologging devices) and two customizable deployment mechanisms (Fig. 2; Bischof 2025). The collar includes a break-away mechanism that separates from the anchor under a predetermined force, as well as a locking tube that slides over bendable barbs for adjustable sizing, following (Kirchoff and White, 2002). The design also ensures that the collar can be safely dropped by the animal, either through wear-and-tear or mechanical breakaway systems in case of entanglement. The self-collaring snare can be deployed as part of a walk-through set (trail set) as done with similar systems described earlier (e.g., Verme 1962; Ahlén 1965). To enhance species-specificity and safety, I considered two baited deployment mechanisms. The first is a custom-built chamber that I designed primarily for collaring ungulates (Fig. 2a, Supplementary Video S1). The chamber uses a compression-release mechanism to deploy the snare loop over the animal's neck when the bait is accessed. A drop-weight (or, alternatively, a spring) tightens the snare, and a catch prevents reversal, allowing the collar to separate from the distal end of the snare. The second deployment mechanism involves an existing, commercially available spring-loaded snare applicator (Collarum®) that exploits the bite-and-pull reflex of canids and has previously been used to live capture red foxes in a research context (Muñoz-Igualada et al., 2008). When triggered, it throws the snare loop over the animal's head. As the animal flees after being startled by the applicator, the collar locks around the neck and eventually separates from the anchor cable (Fig. 2b, Supplementary Video S2).

1.2.3 Implications for wildlife telemetry and ecological inference

Historically, the difficulty and invasiveness of capture have shaped telemetry practices. Autonomous instrumentation offers a way to break from the "long-term, infrequent" paradigm. By reducing the invasiveness and cost of each deployment, we can afford to tag more individuals and for shorter durations, potentially repeatedly (Fig.

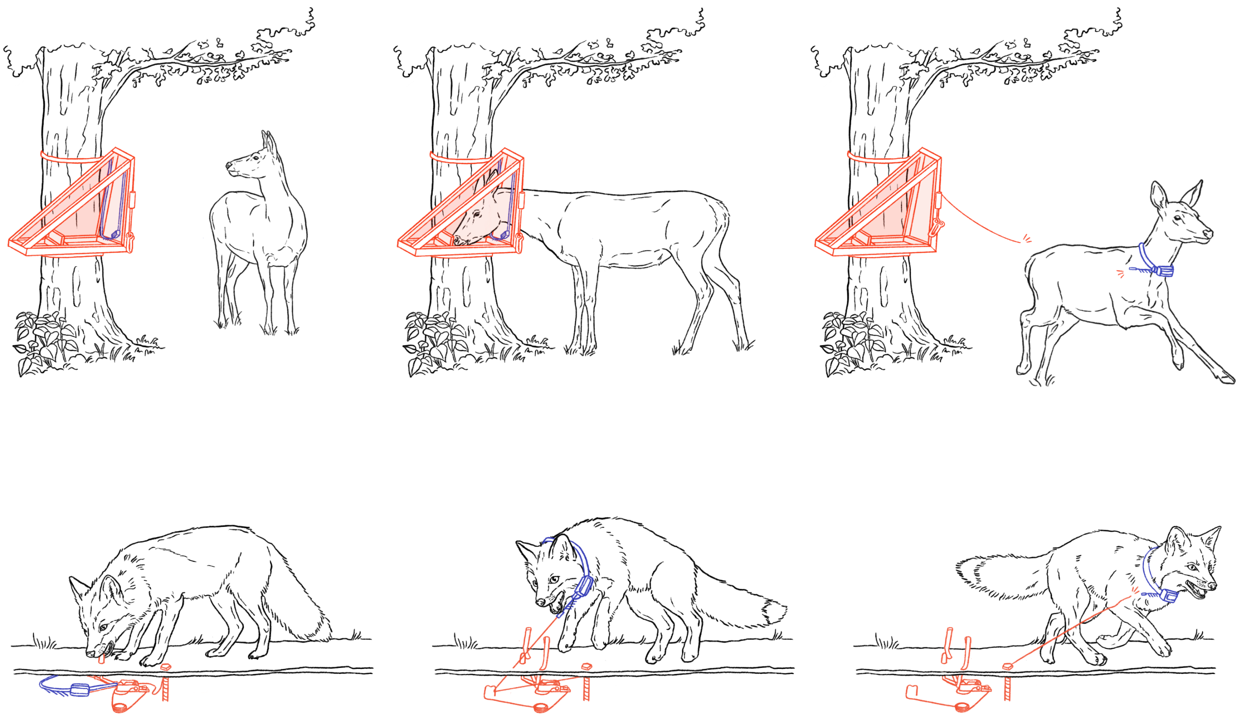

Figure 2. Illustration showing possible approaches for autonomous instrumentation of an ungulate (red deer *Cervus elaphus*, top) and a carnivore (red fox, *Vulpes vulpes*, bottom) using similar snares with integrated tracking collars but different deployment systems. In both systems, snare release is triggered through interaction with bait. The system targeting ungulates is a cubby set with gravity-powered snare drop and constriction, whereas the system targeting foxes is buried as part of a flat set and involves spring-loaded throwing and constriction mechanisms. Proof-of-concept of each system is provided with one video of a successful deployment under controlled conditions (Supplementary Videos S1 and S2). Line drawings by O. S. Bru.

