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Thinking spatially: The importance of geospatial techniques for carnivore conservation

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ABSTRACT

Today, 27% of the known mammalian carnivore species are either extinct or threatened, undermining the health of many ecosystems, which provide resources and services that are crucial for human development. Carnivore research and management have been limited by the predominantly cryptic nature of carnivores, sometimes also by their large-scale habitat requirements and their remote distributions. As a consequence, many carnivore species currently remain under-studied. The increased availability and facilitated interpretation of remote-sensing imagery, combined with recent developments in landscape ecology and geographic information systems, have provided a wealth of analytical tools to overcome many of these traditional setbacks. These can be coupled with advances in multivariate statistics and species distribution models to formalise the link between spatial patterns in environmental variables and species occurrence. Such methods allow a greater understanding of the processes shaping habitat use, the effects of poaching and land-cover change, and assist in the design and monitoring of more targeted actions towards carnivores' long-term conservation.

1. Introduction

The expansion and intensification of human activities are responsible for the current biodiversity crisis, and recent assessments show no reduction in the rate of species loss despite worldwide recognition of the intrinsic, aesthetic and cultural values of biodiversity, as well as its role in securing ecosystem services (Foley et al., 2005; Lambin et al., 2001). According to the Convention on Biological Diversity (CBD), the global population of vertebrates fell by 31% between 1970 and 2006, while preliminary assessments indicate that 23% of all known plants species are already thought to be threatened (Secretariat of the Convention on Biological Diversity, 2010). Habitat loss, over-exploitation, persecution, invasive species, disease and pollution are only some of the threats faced by biodiversity today, while the scale and complexity of the problem imposes great challenges for conservation practitioners, who need to take urgent actions based on limited knowledge (Gittleman et al., 2001; Schipper et al., 2008).

Initially, efforts to protect threatened species were local, reactive and focused on the plight of single taxa (Ray et al., 2005). The subsequent development of a robust conservation science, however, changed this approach towards more strategic and holistic actions, aiming at the maintenance of ecosystem processes and the protection of biodiversity as a whole (Groves, 2003; Ray et al., 2005). This shift in scope, although theoretically more cost-effective and ecologically-sound, lacks the details required to protect fully certain species (*e.g.*, wide-ranging) and its application is seriously constrained by data availability (Ray et al., 2005). In practice, most conservation programmes represent a mixture of both approaches, aiming to safeguard the functioning of natural systems by using certain taxa for planning, implementation and public engagement (Caro, 2010).

Mammalian carnivores provide unique opportunities for this combination of scopes (Caro, 2010): a suite of biological traits makes this Order particularly vulnerable to extinction (Cardillo et al., 2004), while some of the carnivores' features help bridge the gap between the ecosystem and the single-species focus (Gittleman et al., 2001; Ray et al., 2005). Spanning an exceptionally wide range of body sizes (Gittleman and Purvis, 1998), and being found from the polar ice to tropical rainforests (Macdonald, 1989), carnivores are highly adaptable species and many taxa show considerably large home-range sizes and/or dispersal distances (Loyola et al., 2009). Today, 27% of all known mammalian carnivores are threatened or already extinct, and range reductions for many species have been reported as a direct consequence of human activities (Crooks, 2002; Ginsberg, 2001; Karanth and Chellam, 2009; Sunquist and Sunquist, 2001). In addition to their individual plight, mammalian carnivores can act as early indicators of system degradation as their low population densities, small reproductive outputs and long gestation periods, limit the speed of response to changes in the natural environment (Cardillo et al., 2004; Crooks, 2002; Ginsberg, 2001). Predation plays a key role in shaping animal populations and communities through prey killed and the behavioural and life history decisions of both predators and prey (Fryxell and Lundberg, 1994). The top–down regulation exerted by many taxa is crucial for maintaining ecosystem processes and species diversity, while the nonlethal effects of predation are

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important for the preservation of evolutionary forces shaping prey communities (Creel and Christianson, 2008; Miller et al., 2001; Terborgh et al., 2001). Many mammalian carnivores are also economically important, given the costs from the predation of domestic animals (Dickman, 2010; Michalski et al., 2006), and the benefits obtained from wildlife-photography and hunting-based tourism (Gittleman et al., 2001). Additionally, their charismatic nature has proven useful for gaining support from the general public, and many species have become important tools for contextualising the protection of the biota and the maintenance of natural processes (Caro, 2010; Licht et al., 2010).

Despite the clear benefits of including mammalian carnivores at the core of biodiversity conservation, their predominantly cryptic nature and the lack of analytical tools to study their fundamental requirements have traditionally constrained research within this Order (Karanth and Chellam, 2009; Sunquist and Sunquist, 2001). Nonetheless, during the past three decades, the steady development of geospatial techniques has allowed overcoming many traditional setbacks, and so they have been readily adopted by both researchers and practitioners (see *e.g.* Corsi et al., 2000; Cianfrani et al., 2010; Pettorelli et al., 2010; Rondinini et al., 2005; Sánchez-Mercado et al., 2008). Here, we start by providing short relevant background on remote sensing and geographic information systems. We then review the role that geospatial techniques play on carnivore research and discuss the fundamental limitations of the available techniques, as well as the crucial theoretical considerations and developments needed to provide a framework for their adequate use and wider application.

