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Integrating circular economy in urban Amazon

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The Amazon hosts a large biological and cultural diversity with a deeply established knowledge of natural resource management. Nevertheless, many parts of the Amazon are increasingly urban, lacking basic urban services, such as waste management. In this context, the design of new development pathways based on the principles of the circular economy is a promising alternative to align biodiversity conservation and urban changes. Here, based on an analysis of Carauari municipality in the western Brazilian Amazon, we discuss how the principles of the circular economy can be integrated in the Amazonian urban development frontline using the existing co-management organizations.

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INTRODUCTION

Despite the vastness of the largest tropical forest on Earth, many parts of the Amazon are inherently urban, and not necessarily sustainable. For example, while 57% of the population of the Brazilian State of Amazonas was urban in 1980, this jumped to 78% by 2010[1]. Nevertheless, the State of Amazonas has dismaying levels of accessibility for some basic urban services. In 2018, 80% of the urban population had access to treated water, but only 10% had sewage systems[2]. In the same year, the collection of solid waste reached 63% of the entire population, but separation at source for recyclable materials was available only in 11% of the municipalities. Some 86% of municipalities sent their waste to be dumped in open landfills[3]. The region is also characterized by many small informal urban settlements spreading along with the vast network of rivers.

In this essay, we discuss the possibilities available to ensure a more sustainable pathway for urban Amazon via the principles of circular economy (CE), by analyzing opportunities for improving solid waste management through the re-use of by-products of natural resources used in the value chains. The CE framework can be key to biodiversity conservation and urban management conciliation with local well-being. There are several reasons for this. First, the remoteness of some small urban communities, added to the lack of roads and transport systems, makes traditional waste collection and disposal systems difficult to implement in the Amazon. Second, the low population density in most of the Amazon leads to high costs for waste management systems in a region that lacks the financial resources to pay for them. Third, much of the waste contains materials potentially valuable as inputs in biodiversity-based productive activities, as the import of certain materials is both costly and time-consuming. Fourth, the region has a number of communities organized for the commercialization of a variety of products in the different local and global value chains that could build the social and organizational infrastructure required to operate CE initiatives. Finally, as the region modernizes and urbanizes, allied to lack of basic urban services, there is the likelihood that the generation of large quantities of waste will threaten the pristineness of the region, and so bring further powerful threats to its biodiversity. Accordingly, CE models to integrate urban policies, waste management and agro-extractive activities are urgently needed in the Amazon region.

Here, we present the concepts associated with a CE framework, which can be strengthened by incorporating many of the co-management initiatives already present in various value chains in the region. This approach can be used to connect the production of local goods and the generation of waste to the implementation of a CE strategy in small urban centers. We studied an example of an emerging system of CE in the municipality of Carauari, which borders the Juruá River in the western part of the Brazilian Amazon, a conservation hot spot where a series of promising CE and co-management initiatives have occurred. These could serve as models for the development of similar programs in other parts of Amazon.

CE AS A MEANS OF SUSTAINABLE URBAN DEVELOPMENT

CE has become an important concept to identifying solutions for sustainability, which can contribute to making urban development more sustainable, and so enhance the protection of the environment[4]. In this sense, CE can make economic activities more efficient and sustainable by facilitating the integration of productive chains and changing the current linear economic model, based on extraction, production, use, and disposal[5,6]. CE aims to recognize waste in one sector as potential sources of raw materials for other sectors, which may contribute to the elimination of unwanted waste and add value to productive activities[7,8].

The concept of CE has emerged as a means of conciliating the pressures from production systems on the environment and the consumption of natural resources[9,10]. CE is defined as a way to turn goods that are at the end of their service life in one sector into resources for others, closing loops in industrial ecosystems and minimizing waste[10]. The CE is presented both as a restorative and regenerative principle. Its goal is to keep products and materials at their highest possible level of utility and value by distinguishing their technological and biological cycles (Fig. 1). This allows the CE to address the challenges related to resource