1). This opens the door to a telemetry model that is lighter-touch, more scalable, and better suited to capturing ecological variability, obtaining a more detailed mechanistic understanding of natural processes, and, at the same time, drawing broader, population level inferences.

Less-invasive deployment of animal-borne telemetry devices, and the alternative telemetry model it enables, advances the ethical aims of the 3R principle, which collectively seek to minimize the overall burden imposed on research animals (Russell and Burch, 1959; Soulsbury et al., 2020; Zemanova, 2020). Replacement of wild animals with lower-sentient models in wildlife telemetry is not usually feasible when the scientific aim is insight into behavior of a focal species in situ. Reducing the number of animals impacted (Reduction) may also conflict with scientific objectives and statistical requirements, especially given the amount of variation in nature (Soulsbury et al., 2020). Refinement, on the other hand can be directly achieved through less-invasive tagging practices that eliminate physical restraint, chemical immobilization, and direct handling, thereby reducing stress and injury risk. In addition, the approach has the potential to reduce the cumulative burden on individual animals by shortening deployment durations and, through lower energy demands, enabling smaller and lighter devices (see also Soulsbury et al. 2020). This minimizes behavioral alterations and physiological strain associated with long-term collar wear (Manville et al., 2024). Depending on deployment form, less-invasive instrumentation can also reduce unintentional selectivity (Soulsbury et al. 2020; Lamb et al. 2023; but see Davidson 1979) and diminish observer effects associated with invasive tagging (Baclawski, 2018; Manville et al., 2024; Wilson and Wilson, 1989; Zemanova, 2020). Crucially, autonomous deployment allows experimental designs (within- and between-subject) that disentangle capture effects from the effects of wearing devices, helping to overcome some of the circularity inherent in traditional assessments of telemetry impacts.

Automated deployment allows more individuals and, potentially, a more representative sample to be tagged with reduced impact and less effort, improving population coverage, statistical power and ecological inference. Monitoring a larger proportion of a population, even if each individual is only monitored for a short period, can also enhance our understanding of individual heterogeneity in behavior, physiology, and other life history aspects.

Shorter individual monitoring durations enable a higher temporal grain in data collection. Freed from the need to conserve battery life over months or years, researchers can sample at finer temporal intervals, thereby better capturing rapid behavioral changes and transient but ecologically important events, such as interactions with both the biotic and abiotic environment. Ecological mechanisms can only be reliably inferred when the temporal scale of observation is aligned with the temporal scale of the processes generating the observed patterns (Levin, 1992). Consequently, long-term monitoring under the prevailing telemetry paradigm remains essential for addressing questions that operate across broad spatio-temporal scales or individual life histories. These include survival in small populations, dispersal, migration, and processes such as behavioral plasticity or learning. At the same time, short-term deployments applied to many individuals, potentially repeatedly (Fig 1b), can also support robust life-history inference and, by enabling high-throughput data collection, provide a more mechanistic understanding of ecological processes that are missed by coarser temporal sampling.

1.2.4 Limitations, risks, and pathways to safer autonomous instrumentation

The absence of humans during deployment is a key strength and, simultaneously, a distinct limitation of autonomous tagging. While it circumvents stress from capture, restraint, and handling, it also removes direct oversight and intervention during deployment. It therefore requires anticipating failure modes and designing systems that default to safety. System design, set location, and configuration can greatly reduce, but not fully eliminate, the risk of tagging non-target species, attaching tags the wrong way, or tagging individuals already equipped with devices. Multilayered safeguards are essential. For example, for self-collaring snare systems, this would include 1) calibrated breakaway components and internal weak points to prevent injury or body snaring, 2) close monitoring for surveillance and documentation (e.g., using video systems or camera traps) to confirm species identity, collar seating, and departure behavior, and 3) high-frequency post-deployment GPS schedules for close post-tagging monitoring. Rapid response to both successful and unsuccessful collaring events, facilitated by live monitoring (e.g., video surveillance) and alarm systems, would mitigate risks, help solve issues as they emerge, and facilitate performance evaluation. I recommend the development and continued improvement of best management practices and guidelines for autonomous instrumentation and tagging approaches.

