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SPATIAL INSIGHTS FOR MANAGEMENT AND CONSERVATION OF ECOSYSTEM SERVICES AND BIODIVERSITY FOR A SUSTAINABLE FUTURE

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Fevereiro - 2020

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Orientador: Prof. Dr. Milton Cezar Ribeiro

Tese apresentada ao Instituto de Biociências do Câmpus de Rio Claro, Universidade Estadual Paulista, como parte dos requisitos para obtenção do título de doutora em Ecologia e Biodiversidade.

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To past, current and future generations.

Ao meu pai e à minha mãe,

à minha irmã e ao meu irmão,

aos meus dois preciosos sobrinhos.

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“in order to change an existing imagined order,

we must first believe in an alternative imagined order.”

Yuval Noah Harari

Sapiens: A Brief History of Humankind, p. 118

RESUMO

INFORMAÇÕES ESPACIAIS PARA GESTÃO E CONSERVAÇÃO DOS SERVIÇOS ECOSSISTÊMICOS E DA BIODIVERSIDADE PARA UM FUTURO SUSTENTÁVEL

Compreender como os padrões e processos da paisagem afetam a biodiversidade e os serviços ecossistêmicos (ES) – benefícios que as pessoas recebem da natureza – é fundamental para prever suas respostas às mudanças no uso da terra. Para avançar na pesquisa, desenvolver e fornecer informações espaciais apropriadas para as tomadas de decisão, utilizei modelagem e proposições teóricas para expandir o conhecimento sobre serviços ecossistêmicos, biodiversidade e o papel desempenhado pelos seres humanos na conservação da paisagem e seu manejo sustentável. No capítulo 1, considerando a teoria atual e as lacunas de conhecimento acerca de ES, eu propus um *framework* para entender melhor os efeitos da estrutura da paisagem no fluxo de ES, um dos componentes da cadeia de provisão de ES. Com base na literatura, discuti os efeitos da composição e configuração da paisagem nos fluxos de ES, de acordo com seus mecanismos. Enfatizei a necessidade de caracterizar a oferta, o fluxo e a demanda de cada ES, a fim de quantificar e abordar completamente os aspectos espaciais da provisão de ES. No Capítulo 2, identifiquei *hotspots* de biodiversidade usando Modelos de Distribuição de Espécies (SDM) baseados em clima e paisagem para indicar áreas prioritárias para conservação e aquelas ameaçadas por mudanças rápidas no uso da terra, impulsionadas pelo desmatamento e expansão agrícola. Os *hotspots* de biodiversidade representam as áreas com potencial para hospedar várias espécies-chave e, portanto, estas são regiões-chave para serem protegidas. A seleção das espécies e a interpretação dos resultados dos modelos foram realizadas para o Maranhão (um estado brasileiro), enquanto a coleta e modelagem dos dados foram realizadas para um limite ecológico mais amplo. Indiquei as áreas com maior sobreposição de *hotspots* de espécies e não abrangidas pelas áreas protegidas existentes como prioritárias para ações de conservação. Reconheci a necessidade urgente de monitorar áreas com expansão agrícola. Por fim, concluí a tese com uma síntese das principais contribuições, recomendações para futuras pesquisas e uma reflexão sobre as lições aprendidas durante o desenvolvimento do meu doutorado.

PALAVRAS-CHAVE: estrutura da paisagem; fluxo de serviço ecossistêmico; área prioritária para conservação; modelo de distribuição de espécie; Maranhão; sustentabilidade

