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OPINION
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Global Change and Conservation of Solitary Mammals

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INTRODUCTION

Here we argue that understanding the social system of species can help us to conserve them. Many endangered mammals are solitary living (Clutton-Brock, 2021). Here we show how understanding the constraints and the adaptive value of solitary living is important to understand how solitary mammals will be affected and can respond to the different aspects of global change. For example, solitary species might be more vulnerable to global change than sociable species as they miss benefits of living in groups that could mitigate change.

GLOBAL CHANGE IMPACTS BIODIVERSITY

Global change is a major threat to biodiversity (Pimm, 2009; Harley, 2011; Thornton et al., 2014). Anthropogenic-induced global change includes habitat loss (Galbraith et al., 2002), fragmentation (Fahrig, 2003), and climate change (Chapin et al., 2000), all of which are accelerating at a rate unprecedented in earth's history (Etterson and Shaw, 2001). While the factors causing global change are known, the speed and strength at which it occurs is still unsure and we do not know the way in which species will be able to cope and adapt to these changes. Global change occurs at an unprecedent rate and is expected to have severe impacts on ecosystems (Friedlingstein, 2008), decreasing biodiversity (Vitousek et al., 1997; Sih et al., 2011).

UNDERSTANDING THE SOCIAL SYSTEM OF SPECIES, INCLUDING SOLITARY ONES, CAN HELP US TO CONSERVE THEM

In order to overcome and slow biodiversity loss, we need studies informing conservation programs, including those on mammals. There are many ways to prevent the decline of mammal species. One of them is through understanding and analyzing behavior, because changes in behavior can allow for resistance toward change, and constraints on behavioral flexibility restrict resilience (Rymer et al., 2016). Animal social systems have always been a key subject in behavioral ecology as it gives us information about the mating system, the care system, the social organization and the social structure of species (Kappeler, 2019). These four components of social systems are interrelated and influence each other. This has revealed stunning interspecific diversity in the size, composition, and cohesion of social units, as well as in the patterning of reproductive skew, cooperation, and competition among their members (for mammals see Clutton-Brock, 2021). Within mammals, species display a wide variety of social systems ranging from solitary living in many carnivores, to pair-living in some primates, to groups in some species, such as elephants (*Loxodonta africana*) and marmosets (*Callithrix jacchus).* By understanding the social system of a species we are able to predict how a species will respond to global change, and how its responses will be constrained, important information to decide on the best conservation efforts for each species.

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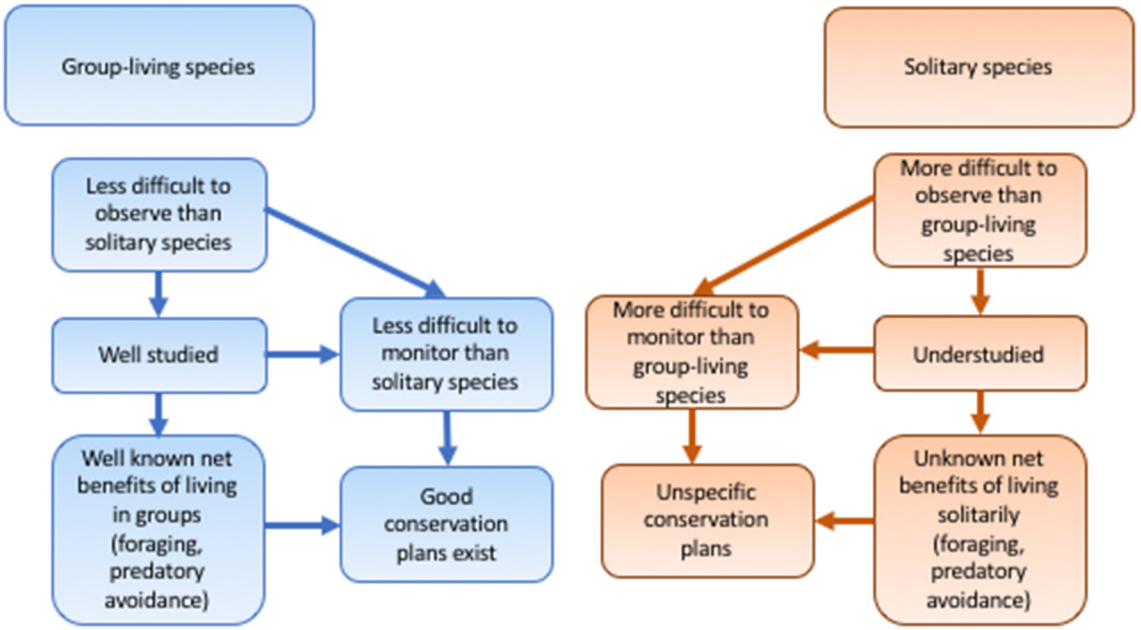

FIGURE 1 | While social species **(left)** are well-studied and understood with regards to their social biology, solitary species **(right)** are understudied. This is likely to affect the quality of species specific conservation plans **(middle)**.

