RESEARCH PAPER

Harnessing Zoo Pharmacognosy For Biopharmaceuticals: Insights Into Animal Self-Medication

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Abstract

Zoo pharmacognosy (zp) is the study of how animals in the wild self-medicate using plants, fungi, soil, and other natural components to prevent or cure disease. This field combines animal behaviour, ecology, and pharmacology to understand natural health strategies and has important implications for conservation, drug development, and sustainable veterinary medicine. A wide range of taxa, including primates, mammals, birds, insects, and reptiles, exhibit self-medicative behaviours. From primates consuming specific leaves for parasite removal to elephants ingesting plants to induce labour, such behaviours illustrate complex interactions between animals and their environment. This review explores the mechanisms behind self-medication, its implications for bioprospecting and drug discovery, and its relevance to wildlife conservation. Challenges such as habitat destruction and biodiversity loss threaten animals' access to medicinal resources, which points to the importance of conservation strategies. Understanding zp gives invaluable information about natural disease prevention and offers a foundation for sustainable healthcare solutions in both human and veterinary medicine.

Keywords: Bioprospecting, Drug Discovery, Wildlife Conservation, Natural Health Strategies.

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1. Introduction

Zoo pharmacognosy (ZP) is a science that investigates the self-medication activity of animals employing plants and other natural substances as a preventive measure or direct treatment to recover health in their natural environment. It is a fascinating concept that comes from the Greek words "zoo," meaning animal; "pharmakon," which translates to drug or remedy; and "gnosis," for knowledge. It describes the remarkable ability of animals to engage with their surroundings and tell the difference between harmful plants and those that can heal them. This research defies conventional anthropocentric perspectives of medicine and breaks new paths towards comprehending the evolutionary and ecological foundations of animal health management (Alamgir, 2017). Over the past few decades, researchers have been increasingly interested in this area as a result of observational and experimental research in different environments globally. Reported evidence of self-medication varies across taxa, such as primates, mammals, birds, insects, and even reptiles (De la Fuente et al., 2022). For example, monkeys are known to apply citrus oil and pungent raisins on their fur as insecticides and antiseptics to avoid insect bites. In the same way, elephants in East Africa consume leaves of trees belonging to the family Boraginaceae to initiate labour and for normal delivery of a calf, while ants and bees employ conifer resin as an antimicrobial to check the transmission of bacteria in the colony (DeFilipps and

Krupnick, 2018). Dogs and cats are also observed to ingest wild grass to induce vomiting. These behaviours probably developed over time, showing that animals have learned how to locate and utilise natural resources such as plants in order to remain healthy (Sueda et al., 2008). Its roots in ethnobiology and ethology, in which initial studies suggested a link between animal behaviour and traditional human medicine, both showing a dependency on natural medicines (Domínguez et al., 2020). It was not acknowledged as an independent area of research until the end of the 20th century, when scientists such as Eloy Rodriguez and Richard Wrangham paved the way with their research, which demonstrated how animals select food in accordance with its possible health effects. Their studies highlighted the interrelationship between the environment of an animal, its diet, and its health in general. This study opened doors for more advanced research on the ways in which animals employ self-medication (Lukovic et al., 2014). A key question of ZP research is whether or not animals have an inborn capacity to recognise medicinal sources or whether these are learned through experience or social learning. Evidence supports a combination of mechanisms, such as inborn talent, which is responsible for triggering some behaviours, e.g., the attraction of insects to antimicrobial resins or the consumption of bitter plants by cattle when sick. While social learning is essential in animals like primates whose young ones tend to copy the adults' foraging behaviour, thus gaining medicine knowledge (Shurkin, 2014). It is significant apart from knowing animals' behaviours and offers a useful model for bioprospecting and drug discovery. By examining the plants and materials selected by animals, researchers are able to detect new bioactive compounds of therapeutic value. This has already borne fruit, for example, with the identification of antiparasitic drugs found in plants consumed by chimpanzees. Additionally, ZP provides insights into sustainable veterinary and wildlife medicine practices that can aid in improving conservation as well as animal welfare (Atanasov et al., 2015). Though promising, the practice is challenged by a number of issues. It's usually hard to distinguish whether an animal is self-medicating or merely reacting to other requirements, such as food or shelter. In addition, environmental degradation, loss of habitat, and reduction in biodiversity of plant and animal populations undermine the basis of ZP. With ecosystems being disrupted, the animals can lose access to medicinal resources, which can compromise their survival and health (Davis and Choisy, 2024). ZP is an interesting crossroads of animal behaviour, ecology, and pharmacology that provides us with information on disease prevention and cure using natural methods. With expanding research in this domain, it can potentially enhance our knowledge of health and medicine for human beings and animals alike. It also calls for the conservation of the diversity of life on our planet and the preservation of healthy ecosystems (Costa-Neto, 2012). This review presents our current understanding of ZP, its major findings, challenges, and future studies. It has far-reaching implications in various fields such as pharmacology, ecology, ethology, and conservation. Through the investigation of self-medication in animals, scientists can learn about novel medicinal compounds, sustainable health care, and how species survive environmental changes. This narrative review delves into the evolution, processes, reported examples, and uses of ZP and its potential research for the future. **Figure 1** shows that ZP is a multidisciplinary field uniting animal behaviour, ecology, pharmacology, conservation, drug discovery, and sustainable veterinary practices.