ABSTRACT

SPATIAL INSIGHTS FOR MANAGEMENT AND CONSERVATION OF ECOSYSTEM SERVICES AND BIODIVERSITY FOR A SUSTAINABLE FUTURE

Understanding how landscape patterns and processes affect biodiversity and ecosystem services (ES) – the benefits people receive from nature – is fundamental to predict their responses to land use change. To advance research, develop, and deliver appropriate spatial information for decision-making, I used models and theory to expand the knowledge about ecosystem services, biodiversity and the role played by humans in landscape conservation and sustainable management. In Chapter 1, taking into account the current theory and knowledge gaps related to ES, I proposed a framework to better understand the effects of landscape structure on the flow component of the ES supply chain. Based in the literature, I discussed the effects of landscape composition and configuration in the ES flows, according to their mechanisms. I emphasized the need to characterize the supply, flow and demand of each ES in order to quantify and thoroughly address the spatial aspects of ES provision. In Chapter 2, I identified biodiversity hotspots using climate- and landscape-based Species Distribution Models (SDM) to indicate priority areas for conservation and those areas threatened by fast land use change driven by deforestation and agriculture expansion. Biodiversity hotspots allowed the recognition of areas with the potential to host several key species and, therefore, those are key regions to be protected. The selection of species and the interpretation of model outputs were conducted for Maranhão, a state in Brazil, while data collection and modelling itself were carried out for a broader ecological boundary. I indicated the priority areas to be conserved as those with higher overlap of species hotspots and not encompassed by existing protected areas. I recognize urgent need to monitor areas with agriculture expansion. Lastly, I concluded the thesis with a synthesis of the main contributions, recommendations for further research and a reflection on the lessons learned during the development of my PhD.

KEYWORDS: landscape structure; ecosystem service flow; priority area for conservation; Species Distribution Model; Maranhão; sustainability

RESÚMEN

INFORMACIÓN ESPACIAL PARA GESTIÓN Y CONSERVACIÓN DE LOS SERVICIOS DE ECOSISTEMAS Y DE LA BIODIVERSIDAD PARA UN FUTURO SOSTENIBLE

Comprender cómo los patrones y procesos del paisaje afectan la biodiversidad y los servicios del ecosistema (ES) – los beneficios que las personas reciben de la naturaleza – es fundamental para predecir sus respuestas al cambio en el uso de la tierra. Para avanzar en la investigación, desarrollar y entregar información espacial apropiada para la toma de decisiones, utilicé modelos y teoría para expandir el conocimiento sobre los ES, la biodiversidad y el papel que juegan los humanos en la conservación del paisaje y su gestión sostenible. En el Capítulo 1, teniendo en cuenta la teoría actual y las brechas de conocimiento relacionadas con los ES, propuse un marco para comprender mejor los efectos de la estructura del paisaje en el componente de flujo de la cadena de provisión de ES. Con base en la literatura, discutí los efectos de la composición y configuración del paisaje en los flujos de ES, de acuerdo con sus mecanismos. Destaqué la necesidad de caracterizar la oferta, el flujo y la demanda de cada ES para cuantificar y abordar a fondo los aspectos espaciales de la provisión de ES. En el Capítulo 2, identifiqué los puntos críticos de biodiversidad utilizando los modelos de distribución de especies (SDM) basados en el clima y el paisaje para indicar áreas prioritarias para la conservación y aquellas áreas amenazadas por el cambio rápido del uso de la tierra impulsado por la deforestación y la expansión de la agricultura. Los puntos críticos de biodiversidad permitieron reconocer las áreas con el potencial de albergar varias especies clave y, por lo tanto, las regiones clave a proteger. La selección de especies y la interpretación de los resultados del modelo se realizaron para el estado brasileño de Maranhão, mientras que la recolección de datos y el modelado en sí se llevaron a cabo para un límite ecológico más amplio. Indiqué las áreas prioritarias a ser conservadas como aquellas con mayor superposición de puntos críticos de especies y no abarcadas por áreas protegidas existentes. Reconocí la necesidad urgente de monitorear áreas con expansión agrícola. Finalmente, concluí la tesis con una síntesis de las principales contribuciones, recomendaciones para futuras investigaciones y una reflexión sobre las lecciones aprendidas durante el desarrollo de mi doctorado.

PALABRAS CLAVE: estructura del paisaje; flujo de servicio ecosistémico; área prioritaria para la conservación; modelo de distribución de especie; Maranhão; sustentabilidad

SUMMARY

BACKGROUND

Humanity is a pervasive species that managed to reach every corner of the planet. Even if there were hidden, or unexplored venues, if any of us acknowledges its existence, one could argue it does not exist at all.

