Module: British Wildlife and Conservation
Title: Tracking the illusion of technology?

Introduction

The innovation of reliable and cost-effective methods for assessment of species richness and abundance is crucial in conservation biology. In the last three decades the interest of monitoring wildlife produced more than 5500 articles with the term ’monitoring’ in the title or abstract published between 1984 and mid-2009 (Lindenmayer and Likens, 2010). Prior to the 1950s, information on animal distribution came from either direct behavioural observation of animal movements, spatially distributed trapping of animals over a period of time, or by following tracks on the ground. The determination of the size and boundaries of national parks, wildlife reserves and marine protected rely partially on animal distribution data collected by conservationists. Because of the rapid technological developments scientists are enabled to conduct research in an entirely new way. The author of this paper reviews the technological developments in wildlife monitoring, their advantages and disadvantages and the effectiveness of novel tracking methods.

Brief history of animal tracking

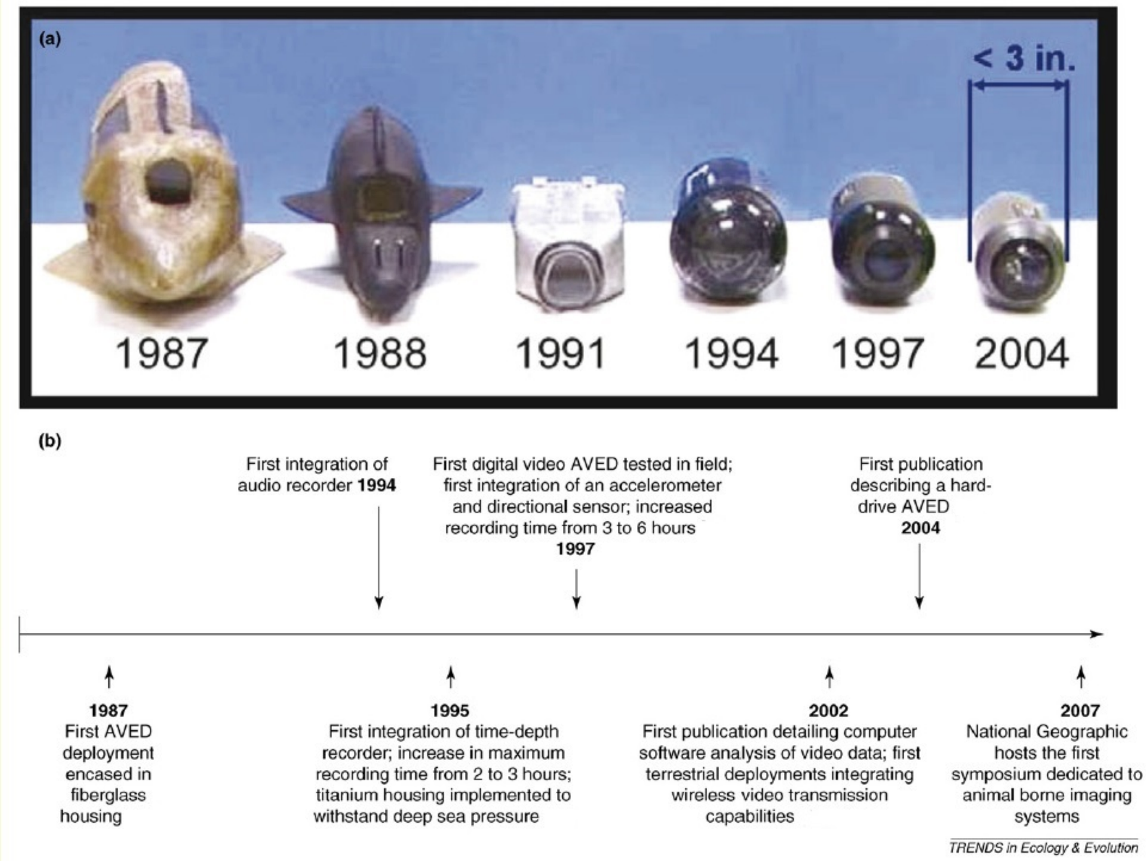
Tracking animals by following their footprints in dust, mud, sand or snow is the oldest known method of identifying mammal’s presence (Bider, 1968). Thirty years ago, direct tracking of marine species was still achieved by visually following balloons towed by animals (Rutz and Hays, 2009). In the 1950s, radiotelemetry was the first milestone in animal ecology, enabling researchers to document patterns of space use by animals (Macdonald et al., 1980). In the 1980s the resource selection analysis (RSA) was introduced (Johnson, 1980) which was the second important milestone in animal distribution studies. RSA identifies key habitats or resources by analysing the frequency which habitats are used relative to some measure of the animal’s availability on a landscape (Thomas and Taylor, 1990).