2. Evolutionary and Ecological Significance of ZP

Global warming and environmental factors have a tremendous impact on animals' self-medicative activities/interactions. Although the context provided here doesn't explicitly explain self-medication in animals, we can use some relevant implications from the facts regarding the impact of climate change on ecosystems and animal behaviour. Seasonal cycles, habitat features, and the availability of resources have an essential impact on the availability of medicinal plants and minerals to animals. Climate change is shifting the timing of repeated biological cycles in plants and animals, which may result in phenological asynchronization (Lang et al., 2024). Moreover, shifts in temperature and precipitation regimes can alter plant community composition and distribution (Yang et al., 2011), which may change the presence and abundance of medicinal plants in certain habitats. Nevertheless, its projections rely on ecological niche modelling, which does not account for animal behavioural ecology or animals' interactions with medicinal plants. So, while it could be useful for predicting broad-scale shifts in habitats, the study is not robust enough because it does not consider the small-scale selective behaviours of ZP. On top of that, there exists a drastic gap in molecular validation of self-medication across different taxa. Many claims made about ZP, especially those dealing with vertebrates, tend to lean towards anecdote and observation rather than controlled genetic testing that would prove the pharmacological value of substances allegedly used. To make matters worse, this has been skewed by taxonomy bias, meaning a few primate species and some insects have been overrepresented in published works. Because of this disparity, cross-country comparisons are necessary for less-studied groups to validate their mechanisms and behaviours using sophisticated yoked studies and hypothesis-driven systems. Climate change and habitat loss can interfere with such interactions by multiple mechanisms. Climatic warming and changes in precipitation patterns can influence the growth of plants and thus, perhaps, alter the chemical composition and medicinal contents of plants (Polley et al., 2017). Droughts and floods can interfere with the availability of particular medicinal resources. In addition, habitat fragmentation and land-use change can restrict animals' access to varied plant communities, thus limiting their options for self-medication. The possible decline in animals' capacity for self-medication as a result of these environmental changes would have serious implications for their survival and health. As climate change continues to affect ecosystems, there might be a need to take into account the conservation of medicinal plants and habitats as part of conservation to preserve the fine balance between animals and their environment (Wang and Gu, 2021). Future studies need to address understanding how climate change influences the availability and effectiveness of medicinal resources for animals and developing ways to counteract these effects.

3. Mechanisms of Self-Medication in Animals

Animal self-medication is an intriguing phenomenon that involves the use of substances or materials for disease treatment, prevention or parasitic infection prevention. Self-medication occurs across many species and can be broadly classified into two types: innate and learned self-medication.