Autonomous tagging also interferes with the collection of ancillary data typically associated with capture, such as health and reproductive status, morphometrics, physiology, or age markers. Recent advances in imaging, remote sensing, eDNA, and AI-based classification may to some extent compensate for these gaps. For example, camera traps and scales (Bassano et al., 2003) at the deployment site can provide sex, age class, morphometrics, and body condition indices. Hair, urine, and scat at deployment sites can supply material for individual identification and endocrinological assessments. Post-deployment observation, e.g. direct or with the help of drones or camera trap arrays, can similarly inform about individual attributes. Hair, saliva, and shed skin cells on dropped collars could provide genetic material for individual identification. Recovered carcasses can yield definitive age and further individual data, assuming tags or other identifiers (artificial or natural) are still present at the time of death. And not all information traditionally gathered during capture is necessary for every study; principles of parsimony suggest collecting only what is required (Bischof et al., 2009). Looking ahead, progress in lighter and more reliable remote drop offs (Rafiq et al., 2023), AI driven analysis of multiple data streams (acoustic/video) that go beyond species identification, tag presence detection (e.g., radio frequency identification; passive integrated transponder tags, etc.), combined with remote or robotic control of deployment (Bishop et al., 2019) could further increase safety and aid in information gathering and documentation. Most importantly, the convenience of autonomous tagging does not absolve researchers of ethical and scientific responsibilities. Instrumentation must remain justified and proportionate to research needs (Hebblewhite and Haydon, 2010; Arrondo and Pérez-García, 2025).

1.3 Conclusions

With this article, I seek to inspire ecologists and wildlife scientists to build on earlier autonomous tagging efforts by integrating past insights with contemporary technological possibilities. Less invasive deployment of telemetry devices represents a refinement of wildlife telemetry that is overdue. It can support low-impact, continuous population monitoring while reducing reliance on invasive field campaigns and high-stress capture events. The intention is not to replace traditional telemetry but rather to complement it by expanding its repertoire and scope for wildlife research and management. A telemetry framework that prioritizes animal welfare, fine temporal grain, and broader population coverage can help meet the growing demand for evidence-based strategies in a world facing accelerating conservation challenges.

AUTHOR CONTRIBUTIONS

RB conceived the idea, conducted the research, and wrote the article.

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PERMITS

All aspects of animal maintenance, handling, and animal trials conformed to laws and regulations in Norway and the research was approved by the Norwegian Animal Research Authority (FOTS) under the auspices of the Norwegian Food Safety Authority (red deer: FOTS ID 31190; red fox: FOTS ID 7864).

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CONFLICT OF INTEREST STATEMENT

The author declares that a patent application has been filed related to the autonomous marking technology shown in the Supplementary video. The technology is currently part of a publicly funded qualification project (Research Council of Norway, NFR360030) aimed at exploring commercialization opportunities. These interests did not influence the study design, data collection, analysis, or interpretation. The author declares that no other commercial or financial relationships exist that could be construed as a potential conflict of interest.

SUPPLEMENTAL DATA

Supplementary Table S1: Technical information for autonomous tagging and instrumentation systems in studies involving terrestrial mammals.

Supplementary Table S2. Overview of study design, species, and outcomes in studies involving autonomous tagging and instrumentation systems for terrestrial mammals.

Supplementary Video S1. Autonomous collaring of a red deer (*Cervus elaphus*) with a GPS collar. The video illustrates a proof-of-concept deployment under controlled conditions. Available via Zenodo: https://doi.org/10.5281/zenodo.19629519

Supplementary Video S2. Autonomous collaring of a red fox (*Vulpes vulpes*) with a dummy GPS-collar. The video illustrates a proof-of-concept deployment under controlled conditions. Available via Zenodo: https://doi.org/10.5281/zenodo.19629717

DATA AVAILABILITY STATEMENT

No empirical data were used in creation of this article.

REFERENCES

Ahlén, I. (1965). *Studies on the Red Deer, Cervus Elaphus L., in Scandinavia: III, Ecological Investigations* (Stockholm: Svenska jägareförbundet)

Allan, B. M., Nimmo, D. G., Ierodiaconou, D., VanDerWal, J., Koh, L. P., and Ritchie, E. G. (2018). Futurecasting ecological research: the rise of technoecology. *Ecosphere* 9, e02163. doi:10.1002/ecs2.2163

Arrondo, E. and Pérez-García, J. (2025). Call for a critical review of widespread use of animal tracking devices. *European Journal of Wildlife Research* 71. doi:10.1007/s10344-025-01906-7

Baclawski (2018). The Observer Effect. In *2018 IEEE Conference on Cognitive and Computational Aspects of Situation Management (CogSIMA)*. 83–89. doi: 10.1109/COGSIMA.2018.8423983. Journal Abbreviation: 2018 IEEE Conference on Cognitive and Computational Aspects of Situation Management (CogSIMA)

Bassano, B., von Hardenberg, A., Pelletier, F., and Gobbi, G. (2003). A method to weigh free-ranging ungulates without handling. *Wildlife Society Bulletin* 31, 1205–1209. doi:10.2307/3784468

