Synthesis and Future Perspectives on Carrion Ecology and Management

Pedro P. Olea, Patricia Mateo-Tomás, and José A. Sánchez-Zapata

Contents

Main Conclusions

Carrion, dead animal matter, is a high-quality ephemeral resource present in all ecosystems, from arctic to tropical biomes in terrestrial and aquatic (freshwater and marine) environments (Fig. 1). Hundreds to thousands of invertebrates and vertebrates species are estimated to be facultative scavengers, i.e. consuming carrion opportunistically, yet a minority of them (<1%) have adapted to exclusively feed on this trophic resource (i.e. obligate scavengers). Carrion underpins therefore a rich food web comprised of microbial, arthropod and vertebrate taxa; a necrobiome that is responsible for the decomposition of carrion (Benbow et al. 2013). Carrion decomposition is a key

Pedro P. Olea and Patricia Mateo-Tomás contributed equally to this chapter.

P. P. Olea (✉)
Centro de Investigación en Biodiversidad y Cambio Global (CIBC-UAM), Universidad Autónoma de Madrid, Madrid, Spain

Departamento de Ecología, Universidad Autónoma de Madrid, Madrid, Spain
e-mail: pedrop.olea@uam.es

P. Mateo-Tomás
Centre for Functional Ecology (CFE), Department of Life Sciences, University of Coimbra, Coimbra, Portugal

Research Unit of Biodiversity, (UMIB, UO/CSIC/PA), Mieres, Spain

J. A. Sánchez-Zapata
Departamento de Biología Aplicada, Universidad Miguel Hernández, Elche, Spain
e-mail: toni@umh.es

P. P. Olea et al. (eds.), *Carrion Ecology and Management*, Wildlife Research Monographs 2, https://doi.org/10.1007/978-3-030-16501-7_12

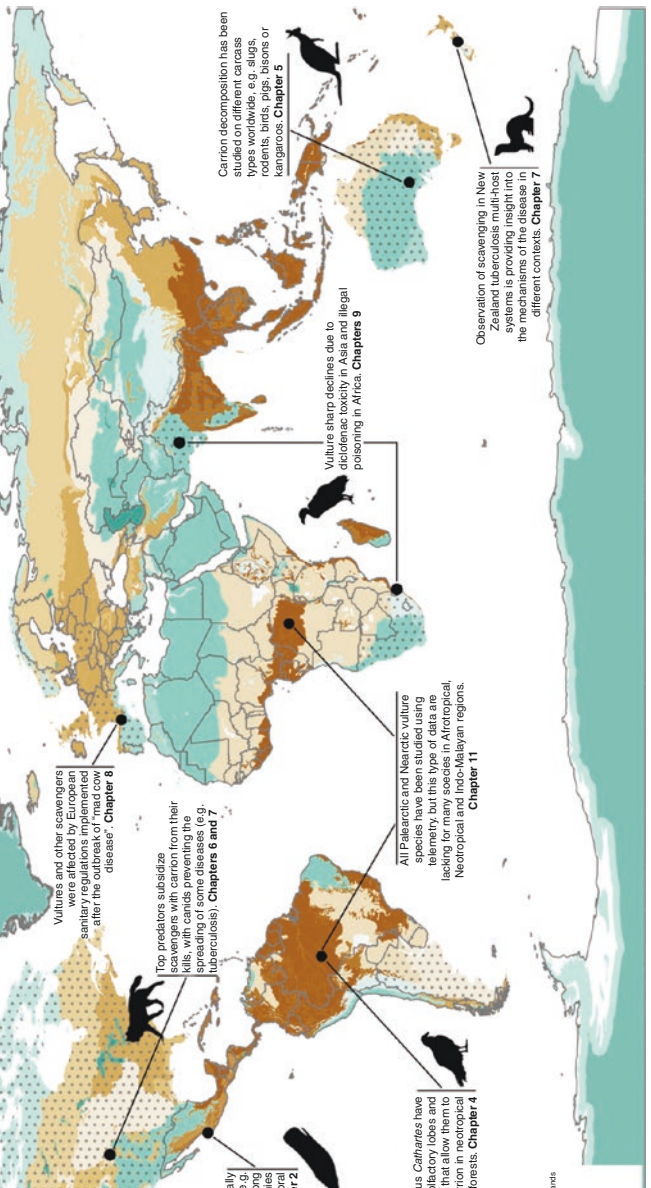

Fig. 1 Scavenging is a widespread strategy present in all ecosystems and this book contains examples on carrion ecology and management from all around the world. Detailed studies on carrion ecology are described in this book for at least the dotted countries. Credit: Patricia Mateo-Tomás

ecological process for ecosystem functioning, related to the recycling of energy and nutrients, and scavenging—i.e. the consumption of carrion by scavengers – plays a crucial role in this process (chapters "Carrion Decomposition" and "Ecological Functions of Vertebrate Scavenging"; Barton et al. 2013). Carcass characteristics (e.g. size) and the biotic (e.g. habitat) and abiotic (e.g. temperature, moisture) environment act as moderators of the process of carrion decomposition, which differs between terrestrial systems and aquatic environments (Beasley et al. 2012; chapters "Carrion Decomposition" and "Ecological Functions of Vertebrate Scavenging")

Scavenging plays an important role in structuring food webs (Wilson and Wolkovich 2011; chapter "Ecological Functions of Vertebrate Scavenging"). Scavengers feeding at carcasses can form structured assemblages that are driven by ecological succession processes in invertebrates and the creation of nested networks in vertebrates (chapters "Invertebrate Scavenging Communities" and "Vertebrate Scavenging Communities"). These feeding relationships involving animal carcasses increase complexity and stability of food webs (chapter "Ecological Functions of Vertebrate Scavenging").