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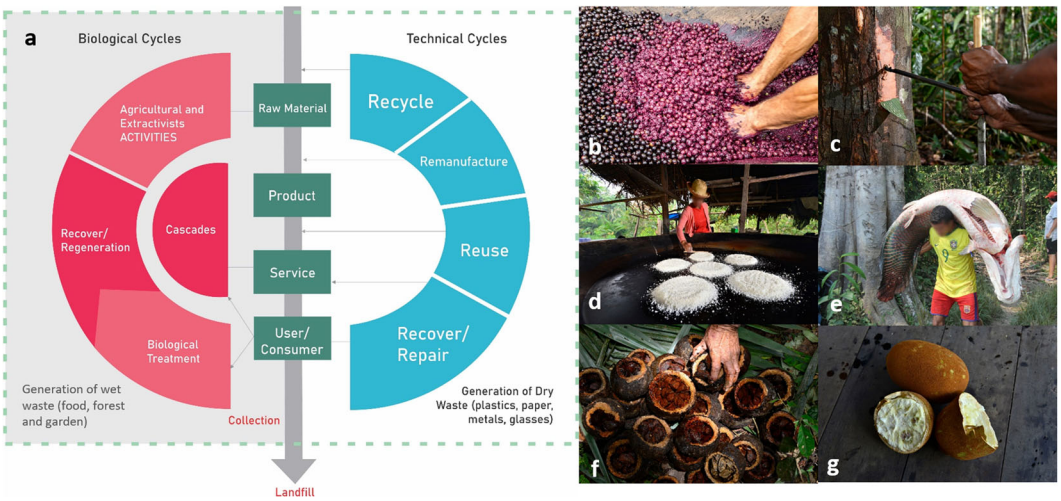

Fig. 1 Livelihoods and waste production in Amazonia. a Potential for integration between organic waste recovery and production and consumption activities in the Amazon and biodiversity-based value chains; **b** co-management of Açaí palm (*Euterpe oleracea*) fruit; **c** co-management of Copaíba (*Copaifera langsdorffii)* oil; **d** production of cassava flour; **e** co-management of arapaima (*Arapaima gigas*); **f** co-management of Brazilian nut (*Bertholletia excelsa*); and **g** cupuaçu (*Theobroma grandiflorum*) fruit. Photos: **b** Hugo Costa, **c**, **d**, **f**, **g** Adriano Gambarini/OPAN, **e** Carlos Peres.

availability and management, while also enabling the generation of economic growth, job, and income creation while, at the same time, reducing environmental impacts and externalities, including climate change[5,10,11]. CE in urban areas also avoids pollution of soil and rivers, which can threaten certain species. Thus, it complements other strategies for biodiversity conservation, such as the creation of protected areas.

In the CE framework, losses are "excluded from the outset", and the waste that cannot be reduced in a production process must be viewed and transformed into raw materials and resources. Biological materials that are nontoxic can be returned to the soil by composting or anaerobic digestion or directly reused by associated cascade processes in other productive sectors. Artificial materials—polymers, glass, metal, and other materials created by man—can be recovered, refurbished, and upgraded, so minimizing the amount of energy required for the system to operate, while maximizing value retention[12–14]. The Amazon has tremendous opportunities to strengthen the CE in small urban centers, as well as presenting many challenges. Transport is expensive and time-consuming, and distances are often great so that making the maximum use of resources becomes essential for minimizing costs. On the other hand, there are challenges to establishing the organizational arrangements for the CE model, since state presence is often light, technical support frequently scarce, and waste management logistics complicated. Thus, the utilization and strengthening of existing organizational models and capacities in other activities are key for managing the CE initiatives.

CO-MANAGEMENT: THE SEED FOR A CE

Worldwide, protected areas represent the main approach for conserving and protecting biodiversity and local livelihoods[12,15]. However, shortages in human resources and funding often threaten and weaken the Brazilian protected area system[13,14], therefore, the creation of new of conservation and local development pathways is imperative. Formal partnerships with communities in small urban centers, such as co-management arrangements, represent a promising alternative for ensuring the alignment between conservation of biodiversity and local well-being, increasing local governance, decentralizing decision making and reducing conservation costs[16].

Co-management of natural resources is widely implemented in different regions of the Amazon. There is a vigorous discussion on the effectiveness of co-management to achieve tangible outcomes for conservation and local development, considering that some examples can also result in conservation failures due to the asymmetry between the finite resource supply and the expansion of high-impact technologies to satisfy the increasing social demands[17]. This raises concerns, especially for slow-growth hardwood species[18], and low-fecundity game species[17], which can be harvested only until resource depletion. However, there are some well-recognized principles that can ensure cohesive arrangements toward successful community-based initiatives, including strong leadership, social capital, well-defined boundaries and explicitly formulated regulations[19–21].