Becciolini, V., Francesco Lanini, and Maria Paola Ponzetta (2019). Impact of capture and chemical immobilization on the spatial behaviour of red deer Cervus elaphus hinds. *Wildlife Biology* 2019, 1–8. doi:10.1111/2981/wlb.00499

Bergvall, U. A., Morellet, N., Kjellander, P., Rauset, G. R., Groeve, J. D., Borowik, T., et al. (2021). Settle Down! Ranging Behaviour Responses of Roe Deer to Different Capture and Release Methods. *Animals : an Open Access Journal from MDPI* 11

Bischof, R. (2025). Wildcollar: An automatic collaring system. Patent application no. 2513825.6, United Kingdom

Bischof, R., Gjevestad, J. G. O., Ordiz, A., Eldegard, K., and Milleret, C. (2019). High frequency GPS bursts and path-level analysis reveal linear feature tracking by red foxes. *Scientific Reports* 9, 8849. doi:10.1038/s41598-019-45150-x

Bischof, R., Zedrosser, A., Brunberg, S., and Swenson, J. E. (2009). A note on opportunism and parsimony in data collection. *Journal of Wildlife Management* 73, 10–21

Bishop, C. J., Alldredge, M. W., Walsh, D. P., Bergman, E. J., Anderson, C. R., Kilpatrick, D., et al. (2019). A noninvasive automated device for remotely collaring and weighing mule deer. *Wildlife Society Bulletin* 43, 717–725. doi:10.1002/wsb.1034

Brown, D. D., LaPoint, S., Kays, R., Heidrich, W., Kümmeth, F., and Wikelski, M. (2012). Accelerometer-informed GPS telemetry: Reducing the trade-off between resolution and longevity. *Wildlife Society Bulletin* 36, 139–146. doi:doi:10.1002/wsb.111

Clarke, C. M. H. and Henderson, R. J. (1978). Snare-marking chamois in New Zealand. *Zeitschrift fuer Säugetierkunde* 434, 232–239

Crouchley, D., Nugent, G., and Edge, K.-A. (2011). Removal of red deer (*Cervus elaphus*) from Anchor and Secretary Islands, Fiordland, New Zealand , 422–425

Cushman, S. A. (2010). Animal movement data: GPS telemetry, autocorrelation and the need for path-level analysis. In *Spatial complexity, informatics and wildlife conservation*, eds. S. A. Cushman and F. Huettman (Tokyo,: Springer). 131–150

Davidson, M. M. (1979). Movement of marked Sika (*Cervus nippon*) and red deer (*Cervus elaphus*) in central North Island, New Zealand. *New Zealand Journal of Forestry Science* 9

Forrest, S., Rodríguez Recio, M., and Seddon, P. (2022). Moving wildlife tracking forward under forested conditions with the SWIFT GPS algorithm. *Animal Biotelemetry* 10. doi:10.1186/s40317-022-00289-9

Hebblewhite, M. and Haydon, D. T. (2010). Distinguishing technology from biology: a critical review of the use of GPS telemetry data in ecology. *Philosophical Transactions of the Royal Society B: Biological Sciences* 365, 2303–2312. doi:10.1098/rstb.2010.0087

Hofman, M. P. G., Hayward, M. W., Heim, M., Marchand, P., Rolandsen, C. M., Mattisson, J., et al. (2019). Right on track? Performance of satellite telemetry in terrestrial wildlife research. *PLOS ONE* 14, e0216223. doi:10.1371/journal.pone.0216223

Kays, R., Crofoot, M. C., Jetz, W., and Wikelski, M. (2015). Terrestrial animal tracking as an eye on life and planet. *Science* 348, aaa2478. doi:10.1126/science.aaa2478

Kays, R., Davidson, S. C., Berger, M., Bohrer, G., Fiedler, W., Flack, A., et al. (2022). The Movebank system for studying global animal movement and demography. *Methods in Ecology and Evolution* 13, 419–431. doi:10.1111/2041-210X.13767

Keith, L. B. (1965). A live snare and a tagging snare for rabbits. *The Journal of Wildlife Management* 29, 877–880. doi:10.2307/3798566

Kirchoff, M. and White, K. (2002). *Development of a passive-capture device technique for radiotagging large animals*. Tech. rep., Alaska Department of Fish and Game, Division of Wildlife Conservation

Lamb, J., Loring, P., and Paton, P. (2023). Distributing transmitters to maximize population-level representativeness in automated radio telemetry studies of animal movement. *Movement Ecology* 11. doi:10.1186/s40462-022-00363-0

Levin, S. A. (1992). The Problem of pattern and scale in ecology: The Robert H. MacArthur Award Lecture. *Ecology* 73, 1943–1967. doi:10.2307/1941447. ISBN: 1939-9170

Manville, A. M., Levitt, B. B., and Lai, H. C. (2024). Health and environmental effects to wildlife from radio telemetry and tracking devices—state of the science and best management practices. *Frontiers in Veterinary Science* 11. doi:10.3389/fvets.2024.1283709