Innate self-medication involves genetically controlled behaviours that are not based on prior experience or learning. These actions are usually seen in all members of a species and are elicited by certain stimuli or physiological conditions. For instance, certain animals automatically eat some plants or drugs when they are sick or parasitised. This natural tendency is believed to have developed over time as a survival mechanism, enabling the animals to battle diseases and infection naturally without invoking conscious decision (Xiao et al., 2021). Alternatively, learned self-medication entails processes that are conditioned by experience, observation, or social learning. Animals can become conditioned to a certain substance or behaviour for the relief of a symptom or better well-being. This form of self-medication is more adaptive and versatile, enabling animals to react to new health threats or environmental adjustments.

Learned self-medication is subject to various factors, including personal experiences, social interactions, and cultural transmission among animal societies (Kim et al., 2017). The distinction between innate and learned self-medication is not always so absolute, since there are some behaviours that will incorporate both innate and learned elements. For example, an animal will have an innate tendency to seek out certain plants when it is sick, but the actual choices of plants and use may be honed by learning and experience. One intriguing feature of self-medication in animals is how neuromodulators play a role in governing these behaviours. Neuromodulators like biogenic amines, neuropeptides, and hormones facilitate signalling of the internal state change and the external environment of an animal. These chemical messengers can reorganise neural circuits so that animals can adjust their behavioural responses in accordance with their internal physiology and external environment. In self-medication, neuromodulators can affect an animal's sense of its own health condition and prompt it to find particular remedies (Kim et al., 2017).

Self-medication behaviours are mediated by different mechanisms in different species and according to the particular health problem. Some animals use sensory information, like taste or smell, to recognise useful substances. Some others might employ visual or touch information in order to identify and choose suitable materials to self-medicate. The immune system also might be involved in initiating self-medication activities, as those animals with weakened immune function would probably tend to participate in such activities (Silva and Gomes, 2017). It is noteworthy, however, that the study of self-medication in animals comes with several challenges. True self-medication and coincidental behaviours might be difficult to differentiate, particularly in free-living populations. In addition, the intricate interaction among innate predilections, learned behaviour, and environmental factors hinders the identification of the precise mechanisms underlying self-medication.

3.1 Neuromodulators Function in Physiological Regulation

The function of neuromodulators/chemical messengers like dopamine, serotonin, and octopamine in mediating internal state changes and directing adaptive behaviour is one of the more intricate and intriguing facets of self-medication. By linking certain substances to symptom relief, dopamine, a neurotransmitter linked to motivation and reward, may encourage self-medicating behaviours. For example, animals that consume a certain plant and feel less ill or uncomfortable may have higher dopaminergic activity, which encourages them to use the plant again. Depending on the animal's health, serotonin, which controls mood and perception, may alter taste and smell perception, affecting the animal's preference for certain plants. When animals experiment with new substances, their risk-taking behaviour may also be impacted by changes in serotonergic pathways.

Octopamine, a functional analogue of norepinephrine, is found in insects. regulates arousal and learning and is involved in behavioural changes during infection. For example, parasitised fruit flies (*Drosophila melanogaster*) show an increased preference for ethanol-containing food, a response thought to be mediated by shifts in neuromodulator levels (Chvilicek et al., 2020).

3.2 Plant Selection and Sensory Cues

When choosing and identifying medicinal substances, sensory perception is crucial: A bitter or astringent taste is used by many animals to identify alkaloids or other secondary plant metabolites. Chimpanzees, for instance, make facial grimaces when they chew bitter medicinal piths, indicating that they rely on taste to identify therapeutic substances (Chvilicek et al., 2020). Olfactory cues are frequently used by herbivorous mammals to recognise particular volatile organic compounds (VOCs) released by plants. It is possible to learn or naturally recognise these chemical cues. For example, when experiencing gastrointestinal distress, elephants have been observed to selectively browse specific leaves, potentially aided by the olfactory detection of bioactive compounds. In certain situations, visual characteristics such as the colour, shape, or fungal infection of the leaves (as in self-anointing capuchins) may help in recognising medicinal resources. In situations where animals roll or rub in specific substances (such as hedgehogs or birds self-anointing) to extract protective compounds, touch and texture may also be important.