Nature and Conservation

Conservation is a human action – be it to protect nature from humans or to spare it for humans themselves. Mace (2014) provoked this debate by showing the changes over time of conservation goals and the science underpinning them. According to her, for some decades, conservation science was targeted at sparing pristine natural assets from human interference. The Anthropocene has come to shift that framing into a more integrative one, in which people are viewed as part of nature. Thus, science has had to dive into human-nature relationships and envision their sustainable co-existence (Johnson et al., 2017). The complexity of social-ecological systems, once we frame people and nature together (i.e. a biocentric worldview), demands further collaboration between social and natural sciences (Bennet et al. 2015). So far, sustainability has evolved as the most promising idea to guide us into the future.

Sustainability

Science has managed to evolve the concept of sustainability since the 1980's (Sartori et al., 2014), however, its conversion into practice is yet to be broadly incorporated by humanity (Purvis et al., 2019). Strong sustainability argues that our "finite planet cannot sustain human life with an economy that intends unlimited growth" (Morandín-Ahuerma et al., 2019). Also, sustainability relies on consumption behavior that do not deteriorate ecosystems and leads to social equity (Morandín-Ahuerma et al., 2019). Having economic values over culture is driving humanity past planetary boundaries. In great effort to reverse this trend and rethink human activities, the Sustainable Development Goals (SDG) were proposed to guide human actions towards a sustainable future (UN, 2016), addressing human population growth, the role of economy in serving us (and not otherwise), greenhouse gases emissions, pollution, biodiversity loss and the spread of invasive alien species, among several other goals (Griggs et al., 2013; Morandín-Ahuerma et al., 2019; Ripple et al., 2017). Changing and adjusting our societal, institutional and individual behaviour towards sustainable habits is the way forward to guarantee nature's limits are not surpassed (Griggs et al., 2013; Rockström et al., 2009).

Science Goals, Economic 'Rules' and Political Decisions

If we could evaluate the positions and responsibilities assumed by scientists, economists and politicians in human societies, we could find that scientists are usually engaged with facts and knowledge derived from sound scientific analysis (Bradford, 2017); while economists are mostly driven by people's behaviour and choices in different contexts (Guerry et al., 2015); and politicians would search for ways to please those who have the power to keep them in power and prioritize decisions based on public opinion (i.e. populism; Dal Bó et al., 2017).

Who rules the world? I wish the answer was "Girls", but we are not there yet. Instead, most nations have political leaders that respond to international markets and aim at economic growth. Rarely, governments main goals are to promote equity and pay off historical debts towards unprivileged groups. Even more unexpected is to have politicians that fight historical privileges. And even when parts of society disagree with politicians' behaviour, very little can they do to demand changes. Recently, however, participatory approaches have emerged to give voice to different groups interested in a matter so that decisions and plans could address diverse interests (Arnstein, 2019). Yet, most decisions still rely on economic profit over environmental viability, and the two overrule social justice. Building a dam that harms indigenous communities, building a road that passes over a low-income neighborhood, undertaking new mineral exploitation and annulling a protected area for that: these are political decisions, pushed by economic pressure from private companies in detriment of less privileged communities. This is how the world works.

Should scientists become politicians, should economists remember they are social scientists, or should politicians become extinct? Integration among social, environmental and economic sciences are leading the way towards better decision-making (Guerry et al., 2015). From the science perspective, bridging the gap between science and society and the gap between theory and practice can put humanity on the sustainability path (Griggs et al., 2013). The role of scientists in overcoming the gap between science and policy has usually been performed as translating scientific discoveries to decision makers. Decades have passed to prove this is not enough. Communicating scientific advances to the general public and discussing the social implications of research outcomes has recently begun to be one of the scientist's duties (Dickson, 2010). Scientists have the power to go further and have stakeholders be part of the construction of knowledge since the beginning: from the conception of a research project to its closure (Elena M Bennett et al., 2015). Therefore, engaging with on the ground practitioners, NGOs, communities, and any other groups of interest has been explored through participatory approaches (Angelstam et al., 2019a) and the co-production of knowledge "to ensure that interventions and policies have appropriate impact and can operate across multiple temporal and spatial scales" (Elena M. Bennett et al., 2015).