Brazilian Amazon hosts some successful examples of co-management, which have ensured strong ecological benefits, including the conservation and population recovery of many overexploited high-value species through territorial protection operated by local communities, many located in small urban centers[22–26]. At the same time, co-management has also ensured a large set of social benefits, including income generation, reduction of gender inequality, cultural maintenance, and increasing of social organizations and self-esteem of local communities[13,22,27,28].

In this context, co-management arrangements emerge as a promising conservation-development strategy integrating the bioeconomy and strengthening the social rights of traditional communities[14]. Using this perspective, a great variety of products derived from Amazonian biodiversity are commercialized, generating income for small urban centers, ensuring the local protection of nature, and providing income to communities[29]. Well-established examples include the co-management initiatives of aquatic resources[22,26], and non-timber forest products, such as palm fruits, oils, seeds, nuts, among others[30].

Co-management of natural resources presents an opportunity in waste management[3]. The majority of waste (~90%) from agro-extractive industries and communities in small urban centers is organic[31,32], and the integration of existing value-chains and the CE framework can provide a strong tool for achieving local development and sustainability (Fig. 1). In this framework, all organic waste (and nontoxic nonorganic material) can be reused directly (via cascade methods) in the municipalities where it is generated, as well as treated and reused in the small urban centers themselves, or productive industries around them. Direct reuse could occur via mulching, which is a well-established agricultural technique used to cover the exposed soil with organic

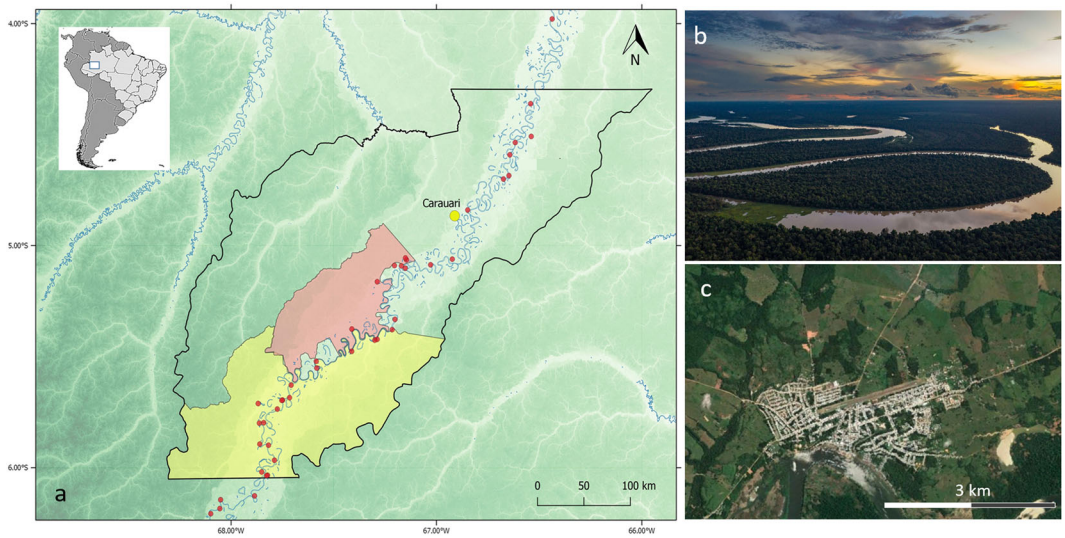

Fig. 2 Juruá River: a bright spot on co-management of natural resources. a Juruá River, a major tributary of Amazonian River where local communities are starting to integrate the co-management arrangements through circular economy principles. Solid black line indicates the boundaries of Carauari municipality; yellow and pink polygons represent two sustainable-use protected areas, Sustainable Development Reserve of Uacari and Extractive Reserve of Medio jurua, respectively; **b** aerial photo of Juruá river; and **c**) urban environment of Carauari. Photo: Marc Latzel.

matter, such as leaves, sticks, and pieces of wood, for nutrition, fertilization, and enrichment of the soil, as well as for recovering and regenerating degraded areas. There is also the possibility of waste treatment through composting and anaerobic digestion, which could produce compost for agricultural production and/or biogas and energy[7,11], in addition to certain waste types that can be processed for the production of animal feed, which can be used as food for the growing aquiculture markets[33].