4. Documented Cases of Self-Medication Across Taxa

Self-medication has been observed across diverse animal taxa, demonstrating that this behaviour is not limited to higher vertebrates but extends to insects, birds, and even reptiles. The methods used vary depending on the species and the environmental challenges they face, including parasites, infections, and dietary toxins. Table 1 documents some notable examples:

Table 1: Documented cases of self-medication across different animal species, detailing the plants used and their medicinal purposes.

S. No	Plant	Animals	Uses	Reference
1	Wild Grass	Dogs and Cats	To induce vomiting	Amillapalli et al., 2016
2	Berberry	Mountain wildlife: sheep, goat, donkey, cow, ox	Bone healing of limbs, bone fracture, internal and external injury	Khan et al., 2014
3	Leaves of *Croton megalobotrys, Datura innoxia* and *D. stramonium*	Chacma baboons	Stimulant activity	Mamillapalli et al., 2016
4	Vero commonia amygdalina of Compositae, i.e. bitter pith	Mahale chimpanzees	Anti-parasitic	Lozano, 1998
5	Leaves from the genus Aspilia (Compositae)	Wild chimpanzees	It has an anti-bacterial effect and is very useful against tumours.	Huffman, 1997
6	Fruits and leaves of *Balanites aegyptica*	Anubis baboons and Hamadryas baboons	To control schistosomiasis	Huffman 1997

7	Leaves of the Brazilian ash tree and the Carcassava tree	Female Muriqui monkeys	Increase estrogen levels in the body, thereby decreasing fertility.	Biser, 2006
8	The fruits of the Monkey's ear tree.	Female Muriqui monkeys	The plant contains a precursor to progesterone called stigmasterol, which increases the monkey's chance of becoming pregnant.	Biser, 2006
9	A tree of the Boraginaceae family from leaves to trunk	African Elephant	To give birth to a healthy calf	Mamillapalli et al., 2016
10	Citrus fruits, leaves and stems of *Piper marginatum* and *Clematis dioica*	Capuchin monkeys (Cebus capucinus)	To repel or kill ectoparasites	Baker, 1996
11	Bay foliage	Dusky-footed wood rats	Reduces the flea larval survival	Hemmes et al., 2002
12	Leaves of wild carrot	Starlings	Reduce the number of fowl mites used in nesting	Clark et al., 1985
13	Twigs of *Indoneeasiella aechioides*	red-wattled lapwing Vanellus indicus	Drove away a venomous snake from its nest	Mamillapalli et al., 2016
14	Milkweed	Monarch Butterfly	To protect their offspring from parasites	Abbott, 2014
15	Resin from conifers	Bees and Ants	Antimicrobial to prevent the spread of bacteria in a colony	Simone-Finstrom and Spivak, 2012
16	Holy basil	Calotes vesicolor	Anti-inflammatory, anti-convulsant, anti-spasmodic	Pandey and Verma, 2017
17	*Dracaena cantleyi* leaf	Orangutan	Anti-inflammatory and treat skin disease	Morrogh et al., 2017
18	*Adenopus abyssinicus* (whole leaves)	Gorilla, bonobo, chimpanzee	Expulsion of the parasite from the gut	Huffman, 1997
19	Roots of *Aeschynomene cristata*	porcupine	Reduced protozoal and bacterial load	Huffman, 2001
20	Roots of *Boerhavia diffusa*	Wild Indian boar	Antihelmintic	Huffman, 1997 and Kumar et al., 2024