Since the 1990s, satellite-based telemetry systems (e.g. ARGOS) are widespread. With the rise of Global Positioning System (GPS) telemetry (Tomkiewicz et al., 2010), there has been a shift towards step-selection RSA methods that can assess animal habitat preferences at the scale of successive locations as seen in a polar bear (*Ursus maritimus*) study (Arthur et al., 1996). GPS coupled with the increased use of Geographical Information Systems (GIS) to sort and manipulate spatial data, led to an expansion in species distribution modelling. These systems were initially suitable for large terrestrial and marine vertebrates (e.g. Ballard et al., 1995; Bethke et al., 1996; Priede and French, 1991; Rempel et al., 1995). Since then, GPS telemetry has become a mainstream technique for animal monitoring and is used with miniaturized digital camera system (Figure 1.). The role of the animal's memory has been suggested to be influential in habitat preference (Spencer, 2012; Moorcroft, 2008), for which video systems could be used for formulating mathematical descriptions of the underlying mechanisms (Holgate, 1971; Moorcroft et al., 2006).

Figure 1. Deployment of AVEDS on many different species(a) An AVED captured the underwater hunting tactics emperor penguins (*Aptenodytes forsteri*) beneath Arctic sea ice (Ponganis et al., 2000) (b) A robotic model of the lateral eye of a horseshoe crab (*Limulus polyphemus*) was created from data collected from an AVED equipped with a micro-suction electrode that measured optic nerve activity (Passaglia et al., 1997) (c) AVEDs were used to examine food selection choices of white-tailed deer (*Odocoileus virginianus*) (Beringet et al. 2004) (d) Crittercam deployed on an African lion to record behaviour (Marshall, 1998).

Environmental Data Collection Systems (AVEDs)

This technology enables researchers to see what the animal sees and experiences in the field while tracking them. Geolocator tags, heart-rate loggers, neuro-loggers and video/still-image loggers are called bio-loggers and function as ‘daily dairies’ of the targeted species (Wilson et al., 2008). Questions about foraging dynamics, reproduction, species interactions, migration and disease transmission often require detailed behavioural data which is accessible with the use of AVEDs. The first AVEDs were deployed on loggerhead (*Caretta caretta)* and leatherback (*Dermochelys coriacea)* turtles in 1987 (Marshall, 1990, see Figure 2). When the size and weight of AVESs decreased, this enabled scientists to deploy it on smaller species as well. However, the practicality of AVEDs is debated due to their cost (Legg and Nagy, 2006), the lack of hypothesis formulation before their deployment and their negative effect on animal welfare (Jewell, 2013). The writer of this paper highlights their potential and suggests their continuous development.



First integration of audio recorder **1994**

First digital video AVED tested in field; first integration of an accelerometer and directional sensor; increased recording time from 3 to 6 hours **1997**

First publication describing a hard-drive AVED **2004**

1987 First AVED deployment encased in fiberglass housing

1995 First integration of time-depth recorder; increase in maximum recording time from 2 to 3 hours; titanium housing implemented to withstand deep sea pressure

2002 First publication detailing computer software analysis of video data; first terrestrial deployments integrating wireless video transmission capabilities

2007 National Geographic hosts the first symposium dedicated to animal borne imaging systems

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Figure 2. The evolution of AVED specifications (a) The National Geographic’s Crittercam’s (b) The timeline of major advances in AVED technology which was retrieved from http://nationalgeographic.com/crittercam/about.htlm.