Mayer, M., Haugaard, L., and Sunde, P. (2021). Scared as a hare: effects of capture and experimental disturbance on survival and movement behavior of European hares. *Wildlife Biology* 2021, wlb.00840. doi:10.2981/wlb.00840

Milleret, C., Bischof, R., Dupont, P., Brøseth, H., Odden, J., and Mattisson, J. (2021). GPS collars have an apparent positive effect on the survival of a large carnivore. *Biology Letters* 17

Murray, D. L. and Fuller, M. R. (2000). A Critical Review of the Effects of Marking on the Biology of Vertebrates. In *Research Techniques in Animal Ecology*, eds. M. C. Pearl, L. Boitani, and T. K. Fuller (Columbia University Press), Controversies and Consequences. 2 edn., 15–64

Muñoz-Igualada, J., Shivik, J. A., Domínguez, F. G., Lara, J., and Gonález, L. M. (2008). Evaluation of cage-traps and cable restraint devices to capture red foxes in Spain. *The Journal of Wildlife Management* 72, 830–836. doi:10.2193/2007-198. ISBN: 1937-2817

Nathan, R., Monk, C., Arlinghaus, R., Adam, T., Alós, J., Assaf, M., et al. (2022). Big-data approaches lead to an increased understanding of the ecology of animal movement. *Science* 375, eabg1780. doi:10.1126/science.abg1780

Rafiq, K., Appleby, R. G., Davies, A., and Abrahms, B. (2023). SensorDrop: A system to remotely detach individual sensors from wildlife tracking collars. *Ecology and Evolution* 13, e10220. doi:10.1002/ece3.10220

Roberts, A., Silverman, E., and Gifford, S. (2018). Sample size considerations for satellite telemetry and animal distributions. *The Journal of Wildlife Management*

82, 1536–1544. doi:10.1002/jwmg.21504

Romanov, A. N. (1956). Automatic banding of wild animals and prospects of its application. *Zoological Journal* 35, 190–20. Re-published: Russian Ornithological Journal 2015, Volume 24, Express Edition 1091: 33-38

Russell, W. and Burch, R. (1959). *The principles of humane experimental technique.* (London: Methuen & Co. Ltd.). Journal Abbreviation: The principles of humane experimental technique. Publication Title: The principles of humane experimental technique.

Siglin, R. J. (1966). Marking mule deer with an automatic tagging device. *The Journal of Wildlife Management* 30, 631–633. doi:10.2307/3798762

Soulsbury, C., Gray, H., Smith, L., Braithwaite, V., Cotter, S., Elwood, R., et al. (2020). The welfare and ethics of research involving wild animals: A primer. *Methods in Ecology and Evolution* 11. doi:10.1111/2041-210X.13435

Stiegler, J., Gallagher, C., Hering, R., Mueller, T., Tucker, M., Apollonio, M., et al. (2024). Mammals show faster recovery from capture and tagging in human-disturbed landscapes. *Nature Communications* 15, 1–13. doi:10.1038/s41467-024-52381-8

Tallian, A., Mattisson, J., Stenbacka, F., Neumann, W., Johansson, A., Støen, O. G., et al. (2023). Proximity-sensors on GPS collars reveal fine-scale predator–prey behavior during a predation event: A case study from Scandinavia. *Ecology and Evolution* 13, e10750. doi:10.1002/ece3.10750

Taylor, R. H. (1969). Self-attaching collars for marking red deer in New Zealand. *Deer* 1, 404–407

Taylor, R. H. and Magnussen, W. B. (1965). Preliminary note on capture and marking of wild ungulates in New Zealand. *New Zealand J. Sci.* 8, 205–213

Trondrud, L. M., Ugland, C., Ropstad, E., Loe, L. E., Albon, S., Stien, A., et al. (2022). Stress responses to repeated captures in a wild ungulate. *Scientific Reports* 12, 16289. doi:10.1038/s41598-022-20270-z

Verme, L. J. (1962). An automatic tagging device for deer. *The Journal of Wildlife Management* 26, 387–392. doi:10.2307/3798016

Williams, H. J., Taylor, L. A., Benhamou, S., Bijleveld, A. I., Clay, T. A., de Grissac, S., et al. (2020). Optimizing the use of biologgers for movement ecology research.