The Ecosystem Service Framework

The concept of Ecosystem Services (ES) emerged in line with the concept of strong sustainability, which primarily claims the non-substitutability of natural capital (Ekins et al., 2003), and the creation of a shared vision of what a sustainable society would actually look like (Costanza et al., 1997). It derived from Westman's (1977) idea of nature's services and was later coined as ES by Ehrlich and Ehrlich (1981). Despite some variation in the concept, ES has drawn attention to the benefits that ecosystems generate for humans (Costanza et al., 1997; Daily et al., 1997; De Groot et al., 2002). Such benefits, that sustain and fulfill human life, result from the interactions among living and non-living elements of the ecosystems and human-engineered components of social-ecological systems (Daily et al., 1997; Guerry et al., 2015). More than that, the concept of ES "provides a valuable framework to define and analyse linkages and dependencies between natural and human systems" (Burkhard et al., 2010).

Biodiversity plays a pivotal role for ecosystem functions maintenance, and therefore, for ES provision (Harrison et al., 2014). Boosted by the relevance of biodiversity and ES for the human wellbeing, some notable initiatives spread out to society the outlook of the challenging paradigm of sustainability: the Millennium Ecosystem Assessment (MA, 2005), The Economics of Ecosystems and Biodiversity (TEEB, 2010) and the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES, 2012; see Box 1 for more information). All of them converged in the combination of economy, ecology and society for the sustainable stewardship of natural capital (Angelstam et al., 2019a). The integration of participatory methods to improve ES frameworks, in a variety of social contexts, has proven to enhance social learning, build capacity and trust as well as work as a tool to mediate power relations (Davies et al., 2015). In the local level, it can offer an alternative source of income via Payment for Ecosystem Services(PES; Wang et al., 2017). Another advantage in the use of ES frameworks is that they can be used to evaluate progress towards sustainability (to monitor the SDGs and the Aichi Targets; CBD, 2010), by monitoring the state and trends of ES provision and biodiversity (Geijzendorffer et al., 2017).

Box 1: Main international initiatives that spread out to society the challenges in the pursuit of sustainability.

MA – Millennium Ecosystem Assessment (MA, 2005)

The first comprehensive global assessment of the implications of ecosystem change for human wellbeing. It can be also considered the scientific basis for action needed to enhance the conservation and sustainable use of those systems and their contribution to people. ES are grouped into a) provision (e.g., food and water supply), b) regulation (e.g., climate regulation), c) cultural (e.g., recreational, spiritual activities), and d) support (e.g., photosynthesis). All these services performed for free by ecosystems are widely assumed to contribute to poverty alleviation and the degradation of these services is also assumed to result in negative effects on human wellbeing (Tallis et al., 2008). In this sense, a fully developed economics should routinely incorporate the value of ES into its analyses (Chapin et al., 2010; Polasky, 2012).

TEEB – The Economics of Ecosystems and Biodiversity (TEEB, 2010)

Five years after the MA a new global initiative emerged, TEEB, which focused on "making nature's values visible". Its principal objective is to mainstream the values of biodiversity and ES into decision-making at all levels. It aims to achieve this goal by following a structured approach to valuation that helps decision-makers recognize the wide range of benefits provided by ecosystems and biodiversity, demonstrate their values in economic terms and, where appropriate, suggest how to capture those values in decision-making.

IPBES – Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES, 2012)