Different taxa, different methods

There is no single tool which allows monitoring multiple different species and in diverse landscapes. However, methodologies have been developed for researching different taxa for decades which provide a fundamental toolbox of technologies for the conservation community (Table 1). The way of identifying individual animals, following their movements, identifying and locating animal and plant species and assessing the status of their habitats remotely have become better, faster and cheaper (Pimm et al., 2015, see Table 2). For example, airplane surveillance for wildlife monitoring has been used for decades but now the unmanned aerial vehicles (UAVs or 'drones') are capable of taking pictures and videos which provide a better and cheaper way of monitoring wildlife distributions.

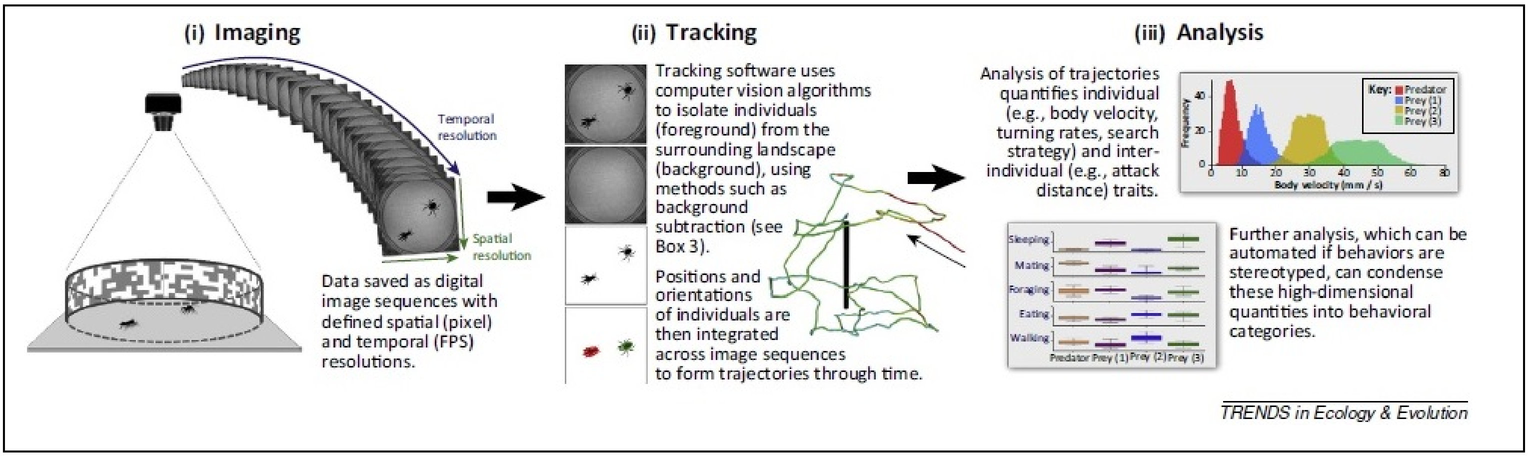
Table 1. Wildlife monitoring methods gathered between 2000 and 2004 in the Journal of Applied Ecology. Different taxa requires different combination of data in order to map their distribution.

Ref	Taxon	Species data	Habitat predictors	GIS
Collingam et al., 2000	Weeds	Biological recording	Remote-sensed imagery	Yes
Cowley et al., 2000	Lepidoptera	Transect survey	Mapped habitat data	No
Milson et al., 2000	Birds	Field survey	Mapped habitat data and field survey	No
Manel et al., 2000	Birds Invertebrates	Field survey	Field survey	No
Bradbury et al, 2000	Birds	Field survey	Field survey	No
Gates & Donald, 2000	Birds	Biological recording	Mapped habitat data	No
Jaberg & Guisan, 2001	Bats	Augmented biological records	Mapped habitat data	No
Manel et al., 2001	Invertebrates	Field survey	Remote-sensed imagery	No
Pearce et al., 2001	Mammals Reptiles Birds	Field survey	Remote-sensed imagery	Yes
Osborne et al., 2001	Birds	Field survey	Remote-sensed imagery	Yes
Suarez-Seoane et al., 2001	Birds	Field survey	Remote-sensed imagery	Yes
Ambrosini et al., 2002	Birds	Field survey	Field survey	No
Schadt el al., 2002	Mammals	Radio-tracking	Remote-sensed imagery	Yes
Holloway et al., 2003	Lepidoptera	Field survey	Mapped habitat data	No
Vaughan et al., 2003	Mammals	Questionnaire	Land classes and farm census	No
Cabeza et al., 2004	Lepidoptera	Transect survey	Mapped habitat data	No
Engler at al., 2004	Plants	Biological recording	Mapped climatic and terrain data	Yes
Jeganathan et al., 2004	Birds	Bird sign	Remote-sensed imagery	Yes
Gibson et al., 2004	Birds	Bird song	Remote-sensed imagery	Yes
Johnson et al. 2004	Mammals	Radio-tracking	Mapped habitat data	Yes
Frair et al., 2004	-	Remote sensing (GPS)	Field survey	Yes