Carcasses represent hotspots of biological diversity. The inter- and intraspecific interactions (e.g. facilitation, competition) that occur at carrion among species and between kingdoms (microbe-animal) drive key ecosystem functions such as biodiversity maintenance and nutrient recycling. Coexistence of species sharing the same carrion underpins biodiversity through facilitation processes and resource partition among species (e.g. species utilizing different parts within a carcass or carcasses of different sizes). The relationships between diversity of scavengers and ecosystem functioning (carrion decomposition, nutrients recycling) provides in turn important benefits for human societies, i.e. ecosystem services, such as carcass disposal and disease control (chapter "Ecological Functions of Vertebrate Scavenging").

Humans have shifted from carrion consumers to carrion suppliers, and thus the relationship of humans and wild scavengers has changed from competition or predation to mutualism and commensalism (Gangoso et al. 2013, chapter "Human-Mediated Carrion: Effects on Ecological Processes"). Humans are increasingly becoming a fundamental piece in carrion ecology due to the growing presence of human-mediated carrion in natural ecosystems worldwide (Oró et al. 2013). The ubiquity of dead livestock, hunting remains or fisheries discards on Earth ecosystems not only alters the spatiotemporal distribution and quality of carrion, but also have consequences for biodiversity maintenance, ecosystem functioning and human well-being (chapter "Human-Mediated Carrion: Effects on Ecological Processes"). Human-mediated carrion has also become a reservoir for toxic residues such as pharmaceutical drugs, lead and pesticides, and thus scavenging this contaminated carrion is likely to propagate the toxics across food webs (chapter "What Makes Carrion Unsafe for Scavengers? Considerations for Appropriate Regulatory Policies and Sound Management Practices"; Figs. 1 and 2). The sustainable management of human-mediated carrion emerges therefore as a pressing issue. To be effective, this management should be science-based, i.e. grounded on the best available knowledge on carrion ecology. Nevertheless, effective carrion management demands also additional knowledge to fill major gaps that still exist regarding not only the conser-

Fig. 2 Illegal poisoning threatens biodiversity worldwide, and especially obligate scavengers such as vultures and condors; 34 Andean condors *Vultur gryphus* were killed with a single Carbofuran-baited sheep carcass set out by ranchers to combat mammalian predators in Argentina in January 2018 (Alarcón and Lambertucci 2018). Credit: Eva López García

vation of biodiversity and ecosystems, but also a better understanding on key ecological functions and services such as carrion decomposition, nutrient recycling or disease control. This knowledge will help to face major drivers of global change that are expected to exert a noticeable impact on carrion ecology, such as land use intensification and degradation, climate change or invasive species.

Under the current scenario of global environmental change, a sharply growing human population demands more food and also generate more waste, including enormous amounts of carrion into ecosystems. We are now starting to assess how these subsidized ecosystems absorb the inputs of human-mediated carrion and the ecological consequences from populations and species to communities and ecosystems (chapters "Human-Mediated Carrion: Effects on Ecological Processes" and "What Makes Carrion Unsafe for Scavengers? Considerations for Appropriate Regulatory Policies and Sound Management Practices"; Oro et al. 2013). However, this issue remains still poorly understood.

What's Next?

Besides providing an updated summary of current knowledge on the topic, the authors of this book identify some "hot topics" that research in carrion ecology should try to answer in the next decades.

Despite the observed increase in scientific research on carrion and scavenging during the last decades, the relative importance of this field within the environmental and biological sciences remains constant (Fig. 1.4) and far below the figures reached by other topics in ecology and conservation (e.g. predation; see chapter "Introduction to the Topic of Carrion Ecology and Management"). Therefore most authors in this book highlight several major knowledge gaps still existing in carrion ecology, identifying some key questions to be answered by researchers in the discipline in the near future.

Data on scavenger assemblages and scavenging dynamics are still lacking in many ecosystems around the world. Authors in this book provide specific recommendations in relation to the research of scavenging communities particularly in island, arctic, tropical, and aquatic ecosystems, as well as in the marine-terrestrial interface (see chapters "Carrion Availability in Space and Time" and "Ecological Functions of Vertebrate Scavenging"). The role of carrion in supporting ecological processes across levels of organization (from individuals to ecosystems) remains still understudied. Further attention is demanded too for the intra- and inter-specific interactions occurring at carrion, highlighting interesting topics such as the microorganism-invertebrate dynamics (see chapter "Carrion Decomposition").