Dry and recyclable waste can have other destinations when repair and reuse are not possible in communities. Some operations, such as selective collection, reverse logistics, and recycling, are best operated by municipalities, states, and federal government, in addition to the private initiatives[34]. These actors have legal obligations within the National Solid Waste Policy (NSWP) in Brazil, for example, including shared responsibility for the products' life cycle[35]. Even though the NSWP has ambitious goals and responsibilities, its implementation is slow and enforcement weak. The shared responsibilities for the product life cycle are not a reality for many products.

AN EMERGING CE SYSTEM IN THE WESTERN AMAZON

Significant areas within the Juruá River basin have an emerging system of CE based on the existing co-management of natural resources[36]. The Juruá River is a major tributary of the Amazon River and extends some 2500 km in western parts of the states of Amazonas and Acre in north-western Brazil. The middle portion of the river hosts three protected areas and Indigenous land, which guarantees the protection of 3,202,158 hectares (Fig. 2). The indigenous people produce almost exclusively organic waste, taking care of their own waste locally. Communities in the region have strong social organizations, which have played a central role in the sustainable management of natural resources for external trade. The main economic activities have been developed with a variety of community-based management practices for several natural resources, including palm fruits, oilseeds, rubber, agricultural products, and fish (Fig. 1)[23,26,37]. A highly diverse natural resource-based economy managed by a strong governance system makes the Juruá River a promising place for the development of a model that integrates the concepts of CE and community-based management.

Carauari is the largest municipality (area of 25,778 km^2) and urban center in the Juruá basin (Fig. 2). It is located approximately 787 km (in a straight line) from the state capital (Manaus). The municipality has a population of 28,076 inhabitants (in 2018) 76.6% of which are urban[1]. In 1977, the municipal population was 20,162 and just 27.5% was urban, indicating a high urban population growth as many people abandoned rural activities and moved to the urban areas in search of better services. The Municipal Solid Waste Management System (MSWMS) includes the waste collection, transportation and final disposal in a landfill[38]. Since 2014, recycling initiatives have been organized by a local recyclable materials association. However, due to logistical complexity, 40 tons of recyclables are taken to Manaus only every 6 months, in a 5-day boat trip, generating large costs, emissions and risks of accident.

In 2016, the municipality collected and sent 1700 tons of waste to the landfill, which represented 0.215 kg/person day[3]. It seems significant that the daily average of generation per capita of waste is well below the national average, which is 0.95 kg/person day[3]. The collection of waste in Carauari serves only the urban population in the main urban center (sede) with 21,507 inhabitants. Therefore, approximately 6569 people (23.4%) in communities scattered along the river in small informal settlements do not have access to MSWMS[3]. Within the urban area, according to local government records, 28 families declared themselves to be recyclable material collectors, but the quantities and destinations of this waste are not known.

Communities living in small urban centers on the banks of the Juruá River, which do not have regular public waste collection services, have a fundamental role in the circular economic system, as many of these small communities are involved in local and global value chains and generate some waste, which could be used locally in other processes. The generation of solid waste in such small urban centers reaches an average of 0.5 kg/person day[31]. Organic matter represents 90% of this waste and is reused mainly to feed animals or composted with forest waste in backyards. The dry solid inorganic wastes (10%) are reused (as glass and plastic packaging), burned or improperly disposed of in the open air. As infrastructure services are practically non-existent in this rural context, solid waste can have serious environmental impacts, with negative effects on the population health, mainly