Novel methods: automated image-based tracking, 3D imaging, scat detection by dogs

Similar to bio-logging, image-based tracking involves digital recording of data, increasing repeatability of studies and allowing biologists to gather data for quantities not considered before. Image-based tracking can be used when individuals are too small to attach bio-loggers or if the equipment itself changes behaviour because of its minimal or zero manual intervention (Kuhl and Burghardt, 2013, see Figure 3). There is a wide range of imaging methods (e.g. infrared, thermal infrared, sonar, 3D, multi-scale gigapixel) that permit tracking in environments where optical video is unsuitable (Hristov et al. 2008; Brandy et al., 2012). When camera-trapping was compared to track surveys (Silveira et al., 2003) it was shown that track counts proved to be more efficient but considering camera-trapping is also an efficient non-intrusive method in most field conditions and it is relatively cheaper in the long term run than track census and line-transects.

Three-dimensional tracking dates back to the 1980s (Dahmen and Zeil, 1984) but it was Pomeroy and Heppner (1992) who succeeded tracking 16 birds in the field. Although 3D tracking is in its early stages there are novel studies that were able to analyse and reconstruct starling flock movements and swarming midges by using industrial high-speed cameras with infrared lenses (Attansi et al., 2013) or analyse social behaviour of rats (Figure 4). Another method has been developed recently



Data saved as digital image sequences with defined spatial (pixel) and temporal (FPS) resolutions.

Tracking software uses computer vision algorithms to isolate individuals (foreground) from the surrounding landscape (background), using methods such as background subtraction (see Box 3).

Positions and orientations of individuals are then integrated across image sequences to form trajectories through time.

Analysis of trajectories quantifies individual (e.g., body velocity, turning rates, search strategy) and inter-individual (e.g., attack distance) traits.

Further analysis, which can be automated if behaviors are stereotyped, can condense these high-dimensional quantities into behavioral categories.

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Figure 3. Computer vision algorithms rely on knowledge about typical shape and size of individuals to aid the segmentation and analysis of images. However, individuals in the wild differ greatly in size and shape which poses major problems with this system (Ohayon et al., 2013). Therefore, imaging is extremely difficult in the field where many individuals from many different species interact across a complex environmental landscape (Dell et al., 2014).

which is scat detection by dogs. It has been used to locate faecal (scat) samples from carnivores in order to confirm the species' presence and also provides the opportunity to collect faecal DNA and hormone information for other analyses (Smith et al., 2001; Wasser et al., 2004; Long et al., 2007a). When this method was compared to camera-trapping and hair snare surveys with scent lures, detection dogs were substantially more effective at detection (Long et al., 2007b), however this is also the most expensive method.

Illusion of technology?

Curious minds will produce new hypotheses, which will drive the development of increasingly sophisticated technology. However, all novel technologies carry the temptation to deploy AVEDs before research questions are clearly identified and descriptive case studies have a low efficiency in