21	Bark of *Ceriops candolleana*	Asiatic two-horned rhinoceros	To remove bladder and urinary tract parasites	Hubback, 1939
22	Roots of *Ligusticum porteri*	Wild Kodiak, Brown bear	Chew and rub on skin for irritation and to repel flies and parasites	Huffman and Vitazkova, 2007
23	Bark of *Holarrhena antidysentrica*	Indian bison	Anti-dysentric activity	Huffman and Vitazkova, 2007
24	Root of *Punica granatum* L	Pig	Expel tapeworms by the anti-cestodal property	Janzen, 1978
25	Leaf of *Tamarindus indica* L. and *Ficus carica L.*	Pregnant lemurs of Madagascar	Endoparasitic property and increase milk production	Shurkin, 2014
26	Freshly scraped bark of *Trattinnickia aspera*	White-nosed coatis (Nasua narica)	Vigorous rubbing on the fur for irritation and to repel flies and parasites.	Huffman, 1997

5.2 Veterinary Medicine and Wildlife Conservation

Knowledge of how wild animals self-medicate can actually shape veterinary practice and enhance the well-being of captive animals. The idea fits into the increasing acceptance of traditional animal health practices and their possible relevance to contemporary veterinary medicine. Research has revealed that different wild animals do practice self-medication, and in most cases, these involve using plants or other natural remedies to heal from diseases or enhance their well-being. This information can be most useful for zoological organisations, which are now keen on animal conservation and welfare (Beer et al., 2023). With the use of natural medicines and providing animals with access to drugs, zoos stand to improve the health of kept animals without overdependence on man-made medications. Local traditional ethnoveterinary practices, which usually employ plants, animals, and minerals in the management of animal disease, are of great value, as they offer indications of possible natural remedies (Singh et al., 2020). For example, in the Mediterranean, farmers traditionally employed local material to treat their animals, with plants being the backbone of folk-veterinary treatments. These ancient customs may be modified and implemented with captive wildlife, providing other treatments that might be less stressful and more natural for the animals. Incorporating animal self-medication knowledge and traditional ethnoveterinary medicine into contemporary zoological medicine can enhance animal welfare and conservation. This practice is consistent with the changing function of zoos as pioneers in wildlife conservation and welfare management (Beer et al., 2023). Through the provision of natural medicinal resources and the integration of traditional knowledge, veterinarians and animal caregivers can possibly promote the health of captive wildlife and minimise the use of synthetic medications.

6. Ethnomedicine and Traditional Healing

In the fascinating world of ethnomedicine, the way animals self-medicate has played a crucial role in shaping traditional healing practices among various indigenous cultures. Take the Adi women in northeastern India, for instance; they've been tapping into their rich local biodiversity for medicinal purposes for generations. They skilfully use plants from their diverse ecosystems, not just for nutrition but also for their healing properties. This deep-rooted knowledge highlights the strong connection between local biodiversity and human health, showcasing their remarkable understanding of species that hold both cultural and medicinal value (Kunwar et al., 2010). Similarly, in far-west Nepal, traditional healing methods are deeply intertwined with the use of medicinal plants, which are cherished not only for their healing abilities but also for their everyday applications. These age-old practices emphasise the significance of empirical knowledge gained from observing nature, including how animals care for themselves, which has ultimately influenced modern pharmacology and conservative approaches (Ma et al., 2015). Native American healing traditions have been shaped significantly by the natural behaviours of animals. These practices are deeply connected to spirituality, community, the environment, and the self, where grasping the biological activities of various organisms is essential to their healing methods. For instance, Tibetan ethnomedicine utilises poisonous plants, but only after they've been processed in ways inspired by how animals interact with these plants. This leads to a rich understanding and application of their medicinal properties (Bullitta et al., 2018). The relationship between ethnobiology and traditional medicine showcases a beautiful synergy, where cultural insights into animal self-medication are woven into sustainable and effective healthcare systems. These practices not only help preserve biodiversity but also enhance social-ecological resilience and cultural identities, providing valuable lessons for achieving broader global health and sustainability objectives.