The great potential of new technologies for broadening knowledge on carrion ecology and supporting the effective management of carrion and carrion-eaters is also recognized by several authors in this book (e.g. chapters "Invertebrate Scavenging Communities" and "Carrion Decomposition"). In fact, the methodological section provides some examples of how different technologies (e.g. GPS tracking, underwater laboratories) can be used to support research on the topic. Underwater cabled laboratories such as Ocean Networks Canada's VENUS Observatory has demonstrated high usefulness for studying carrion ecology in challenging environments such as marine waters (Fig. 1).

A better quantification of the spatiotemporal availability of carrion is a major topic to deal with, as it would lead to a better understanding of scavenging dynamics.

The more explicit use of experimental approaches is also remarked to better assess ecological theories regarding the impact of different drivers of global change on carrion ecology (see above). Disease dynamics at carrion are an emerging issue with important questions to be addressed (e.g. from the use of carrion by scavengers and the subsequent exposure to different diseases to the role of human related factors in such disease dynamics; see chapter "The Role of Scavenging in Disease Dynamics"). It is needed to know the role that scavengers play in the control and dissemination of disease (Fig. 1).

A major claim of several authors in this book asks for developing and strengthening interdisciplinary collaboration among professionals from the different scientific disci-

plines involved in the study of carrion and its consumption. Further insight into carrion ecology is expected to result from combining molecular and ecological perspectives (see chapter "Carrion Decomposition"). While the collaboration of microbiologists, entomologists, vertebrate zoologists and ecologists is necessary to better understand carrion decomposition, the study of disease dynamics at carcasses would benefit from close collaboration between wildlife ecologists and public health professionals.

Scavenging in the Anthropocene

Scavengers and scavenging processes face major changes in the increasingly humanized ecosystems that characterize the Anthropocene. Provided that temperature is recognized as a modulator of carcass persistence and scavenging dynamics, this factor (along with habitat type, and species and carrion size) should be considered in the design of studies of carrion ecology (chapter "Ecological Functions of Vertebrate Scavenging"). Knowing how temperature determines the fate of carcasses will be also useful to predict how climate change will likely affect both carrion availability, through altering mortality patterns (e.g. disease, extreme weather), and the rates of carrion decomposition in ecosystems.

Assessing the potential effect of global change on both carrion availability and its consumption across the globe is of paramount importance in carrion ecology (see chapter "What Makes Carrion Unsafe for Scavengers? Considerations for Appropriate Regulatory Policies and Sound Management Practices"). The increasing presence of humans in natural ecosystems is severely impacting carrion availability and consumption at all ecological levels (i.e. from individuals and populations to communities and ecosystems; see chapter "Human-Mediated Carrion: Effects on Ecological Processes"). In this regard, scavengers, particularly obligate scavengers, face major carrion-related threats such as contamination of carrion by multiple toxic compounds and abrupt changes of food sources driven by regulatory measures (Fig. 2). The effect of toxic residues in carcasses on micro-scavengers (arthropods) should be further acknowledged and explored in order to develop mitigation measures accordingly (chapter "What Makes Carrion Unsafe for Scavengers? Considerations for Appropriate Regulatory Policies and Sound Management Practices").

The conservation of species-rich guilds of scavengers is a key issue for ecosystem functioning. Reinforcing the science-management interface in carrion ecology is therefore needed to tackle scavenging conservation, especially considering the critical situation of some scavenging species such as vultures worldwide (i.e. 16 out of 22 species threatened according to IUCN; chapter "Vertebrate Scavenging Communities") or top predators. The emerging recognition of the ecosystem services provided by scavengers might help to reverse their decline. More efficient policies and management based in science is therefore needed to better conserve scavengers and scavenging processes in ecosystems in a rapidly changing world.

References

Alarcón PAE, Lambertucci SA (2018) Pesticides thwart condor conservation. Science 360:612
Barton PS, Cunningham SA, Lindenmayer DB, Manning AD (2013) The role of carrion in maintaining biodiversity and ecological processes in terrestrial ecosystems. Oecologia 171:761–772
Beasley JC, Olson ZH, Devault TL (2012) Carrion cycling in food webs: comparisons among terrestrial and marine ecosystems. Oikos 121:1021–1026
Benbow ME, Lewis AJ, Tomberlin JK, Pechal JL (2013) Seasonal necrophagous insect community assembly during vertebrate carrion decomposition. J Med Entomol 50:440–450
Gangoso L, Agudo R, Anadón JD, de la Riva M, Suleyman AS, Porter R, Donázar JA (2013) Reinventing mutualism between humans and wild fauna: insights from vultures as ecosystem services providers. Conserv Lett 6:172–179
Oro D, Genovart M, Tavecchia G, Fowler MS, Martínez-Abraín A (2013) Ecological and evolutionary implications of food subsidies from humans. Ecol Lett 16:1501–1514
Wilson EE, Wolkovich EM (2011) Scavenging: how carnivores and carrion structure communities. Trends Ecol Evol 26:129–135