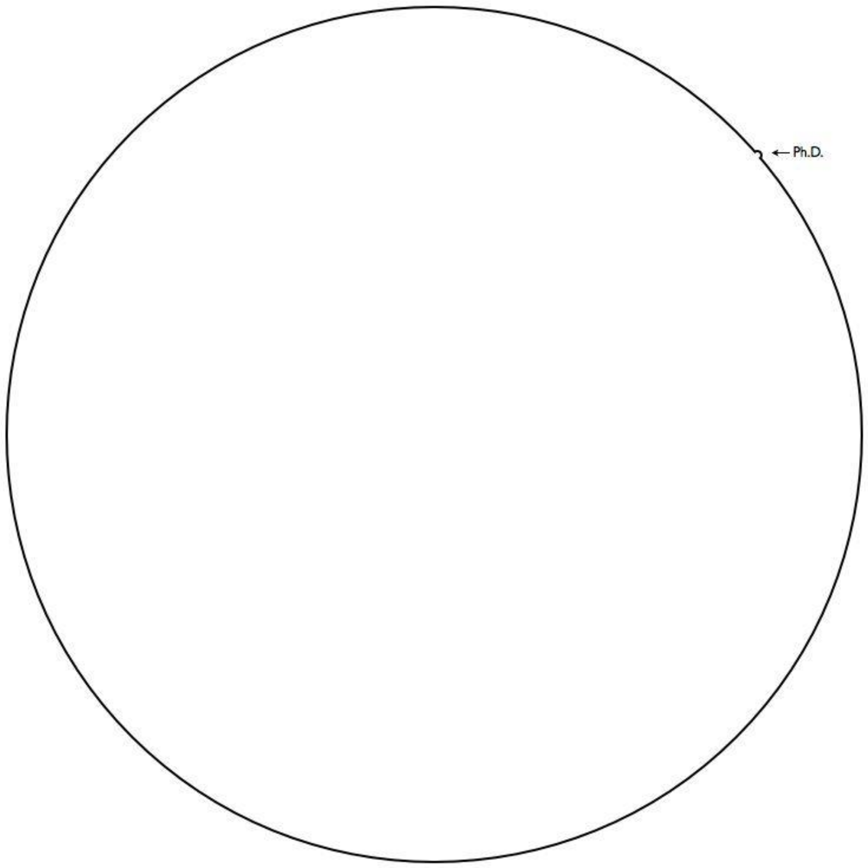
Despite the complexity of ES identification, quantification and valuation advances in data acquisition, methods and technology regarding ES approach have been consistent since the MA (Guerry et al., 2015). The next step requires the inclusion of such advances in the implementation of action plans, management and policies.

The IPBES was proposed as a mechanism to further strengthen the science-policy interface on biodiversity and ES. IPBES contributes to existing processes that ensure that decisions are made on the basis of the best available scientific information on conservation, sustainable use of biodiversity and ES. It was established in 2012 as an independent intergovernmental body open to all member countries of the United Nations. The members are committed to building IPBES as the leading intergovernmental body for assessing the state of the planet's biodiversity, its ecosystems and the essential services they provide to society. More recently, they incorporated the concept of Nature's Contributions to People (NCP) to broaden perspectives about the relatioships between people and nature and include different worldviews (Díaz et al., 2018).

Spatial Planning Matters

Spatial planning provides the basis for the development and implementation of good governance by integrating legal, economic, social, and rights-based instruments (Albert et al., 2020). It provides the on-the-ground link for economic, social and environmental policies. Furthermore, the use of spatial instruments in decision making across scales emerges as a powerful tool to balance diverse interests (Angelstam et al., 2019a) and promote the engagement of stakeholders in planning decisions (Albert et al., 2020). One of the challenges highlighted by Albers et al. (2020) to target biodiversity and ES in spatial planning is having spatial information in appropriate resolution for multiple scales (i.e. different spatial resolution and extents of influence; Jackson and Fahrig, 2015). Besides, understanding how landscape patterns and processes affects biodiversity and ES is key to predict their responses to land use change and deliver appropriate spatial information (Jones et al., 2013). The inclusion of ES and biodiversity as targets in spatial planning requires not only tools capable of analysing trade-offs (Jones et al., 2013) and dealing with power asymmetries (Reed et al., 2017), but also a deeper understanding of how landscape patterns affects both of them (Jones et al., 2013).

Ruckelshaus et al. (2015) listed some lessons learned from 20 cases of application of biodiversity and ES information in decision-making. Among them, they recognized that creating a mutual understanding of ES and biodiversity-related information in an iterative science-policy process increases credibility and legitimacy of information to support decisions, despite being time consuming (Ruckelshaus et al., 2015). They also indicate that engaging with stakeholders to know what they need and empowering local experts enhance credibility and ownership of ES models and information resulting in effective contribution for the decision-making process (Ruckelshaus et al., 2015).