Journal of Animal Ecology 89, 186–206. doi:https://doi.org/10.1111/1365-2656.13094

Wilmers, C., Nickel, B., Bryce, C., Smith, J., Wheat, R., and Yovovich, V. (2015). The golden age of bio-logging: How animal-borne sensors are advancing the frontiers of ecology. *Ecology* 96, 1741–1753. doi:10.1890/14-1401.1

Wilson, R. P. and McMahon, C. R. (2006). Measuring devices on wild animals: what constitutes acceptable practice? *Frontiers in Ecology and the Environment* 4, 147–154. doi:10.1890/1540-9295(2006)004[0147:MDOWAW]2.0.CO;2

Wilson, R. P., Redcliffe, J., Holton, M., Hopkins, P., Thomas, V., Rosell, F., et al. (2025). Why catch when you can throw? A framework for tagging animals without capture or restraint. *Royal Society Open Science* 12. doi:10.1098/rsos.250139

Wilson, R. P. and Wilson, M.-P. T. (1989). A Peck Activity Record for Birds Fitted with Devices (Registros de la Actividad de Picoteo en Aves a las Que se le Han Puesto Aparatos de Monitoreo). *Journal of Field Ornithology* 60, 104–108

Zemanova, M. (2020). Towards more compassionate wildlife research through the 3Rs principles: Moving from invasive to non-invasive methods. *Wildlife Biology* 2020. doi:10.2981/wlb.00607

Supplementary Tables

For: *Rethinking terrestrial wildlife telemetry through instrumentation without capture and handling (Note: This manuscript is a preprint and has not been peer reviewed.)*

Table S1. Technical information for autonomous tagging and instrumentation systems in studies involving terrestrial mammals

Paper reference	Identification/tracking type	System description	Mode/mechanics of tagging	Field setup type
Romanov 1956	Numbered tag or medallion with "passport"; also proposes radio and sound emitters	Self-collaring snare: modified snare with snap-lock (carabiner) and breakaway	Collar part of snare constricts around neck, locks on itself and breaks away from anchor line	Walk-through sets along trails/runways
Verme 1962	Colored collars with numbered metal bird bands	Self-collaring snare: collar out of hollow braided polythene rope; sliding ring and snap-lock	Collar part of snare constricts around neck, locks on itself and breaks away from anchor line	Walk-through sets along trails/runways
Taylor & Magnussen 1965	Numbered tags and colored streamers	Self-collaring snare: sliding ring and snap-lock, based on Verme 1962	Collar part of snare constricts around neck, locks on itself and breaks away from anchor line	Walk-through sets along trails/runways
Keith 1965	Stainless clip with ID number engraved	Self-collaring snare: sliding ring and stainless clip	Collar part of snare constricts around neck, locks on itself and breaks away from anchor line/wire	Walk-through sets along trails/runways
Ahlén 1965	Colored reflectors	Self-collaring snare based on Romanov 1956 and Verme 1962; anchor line out of fishing line; modified lock not described	Collar part of snare constricts around neck, locks on itself and breaks away from anchor line/wire	Walk-through sets along trails/runways
Siglin 1966	Numbered tags and sheep bells	Self-collaring snare: collar out of hollow braided polythene rope; sliding ring and snap-lock	Collar part of snare constricts around neck, locks on itself and breaks away from anchor line/wire	Walk-through sets along trails/runways
Beale 1966	Plastic streamers	Rubber collar stretched over wooden frame; collar held in place by steel release pins	Animal reaches head through wooden frame, activates trip pan in water trough which releases hinged pins allowing collar to constrict around neck	Frame with collar mounted over water trough; camera records deployments
Taylor 1969	Collared PVC flashes; serial number engraved on snap-lock	Self-collaring snare: collar out of hollow braided polythene rope; sliding ring and snap-lock	Collar part of snare constricts around neck, locks on itself and breaks away from anchor line	Walk-through sets along trails/runways; configured into lines of 30–60 snares

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Table S1 (continued)

Paper reference	Identification type	System description	Mode/mechanics of tagging	Field setup type
Verme 1973	Numbered identification tag; collar coding	Self-collaring snare with snap-lock; details not reported but may be based on Verme 1962	Collar part of snare constricts around neck, locks on itself and breaks away from anchor line	Walk-through sets along trails/runways
Clarke & Henderson 1978	Brightly colored nylon tags	Self-collaring snare: collar out of hollow braided polythene rope; sliding ring and snap-lock; weakened breakaway cord	Collar part of snare constricts around neck, locks on itself and breaks away from anchor line	Walk-through sets along trails/runways/ledges
Davidson 1979	Identification tag (numbered copper sleeves)	Self-collaring snare based on Verme 1962: collar out of braided nylon or polythene rope; sliding ring and snap-lock; soldered breakaway	Collar part of snare constricts around neck, locks on itself and breaks away from anchor line	Walk-through sets along trails/runways
Mahan et al. 1994	Colored material for visual identification	Plastic cable-tie collars with medical tubing sleeve, positioned over the entrance of a bait chamber	Spring- or solenoid-based constriction of the cable-tie around the neck when triggered by animal reaching the bait	Cubby sets with baited chamber
Kirchoff & White 2002	VHF transmitters	Self-collaring snare with integrated VHF: sliding ring and multiple one-way barbs for flexible and relaxing sizing; experimented with different breakaway mechanisms, locking mechanisms with a single barb, and collars with an expanding section for flexible sizing	Collar part of snare constricts around neck, locks on itself and breaks away from anchor line	Walk-through sets along trails/runways
Crouchley et al. 2011	VHF transmitters	Self-collaring snare based on Taylor 1969; with integrated VHF transmitter	Collar part of snare constricts around neck, locks on itself and breaks away from anchor line	Walk-through sets along trails/runways; combined with gates/fencing to funnel animals

