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A Game-Theoretic Analysis of Cattle Ranchers and Government Strategies for Yaguarete conservation

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The Paraguayan Chaco is a natural landscape very important for the conservation of important populations of jaguars (Panthera onca) [3]. But the growing conflict between jaguar conservation and cattle ranching represents a major challenge in this region. The predation on cows implies ranchers facing economic losses, and consequently leading to its retaliatory killing. This and another anthropogenic factor are driven jaguars' population to the edge [7]. Retaliation hunting also disrupts the whole ecosystem balance and can trigger harder conservation regulations, both at the government level and in the meat-buying markets [4],[2]. At the same time, market trends increasingly penalize unsustainable commodities production practices pushing for more eco-friendly certifications. This ongoing conflict requires a strategic solution, specially regarding the extensive ranching models practiced in the Paraguayan Chaco, and the need to protect the livestock and the biodiversity conservation.

To this end, we model the payoff of each agent (rangers, and government) paying in the game and the replicator dynamics is implemented to model the games' dynamics. This yields to a nonlinear ordinary system of differential equations [1, 5].

We use a game-theoretic approach to explore possible equilibrium points, where both actors, the main stakeholders Ranchers, and the Government, can achieve a stable coexistence in this scenario. Ranchers can adopt cooperative strategies adopting non-lethal predator deterrents and participation in conservation programs, or non-cooperative strategies, including illegal retaliation hunting. The Government, acting the regulatory entity, can enforce environmental policies, impose sanctions for illegal killings, or offer economic incentives such a compensation for livestock losses and subsidies for avoiding predation infrastructure. The interaction between both actors creates a dynamic system where the balance between livestock production and jaguar conservation is constantly shifting [1].

Pure equilibrium situations include both strict government enforcement or complete government inaction, resulting in rancher resistance and jaguar population decline [6]. A more suitable solution lies in mixed strategy equilibria, with economic incentives that encourage ranchers to protect jaguars while maintaining livestock profitability. Adaptive policies, including market-driven incentives for jaguar-friendly beef production, selective enforcement, and targeted compensation programs, can create a dynamic equilibrium with benefits for both, ranchers, and government. This framework provides a strategic foundation for balancing economic viability with biodiversity conservation and, reducing long-term conflicts between productive sector and wildlife.

This is an on going work, and we observe that certain equilibrium points, which are the base of the actual governmental policy to conserve wild species, are unstable. Another, equilibrium points are more susceptible to change their nature (or making it more robust) by modifying their payoff by using external agents, such as the market, a new law or NGOs, to enhance cooperation to conserve wild jaguar.

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References

[1] R. Botta, G. Blanco, and C. E. Schaerer. "Discipline and punishment in panoptical public goods games". In: **Scientific Reports** 14.7903 (2024). DOI: 10.1038/s41598-024-57842-0.

[2] W. Jędrzejewski, R. Carreño, A. Sánchez-Mercado, K. Schmidt, M. Abarca, H. S. Robinson, E. O. Boede, R. Hoogesteijn, Á. L. Viloria, H. Cerda, G. Velásquez, and S. Zambrano-Martínez. "Human-jaguar conflicts and the relative importance of retaliatory killing and hunting for jaguar (*Panthera onca*) populations in Venezuela". In: **Biological Conservation** 209 (2017), pp. 524–532. DOI: 10.1016/j.biocon.2017.03.025.

[3] R. G. Morato et al. "Jaguar movement database: a GPS-based movement dataset of an apex predator in the Neotropics". In: **Ecology** 99.7 (2018), pp. 1691–1691. DOI: 10.1002/ecy.2379.

[4] A. Romero-Muñoz, R. G. Morato, F. Tortato, and T. Kuemmerle. "Beyond fangs: beef and soybean trade drive jaguar extinction". In: **Frontiers in Ecology and the Environment** 18.2 (2020), pp. 67–68. DOI: 10.1002/fee.2165.

[5] J. M. Smith and G. R. Rice. "The Logic of Animal Conflict". In: **Nature** 246.5427 (1973). DOI: 10.1038/246015a0.

[6] P. D. Taylor and L. B. Jonker. "Evolutionary stable strategies and game dynamics". In: **Mathematical Biosciences** 40.1 (1978), pp. 145–156. DOI: 10.1016/0025-5564(78)90077-9.

[7] J. J. Thompson, C. Martínez-Martí, and H. Quigley. "Anthropogenic factors disproportionately affect the occurrence and potential population connectivity of the Neotropic's apex predator: The jaguar at the southwestern extent of its distribution". In: **Global Ecology and Conservation** 24 (2020), e01356. DOI: 10.1016/j.gecco.2020.e01356.