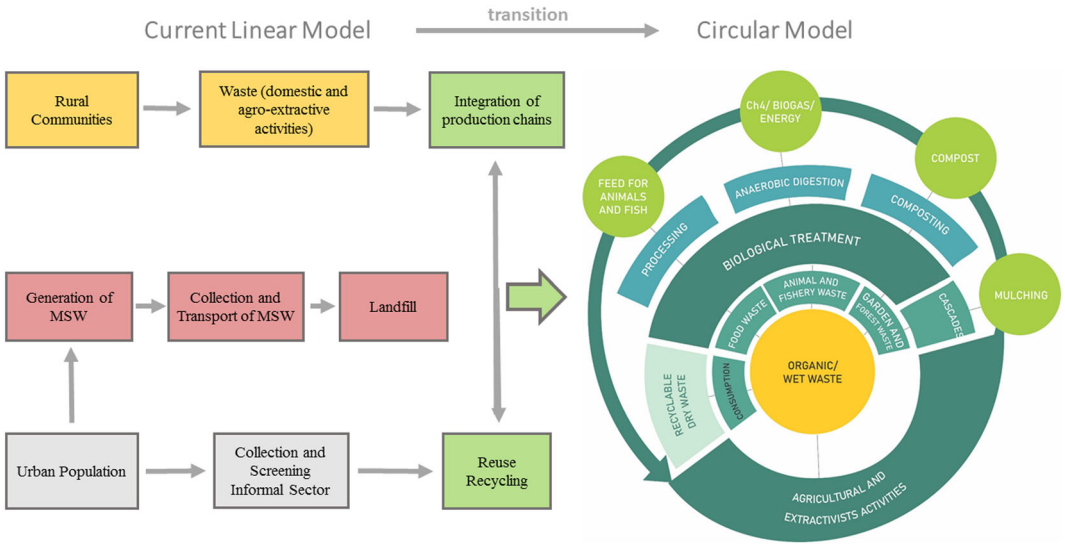

Fig. 3 Co-management and circular economy. Proposal for the Integration of Waste Management Systems and Agro-Extractive Activities using Circular Economy concepts and structures.

resulting from inadequate handling of hazardous waste, such as batteries, light bulbs, oils, and others[31]. There is a need to connect these rural communities to the small urban centers and having these, in turn, form a network for strengthening CE opportunities.

Within the CE perspective, some initiatives have already been developed to mitigate the potential social and environmental impacts of inadequate waste management, and also generate economic benefits for local communities. Examples include the agroindustry that produces oils from andiroba (*Carapa guianensis*) and murumuru (*Astrocaryum murumuru*) for a large cosmetics company and reuses its waste[39], benefiting around 400 families. After the collection by these families, the seeds are processed in the agroindustry with the potential to process 36 tons/year of oils. For every ton of product, approximately 2 tons of waste is generated, giving potential for some 20 tons of waste in 2019. The fruit peels were being reused in the forests by the communities themselves in home gardens for example, while the oilcake (approximately 70% of the waste, or in this case 14 t/year) was being processed and turned into soap for local use.

Fisheries co-management is also an important activity for communities along the Juruá River. One example of this is how local communities and indigenous peoples have been working to achieve a local population recovery of the giant arapaima (*Arapaima gigas*), the largest scaled freshwater fish on Earth. This model aligns biodiversity conservation and social needs, so promoting a substantial increase in local well-being[22,27]. Every year, communities used to harvest around 100 tons of processed fish within sustainable management rules, generating about 7500 kg of residues. Rural communities now take advantage of this material, mixing it with the residues from other productive chains to produce feed on which to rear freshwater turtles, another high-value resource in the region. This strategy is important in ensuring the economic viability of community-based management of freshwater turtles, another successful program on the Juruá River[26]. Such initiatives can contribute to the transition from the current linear model (waste management and extraction of raw materials) to a model based on the CE (Fig. 3).

FUTURE DIRECTIONS

Models like the one from the Carauari municipality in the Juruá region show the kind of alternatives that can be used to expand CE initiatives in areas surrounding small urban centers in the Amazon, as there are several localities where co-management initiatives are in operation that both protect local biodiversity and generate value in value chains. The integration of co-management and CE is a clear example to strengthen and expand sustainable urbanization linked to biodiversity-based agro-industries. An over-exploitation of biodiversity-based products that are valuable in the market can lead to the extinction of some species, as has happened along with Brazilian history. In early colonial history, Brazil experienced the almost extinction of Pau-Brasil (*Paubrasilia echinata*), the tree that gives the name to the country, as it was over-harvested to produce die for clothes in Europe. However, overexploitation of natural resources can be avoided by following some tangible ecological principles, including the harvesting quota and establishment of no-take harvesting zones[23].

Recently, more than 1200 scientists suggested that one way to recover the Brazilian governance of ecosystem services to develop sustainable agro-industries, including the expansion of biodiversity-based production systems[14]. Although promising, this strategy depends on initial external support, due to the evident lack of investment and local capacity to scale it up. There is an urgent demand to invest in logistics, infrastructure, and capacity building in Amazon to provide sustainable livelihood alternatives to the local, increasingly urban, population, while at the same time taking into account all local environmental complexities to ensure a proper model that can deliver strong socioeconomic and ecological outcomes[30]. Infrastructure investments include refrigeration boats, equipment for processing native fruits, and frozen warehouses for fish. In addition, there is a need to overcome the main bottlenecks to recycling chain establishment, and ensure the transition to a CE model, by, for example, supporting the diagnosis of existing value chains to accurately estimate product and waste flow and how these might be integrated; quantifying dry and recyclable waste; providing logistic support for productive sectors in supporting reverse remanufacturing; as well as analyzing the main infrastructure in the region to promote productive sector interconnectivity.