Continued on next page

Table S1 (continued)

Paper reference	Identification type	System description	Mode/mechanics of tagging	Field setup type
Bishop et al. 2019	VHF transmitters	Expandable collar with integrated VHF transmitter stretched over opening of bait compartment in a cage with one-way gates for entry and exit; high degree of automatization, including RFID-based prevention of repeat-tagging	Sensor-triggered actuator allows expanded collar to constrict around neck; animal weighed by scale integrated in the cage floor	Device placed in habitat; site pre-baited; cameras document deployment
Wilson et al. 2025	VHF transmitters	Glue-on VHF tags on natural burs; gate-type deployment device	"Bur-tagging": sensor-triggered projector or contact brush deposits burs with tag onto animal passing through gate	Walk-through or baited sets with gate placed on or off trails; cameras document interactions with device

Table S2. Overview of study design, species, and outcomes in studies involving autonomous tagging and instrumentation systems for terrestrial mammals.

Reference	Year study done	Location	Species targeted	Number of devices deployed	Number & species believed tagged	Number & species recaptured/detected
Romanov 1956	1954–1955 (field observations of unintentional "tagging" with capture/kill snares)	USSR (northern taiga)	Proposed self-tagging with collaring snare for forest game birds and mammals	not reported (proposal only)	not reported (proposal only)	not reported (proposal only)
Verme 1962	∼1960–1962 (pilot study: 1961)	USA (Michigan); pilot study: Northern Michigan	White-tailed deer (*Odocoileus virginianus*)	694 snares; pilot study: 73 snares	≤367 (based on collars unaccounted for, assumed most picked up by target species; likely repeat-tagging); pilot study: 52 white-tailed deer	Not reported; pilot study: 1 recovery; periodic re-sightings/recoveries
Taylor & Magnussen 1965	Start: Not reported; end: early 1965	New Zealand (Nelson Lakes)	Red deer (*Cervus elaphus*)	Not reported	∼35 red deer total (mixed methods; subset self-collaring snares)	≥6 resightings (mixed methods; subset self-collaring snares)
Keith 1965	1963	Canada (Alberta) & USA (Wisconsin)	Snowshoe hare (*Lepus americanus*); Eastern cottontail (*Sylvilagus floridanus*)	Hare: 260 snare nights; Cottontail: 231 snare nights	19 hares (assumed); 11 cottontails (assumed)	2 hares recaptured; 4 cottontails recovered
Ahlén 1965	1960s (5 year duration)	Sweden (Skåne)	Red deer (*Cervus elaphus*)	Not reported	≈52 Red deer	Not reported; some re-sightings
Siglin 1966	1964 (winter & summer)	USA (Colorado; Cache la Poudre drainage)	Mule deer (*Odocoileus hemionus*)	832 (749 on winter range, 83 on summer range)	≈74 mule deer (55 on winter range; 19 on summer range, based on missing collars)	Not reported; re-sightings used for movement inference

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Table S2 (continued)

Paper reference	Year study done	Location	Species targeted	Number of snares deployed	Number & species believed tagged	Number recaptured/detected (species)
Beale 1966	1964 (fall)	USA (Utah; Desert Experimental Range)	Pronghorn (*Antilocapra americana*)	∼25 attempts	18 adult pronghorn antelope does; ≥10 different individuals	Not reported; collar retention assumed to be ≈10 months
Taylor 1969	1963–1969; prototype field testing: 1965-1966	New Zealand (Nelson Lakes, South Island)	Red deer (*Cervus elaphus*)	500 snare collars deployed during field trials	≈275 red deer (presumed based on 340 collars taken; adjusted for repeat tagging of some individuals)	51 dead recoveries; ≥6 collars retained >2 y
Verme 1973	1962–1971	USA (Michigan, Upper Peninsula)	White-tailed deer (*Odocoileus virginianus*)	Not reported; large scale, programmatic winter-yard deployments	>3000 white-tailed deer believed tagged	328 collars recovered total; 211 hunter-killed (movement distances analyzed)
Clarke & Henderson 1978	1973–1977	New Zealand (Canterbury; Southern Alps)	Chamois (*Rupicapra rupicapra*)	380 snares	∼220 chamois assumed marked (268 collars taken)	≥86 individual observed (25% with multiple collars); many re-sightings
Davidson 1979	1964–1974	New Zealand (North Island)	Sika deer (*Cervus nippon*); Red deer (*Cervus elaphus*)	≥1200 snares by 1966 (repeatedly repaired and reset) and most removed by 1967; 365 snares maintained until 1974;	798 collars "missing"; assumed to be taken by deer	Recovered 54 Sika deer and 30 red deer; additional inferred; multiple re-sightings
Mahan et al. 1994	1991–1992 (field) & 1991 (lab)	USA (Pennsylvania)	Red squirrel (*Tamiasciurus hudsonicus*)	Device-based attempts = 26	19 red squirrels collared (13 field; 6 lab)	All red squirrels recaptured, one after ∼6 months, remainder after ≤3 months