7 Integrating ZP into Conservation Strategies

The integration of ZP into conservation strategies could enhance our understanding of wildlife behaviour and ecosystem interactions, contributing to more effective conservation practices. This approach aligns with the concept of animal agency discussed in Domínguez-Martín et al. (2020), which emphasises the importance of recognising animals as active participants in conservation and management. By studying how animals self-medicate, we can gain insights into their cognitive abilities, decision-making processes, and adaptive behaviours, all of which are crucial for developing more effective conservation strategies. Incorporating ZP into conservation efforts could also contribute to the development of novel treatments for wildlife diseases, aligning with the precision medicine approach discussed in Whilde et al. (2017). By observing and analysing the self-medicating behaviours of animals, researchers could identify potential natural remedies for various ailments affecting wildlife populations. This knowledge could be particularly valuable in addressing emerging epizootic diseases, which are identified as a significant threat to biodiversity conservation (Whilde et al. 2017). Due to a lack of case studies and real-world difficulties in field applications, its emphasis on customised treatment approaches in conservation biology is encouraging but mostly aspirational. Furthermore, the accuracy of self-medication observations varies greatly among taxa, even though incorporating ZP into conservation may reveal natural therapeutic agents. Many of these observations lack pharmacological or molecular validation and are instead anecdotal or correlational. Therefore, careful, species-specific research—ideally combining behavioural, ecological, and biochemical approaches—is necessary to translate these behaviours into practical medical interventions for wildlife diseases. Furthermore, the integration of ZP into conservation strategies could enhance our understanding of ecosystem services and the importance of maintaining biodiversity. As discussed in García-Llorente et al. (2018), the ecosystem service approach holds potential for more comprehensively integrating the social dimension into decision-making in protected areas. By recognising the medicinal value of certain plants and substances to wildlife, we can strengthen arguments for habitat protection and biodiversity conservation. However, implementing ZP in conservation strategies may face challenges similar to those encountered in other innovative conservation approaches. As noted in Fergus et al. (2024), which discusses the use of artificial intelligence in conservation, issues related to data quality, model accuracy, and logistical constraints may arise. Additionally, as highlighted in Redpath et al. (2015), conflicts over conservation efforts can be significant obstacles, and integrating new approaches like ZP may require careful consideration of various stakeholders' interests. To effectively integrate ZP into conservation strategies, a multidisciplinary approach would be necessary. Collaboration between wildlife biologists, ecologists, pharmacologists, and conservation practitioners would be essential to fully leverage the potential of ZP in conservation efforts.

8. Conclusion

ZP bridges animal behaviour, ecology, and pharmacology, offering critical insights into natural health strategies. It holds significant implications for conservation, drug discovery, and sustainable veterinary practices. However, the increasing threats of habitat destruction and climate change jeopardise the availability of medicinal resources for wild animals. Despite growing interest, several research gaps remain. There is a pressing need for controlled experimental studies to confirm self-medicative behaviours across species and for molecular analyses to identify and characterize the bioactive compounds selected by animals. Additionally, more cross-disciplinary research is required to explore the evolutionary drivers of these behaviours and their potential applications in human and veterinary medicine. Future research should focus on addressing these gaps to advance both ecological understanding and biomedical innovation.

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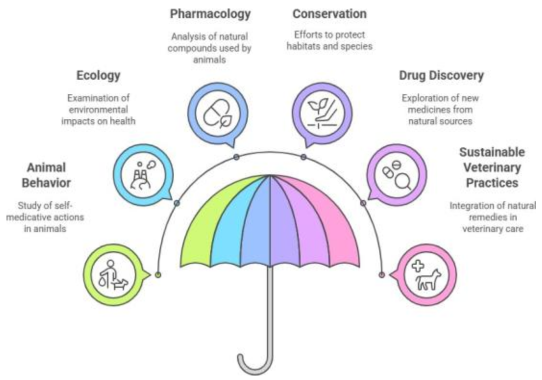

Figure 1. ZP as a multidisciplinary field uniting animal behaviour, ecology, pharmacology, conservation, drug discovery, and sustainable veterinary practices.