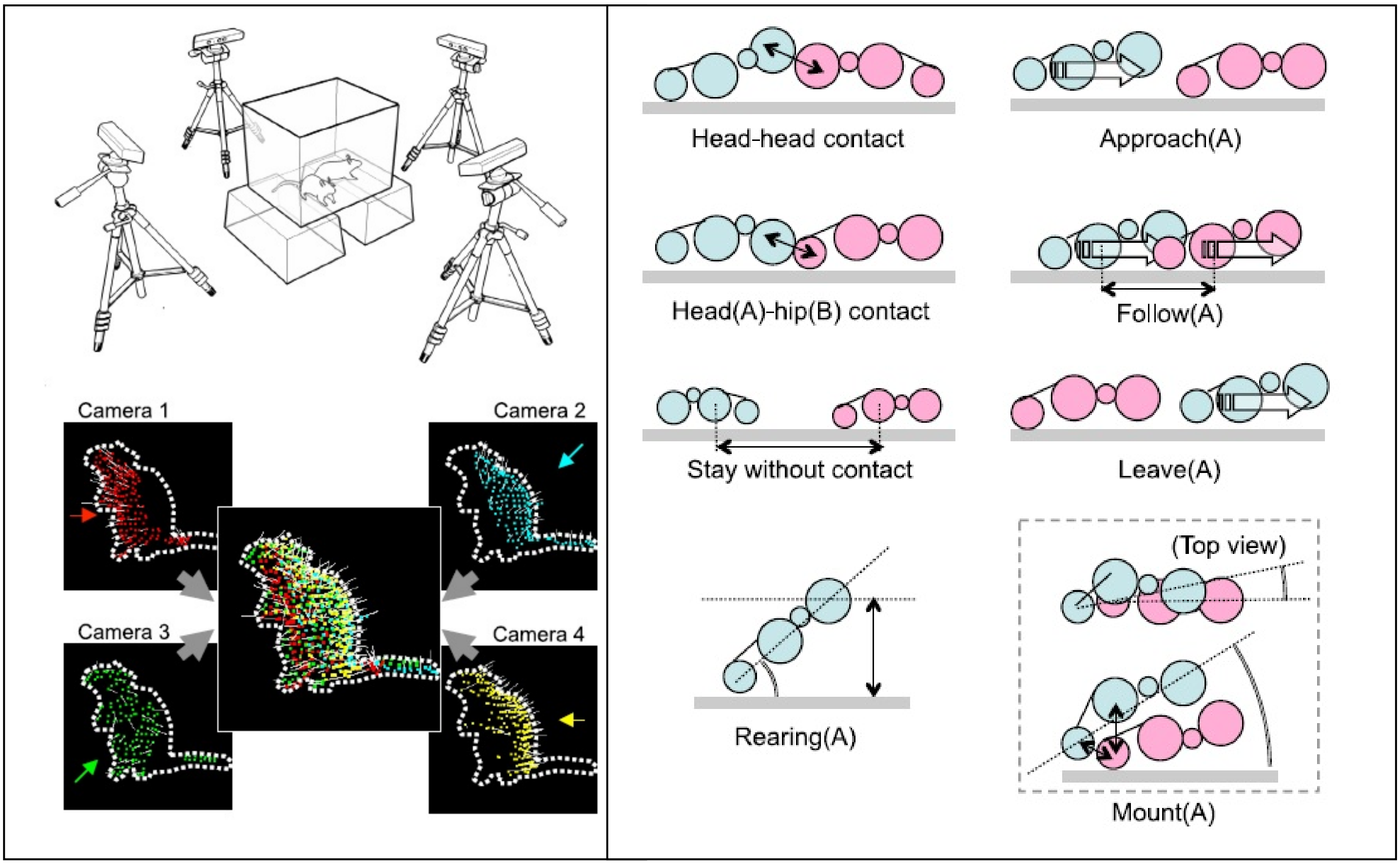

Figure 4. A 3D-video-based computerized analysis was tested out by Matsumoto et al. (2013) on rats of their social and sexual interaction. Although this technological development cannot be implemented to study animal distribution, it could be applied to studies of primates which opens a new door to investigate the neuroscience of social and sexual behaviour.

building scientific knowledge. For example, how could camera-traps and drones stop poaching? The need to solve real-world problems in conservation biology has placed methodological developments at the forefront. The oldest, most simple methods of animal tracking are still proving to be the best. Carpenter (1998) suggested that ecosystem science is like a table supported by the four legs of theory, experimentation, cross-site comparisons and long-term studies. If one 'leg' is missing, good science will 'collapse'. The writer of this paper empathises with the need for technological development but raises the question of its efficiency and cost-effectiveness.

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