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Table S2 (continued)

Paper reference	**Year study done**	**Location**	**Species targeted**	**Number of snares deployed**	**Number & species believed tagged**	**Number recaptured/detected (species)**
Kirchoff & White 2002	2001–2002	USA (four islands in SE Alaska)	Elk (*Cervus canadensis*); Sitka deer (*Odocoileus hemionus sitkensis*); wolves (*Canis lupus*)	78 snares	3 elk, 1 Sitka deer, 1 wolf, 1 black bear (*Ursus americanus*)	VHF detections
Crouchley et al. 2011	2003–2010	NZ (Fiordland: Anchor & Secretary Islands)	Red deer (*Cervus elaphus*)	10 snares	0 confirmed	0 confirmed
Bishop et al. 2019	2010–2012	USA (Colorado; multiple sites)	Mule deer fawns (*Odocoileus hemionus*)	Device-based: 1 device, used during a series of R&D cycles	10 collaring events; 8 unique mule deer fawns (shed $\sim$4 w)	repeated detections
Wilson et al. 2025	2022 (UK) & 2024 (Greece)	UK (South Wales) & Greece (Kerkini)	Golden jackal *Canis aureus*; feral dogs (*Canis familiaris*, plus tests on domestic dogs)	Active gates: 25 gate-nights	4 feral dogs tagged; 0 jackals	2 VHF tags recovered; 1 dog located $\sim$12 h after tagging

REFERENCES

Ahlén, I. (1965). *Studies on the Red Deer, Cervus Elaphus L., in Scandinavia: III, Ecological Investigations* (Stockholm: Svenska jägareförbundet)

Beale, D. M. (1966). A Self-Collaring Device for Pronghorn Antelope. *The Journal of Wildlife Management* 30, 209–211. doi:10.2307/3797911

Bishop, C. J., Alldredge, M. W., Walsh, D. P., Bergman, E. J., Anderson, C. R., Kilpatrick, D., et al. (2019). A noninvasive automated device for remotely collaring and weighing mule deer. *Wildlife Society Bulletin* 43, 717–725. doi:10.1002/wsb.1034

Clarke, C. M. H. and Henderson, R. J. (1978). Snare-marking chamois in New Zealand. *Zeitschrift fuer Säugetierkunde* 434, 232–239

Crouchley, D., Nugent, G., and Edge, K.-A. (2011). Removal of red deer (*Cervus elaphus*) from Anchor and Secretary Islands, Fiordland, New Zealand , 422–425

Davidson, M. M. (1979). Movement of marked Sika (*Cervus nippon*) and red deer (*Cervus elaphus*) in central North Island, New Zealand. *New Zealand Journal of Forestry Science* 9

Keith, L. B. (1965). A live snare and a tagging snare for rabbits. *The Journal of Wildlife Management* 29, 877–880. doi:10.2307/3798566

Kirchoff, M. and White, K. (2002). *Development of a passive-capture device technique for radiotagging large animals*. Tech. rep., Alaska Department of Fish and Game, Division of Wildlife Conservation

Mahan, C. G., Yahner, R. H., and Stover, L. R. (1994). Development of remote-collaring techniques for red squirrels. *Wildlife Society Bulletin (1973-2006)* 22, 270–273

Romanov, A. N. (1956). Automatic banding of wild animals and prospects of its application. *Zoological Journal* 35, 190–20. Re-published: Russian Ornithological Journal 2015, Volume 24, Express Edition 1091: 33-38

Siglin, R. J. (1966). Marking mule deer with an automatic tagging device. *The Journal of Wildlife Management* 30, 631–633. doi:10.2307/3798762

Taylor, R. H. (1969). Self-attaching collars for marking red deer in New Zealand. *Deer* 1, 404–407

Taylor, R. H. and Magnussen, W. B. (1965). Preliminary note on capture and marking of wild ungulates in New Zealand. *New Zealand J. Sci.* 8, 205–213

Verme, L. J. (1962). An automatic tagging device for deer. *The Journal of Wildlife Management* 26, 387–392. doi:10.2307/3798016

Verme, L. J. (1973). Movements of white-tailed deer in upper Michigan. *The Journal of Wildlife Management* 37, 545–552. doi:10.2307/3800320

Wilson, R. P., Redcliffe, J., Holton, M., Hopkins, P., Thomas, V., Rosell, F., et al. (2025). Why catch when you can throw? A framework for tagging animals without capture or restraint. *Royal Society Open Science* 12. doi:10.1098/rsos.250139