SOLITARY SPECIES MISS THE BENEFITS FROM GROUP-LIVING AND MIGHT BE MORE VULNERABLE TO GLOBAL CHANGE THAN SOCIABLE SPECIES

Conservation efforts for solitary species might differ from those of group-living species. The social system of a species induces costs and benefits that are reliant on the environment, especially with regards to competition for resources (mates, food shelter), and how the social system impacts on predation risk (Kappeler et al., 2013). The net outcome of these costs and benefits will change when the environment changes. Species that live in groups might be buffered from these changes due to the benefits of group living, especially improved foraging and predator avoidance (Krause and Ruxton, 2002). The extent that solitary species show behavioral flexibility to cope with changes in resource availability and predation pressure is unknown, i.e., the extent that individuals can alter their behavior reversibly in response to changing environmental conditions (Gordon, 1991). This is why we need to study the behavioral flexibility of solitary species under varying environmental conditions to assess their vulnerability to global change (Huey et al., 2012). As solitary species miss the benefits from group-living they might be more vulnerable than sociable species.

ALLEE EFFECT AND SOLITARY SPECIES

The Allee effect describes a positive correlation between individual fitness and population density, with individuals benefitting from the presence of conspecifics (Allee, 1927). When living in groups, individuals can benefit from the Allee effect, by reducing predation pressure and gaining easier access to mating partners (Stephens and Sutherland, 2000). The Allee effect can thus be seen as a driving force behind animal spatial structure and sociality (Stephens and Sutherland, 2000). Due to climate change (obligate) sociable species might suffer from fitness costs induced by reduced group sizes. However, even solitary species might benefit from higher population density making it easier to find mating partners or reducing predation pressure (because predators have more prey to choose from), unless—as in sociable species—high population density increases intra-specific competition. Thus, so far it is unknown in how far the correlation between fitness and population density differs between sociable and solitary species, nor do we know at which population density positive Allee effects are overrun by negative effects of intra-specific competition. Therefore, in both sociable and solitary species the Allee effect should be taken into account when predicting how changes in population density induced by climate change affect extinction risk.

SOLITARY SPECIES MIGHT BE UNDERSTUDIED WHEN COMPARED TO SOCIABLE SPECIES

Solitary species might be understudied when compared to sociable species, especially with regards to their social behavior (**Figure 1**). First, for decades researchers rather studied sociable than solitary species as the focus of behavioral ecology was on the benefits of group-living and aspects like alloparental care (Clutton-Brock, 2021). Second, species that live solitarily

are often more difficult to observe as they are nocturnal and shy, live in dense habitat (many small mammals), or have huge home ranges (solitary carnivores). In addition, the fact that they live alone makes them more difficult to monitor (**Figure 1**). The combination of a research focus on sociable species and the discrete nature of solitary species explains why they are understudied with regards to behavior, their trade-offs (energy, resources, time), and how these trade-offs might change and affect their resilience under conditions of global change.

TO CONSERVE MAMMALIAN BIODIVERSITY, WE NEED TO UNDERSTAND WHY SOLITARY LIVING IS AN ADAPTIVE TRAIT

Six hundred and seventy nine of the 5,500 mammalian species are endangered (IUCN redlist) and many of them are solitary living. The first mammal that became extinct as a direct cause of climate warming was the solitary Bramble Cay mosaic-tailed rat (*Melomys rubicola*; Fulton, 2017; Waller et al., 2017). It became extinct because of an ocean inundation, i.e., high water levels and storm surges caused by an increased frequency of extreme weather events, which were caused by anthropogenic climate change (Waller et al., 2017). Other well-known examples of endangered solitary mammals that are threatened by climate change include polar bears (*Ursus maritimus*), snow leopards (*Panthera uncia*), tigers (*Panthera tigris*), and panda bears (*Ailuropoda melanoleuca*). It can be expected that many less well-monitored solitary small mammal species are threatened by climate change.

Many endangered species are solitary and thus understanding constraints and the adaptive value of solitary living is important to conserve them. The persistence of mammals being solitary living after *170* my of mammalian evolution (Rowe, 1988) indicates that it is an adaptive social system for many environments. To conserve mammalian biodiversity, we need to understand why solitary living is adaptive for many species. However, while for decades the costs and benefits of group living have been studied, it is not known what makes solitary living adaptive. Without knowing the costs and benefits of solitary living we will not know how the trade-offs that solitary species face will change with global change. At the moment, we do not even know which are their most restricting trade-offs, whether it is with regards to food, shelter, predation, or maybe finding mating partners.

AUTHOR CONTRIBUTIONS

C-AO, CS, and LM conceived of and wrote the manuscript. All authors approved the final manuscript.

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