Keep pushing.

Matt Might[1]
The Illustrated Guide to a Ph.D.[2]

[1] http://matt.might.net/ Accessed in Jan/2020.
[2] http://matt.might.net/articles/phd-school-in-pictures/ Accessed in Jan/2020.

CONTRIBUTIONS AND RECOMMENDATIONS

"Everything always changes and nothing remains still…
…you cannot step twice into the same stream"
Heraclitus of Ephesus (535 BC–475 BC)

Step Out of the Science Sphere and Bridge the Theory-Practice Gap

Shifting the current economic paradigm towards the sustainability ideals has emerged as a promising venue to ensure wellbeing for the increasing human population, without surpassing the planetary boundaries. Since their proposition in 2015, the Sustainable Development Goals (SDGs) have been debated and advances have been made to address their interdependencies and overlaps (Nilsson et al., 2016). Efforts to operationalize the 2030 Agenda on Sustainable Development (UN, 2016) and avoid perverse trade-offs indicate that coordination across sectors, societal actors and among different income countries is key (Stafford-Smith et al., 2017). The implementation of such transformative agenda takes place in diverse local contexts under the lead of national governments.

Science may have a significant contribution for action to take place, by designing innovative strategies to transform and monitor the outcomes of current and new practices (Sachs et al., 2019). Successful accomplishment of these tasks depends on scientists' engagement with real world events and on-the-ground practices. For the natural scientists concerned with biodiversity conservation, in the words of van der Leeuw (2018), "we must now go a step further and finally acknowledge that the real sustainability challenge is societal, not environmental." This can be interpreted by natural scientists as an invitation to join forces with social scientists to anticipate and prepare societies for the changes to come. Positive transformation can result from acknowledging and understanding these changes; informing societies and stakeholders; communicating to the general public; developing innovative solutions; securing adaptive capacities for governance; and strengthening societies' resilience.

Contributions to the Field

The sustainability paradigm requires a general understanding of current and future human impacts on the planet, so that we have the chance to adapt and avoid undesirable outcomes. Hence, planning the use of the space, in the form of environmental or landscape planning, it is possible to reach better outcomes if it is based in the understanding of spatial processes and patterns. Spatial science has evolved along with processing capacities of computers and high-quality data availability. It has improved the way several scientific disciplines address the complex issues faced by socio-environmental systems in local, regional and global scales. Taking all into account, advances in this field has increasingly provided reliable spatial information for decision-makers and stakeholders.

Nonetheless, science is not the solution to all problems. Much on the contrary. Despite all the elucidation on the consequences of biodiversity loss and ecosystems degradation to the provision of ES and human wellbeing, many other *forces* influence decisions towards the unsustainable use of land and overexploitation of resources worldwide. Therefore, sound science is not enough to ensure humanity will choose the promising paths for a sustainable future. Many of the humanity's possible future trajectories will take their course in spite of scientific warnings and discoveries. Yet, in the brief history of humans inhabiting the planet, drastic turning points can always be triggered by scientific innovation (e.g., navigation capacity; medical advances; technological development). Therefore, it is important to recognize that science and knowledge have a role to play in the course of history, "but we are no different from other citizens in society, except that we have been trained in a particular way of thinking that is as relevant to the dynamics of society as any other" (van der Leeuw, 2018).

In a general view, my PhD research and all the challenges faced along with it, contributed to my formation as a scientist and widened my perspective and understanding of the current endeavours towards a sustainable future. I developed both chapters presented here motivated by the potential of ES frameworks in raising awareness about the benefits humans get from biodiversity and nature. I defined the two main chapters of this thesis and my participation in other academic activities with the main goal of using the ES concept potential to connect environmental, social and economical spheres in a common language. It was very challenging but very gratifying at the end. This connection can be explored in the ES framework by quantifying, mapping, valuing and communicating. On pursuing this venue, I realized how challenging it was. First, because it is a consolidating field, in which concepts and tools are being tested. Second, because even though divergent and confronting ideas enrich the scientific debate, they can also undermine the consolidation of practices.

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