2. Remote sensing

Remote sensing, in its broadest definition, refers to measuring a particular quality of a given feature without being in physical contact with the feature itself (Jensen, 2007). This includes the detection of electromagnetic energy from the Earth surface by sensors onboard satellites (Turner et al., 2003). The Earth Resources Technology Satellite (ERTS, currently known as Landsat) launched in 1972, was the first space-borne instrument designed with remote-sensing capabilities for the survey of natural systems (Boyd and Danson, 2005). Since then, a steady progress on imagery acquisition and development of interpretation procedures has opened the door to cost-effective data collection across broad spatial and temporal scales, adding new dimensions to ecological studies, as well as many other fields of research (Aplin, 2004, 2005; Boyd and Danson, 2005; Eastman, 2006; Erdas, 2002; Jensen, 1996; Turner et al., 2003). Today, the archive of satellite imagery spans over a period of four decades, with revisiting times between 1 and 16 days and spatial resolutions ranging from 0.6 m to 10 km (Jensen, 1996; Kerr and Ostrovsky, 2003; Turner et al., 2003). Kerr and Ostrovsky (2003), highlighted the use of remote sensing to assist ecological research in three areas: (1) land cover classification, (2) integrated ecosystem measurements and (3) change detection (Tables 1 and 2).

3. Geographic information systems

Information systems facilitate the organization, storage, access, manipulation and synthesis of multi-sourced data, to enable problem solving in a wide variety of disciplines (Longley et al., 2005). Geographic Information Systems (GIS) are a particular type of information system that allows associating geographic locations to the records compiled; to not only keep track of the certain elements and processes of interest, but also to know where they are situated or taking place (Longley et al., 2005). The rise of computing systems during the 1970s and 1980s provided unprecedented processing, storage and visualization capabilities, leading to the incorporation of GIS into a wide variety of biodiversity-related disciplines, including ecology, biogeography and wildlife conservation (see *e.g.*, Bernhardsen, 2002; Brooker and Michael, 2000; Corsi et al., 2000; Foody, 2008; Longley et al., 2005).

The rise of GIS promoted the development of a variety of spatially explicit databases that have granted free access to information on the distribution of biomes and ecoregions, species richness and diversity, climatic conditions, land-cover and vegetation types, human population and footprint, together with land-use ordination amongst many others (*e.g.* Cóndor, 2010; GBIF, 2009; GLCF, 2007; MRLC, 2010; Sanderson et al., 2002a,b; WDPA, 2010). These databases have been fundamental for accelerating the incorporation of GIS into ecological and biogeographical research, as well as into the processes of design, prioritisation, management and monitoring for biodiversity conservation (Myers et al., 2000; Roberts et al., 2002; Schipper et al., 2008; Schmitt et al., 2009; Walpole et al., 2009). For example, the status of the world's mammals was evaluated by Schipper et al. (2008), based on data collected by the IUCN involving information of species distribution and ecology, threats and conservation interventions undertaken so far. Cardillo et al. (2004) estimated extinction risk within Carnivora in relation to biological traits and human population densities.

4. Carnivore conservation and geospatial techniques

4.1. Working with minimum information: landscape classification and habitat suitability

Carnivore distributions sometimes exhibit strong association with known features of their environment. When such associations are

Table 1
Sensors most commonly used in biodiversity-based studies, highlighting their main applications (Liew 2001; Satellite Imaging Corporation 2001; Turner et al., 2003; Pettorelli et al., 2005a; Spot Image 2010; DigitalGlobe, Inc. 2011; Irons 2011; Maccherone 2011; US Department of Commerce - NOAA – NESDIS 2011).

Sensor	Date launched	Resolutions			Application
		Spectral	Temporal (days)	Spatial (m)	
AVHRR†	1981	V, NIR, SWIR, TIR	1 day — bimonthly	1100 – 25,000	Land cover, status of vegetative, oceanic patterns.
TM†	1982	V, NIR, SWIR, TIR	16	30 V, 120 TIR	Land cover, community composition and/or species occurrence, primary productivity, phenology, status of vegetative formations.
SPOT†	1986	V, PCH, NIR, SWIR	1–3	2.5–20	Land cover, community composition and/or species occurrence, primary productivity, phenology, status of vegetative formations.
ETM+	1999	V, PCH, NIR, SWIR, TIR	16	3 V, 60 TIR, 15 PCH	Land cover, community composition and/or species occurrence, primary productivity, phenology.
MODIS	1999	V, NIR, SWIR, TIR	1–2	250–1000	Land cover, ocean colour, phytoplankton and biochemistry.
IKONOS†	1999	V, PCH, NIR	3	4 V, 1 PCH	Land cover, community composition and/or species occurrence, primary productivity, phenology.
Quickbird†	2001	V, PCH, NIR	1–3.5	2.44–2.88	Land cover, community composition and/or species occurrence, primary productivity, phenology.

AVHRR = Advanced Very High Resolution Radiometer, TM = Landsat Thematic Mapper, SPOT = Satellite Pour l'Observation de le Terre, ETM + = Enhanced Thematic Mapper Plus, MODIS = Moderate-resolution Imaging Spectroradiometer. V = Visible, PCH = Pancromatic, NIR = Near Infrared, SWIR = Short Wave Infrared, TIR = Thermal Infrared, MW = Microwave.
†NDVI products derived from images obtained with these sensors have also a variety of applications for biodiversity-based studies; for more information see Pettorelli et al. (2005a, 2011).