There is no one-fits-all solution to ensure a sustainable future for the Amazon, but the overall key to doing so certainly lies in how to conciliate the conservation of biodiversity, urbanization, and local development. Although political support not always trend in this direction[14], the alignment between co-management arrangements and CE framework can generate important socio-ecological outcomes, including food and energy security; reduction of certain production costs and environmental impacts; and increase in

added value to the region's production chains. Brazilian society, the international community, and the market players should work together with the Brazilian government towards a more sustainable policy for the Amazon, with a special focus on small urban communities and biodiversity assets that can generate wealth and well-being with the standing living forest. Using existing co-management practices to strengthen CE initiatives in the urban areas of the region could form one of the pillars for promoting a sustainable pathway model within the Amazon.

DATA AVAILABILITY

All relevant data and information used are available in this article. Complementary information can be obtained with the authors under request.

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REFERENCES

1. IBGE—Instituto Brasileiro de Geografia e Estatísticas. *Cidades. Brasília*. http://www.cidades.ibge.gov.br (2020).
2. SNIS—Sistema Nacional de Informações em Saneamento Básico, 2019. *Diagnóstico dos Serviços de Água e Esgotos – 2018 [Diagnosis of Water and Sewage Services—2018]*. Brasil, Brasília, DF. http://www.snis.gov.br/diagnostico-anual-agua-e-esgotos/diagnostico-dos-servicos-de-agua-e-esgotos-2018 (2019).
3. SNIS—Sistema Nacional de Informações em Saneamento Básico, 2019. *Diagnostico do manejo de Resíduos sólidos 2018 [national system of information on sanitation. Solid waste management inventory 2018]*. Brasil, Brasília, DF, 2019. http://www.snis.gov.br/diagnostico-anual-residuos-solidos/diagnostico-do-manejo-de-residuos-solidos-urbanos-2018 (2019).
4. Suavé, S., Bernard, S. & Sloan, P. Environmental sciences, sustainable development and circular economy: alternative concepts for trans-disciplinary research. *Env. Dev.* **17**, 48–56 (2016).
5. EMF—Ellen MacArthur Foundation. *Towards a Circular Economy: Business Rationale for an Accelerated Transition*. https://www.ellenmacarthurfoundation.org/assets/downloads/TCE_Ellen-MacArthur-Foundation_9-Dec-2015.pdf (2015).
6. Kirchherr, J., Reike, D. & Hekkert, M. Conceptualizing the circular economy: an analysis of 114 definitions. *Resour. Conserv. Recycl.* **127**, 221–232 (2017).
7. Paes, M. X. et al. Transition to circular economy in Brazil: a look at the municipal solid waste management in the state of São Paulo. *Manage Decis*. https://doi.org/10.1108/MD-09-2018-1053 (2019).
8. Prendeville, S., Cherim, E. & Bocken, N. Circular cities: mapping six cities in transition. *Environ. Innov. Soc. Trans.* **26**, 171–194 (2018).
9. Silva, A. et al. From waste to sustainable materials management: three case studies of the transition journey. *Waste Manag.* **61**, 547–557 (2017).
10. Stahel, R. W. Circular economy—a new relationship with our goods and materials would save resources and energy and create local jobs, explains. *Nature.* **531**, 435–438 (2016).
11. Paes, M. X. et al. Municipal solid waste management: Integrated analysis of environmental and economic indicators based on life cycle assessment. *J. Clean Prod.* **254**, 119848 (2020).
12. Coetzee, B. W., Gaston, K. J., & Chown, S. L. Local scale comparisons of biodiversity as a test for global protected area ecological performance: a meta-analysis. *PloS ONE* **09,** 1-11 (2014)
13. ICMBio—Instituto Chico Mendes de Conservação da Biodiversidade. *Seminário de Cadeias Produtivas Médio Juruá* https://www.icmbio.gov.br/portal/ultimas-noticias/20-geral/10040-medio-jurua-recebe-seminario-de-cadeias-produtivas (2018).
14. Levis, C. et al. Help restore Brazil's governance of globally important ecosystem services. *Nat. Ecol. Evol.* **4**, 172–173 (2020).
15. Watson, J. E., Dudley, N., Segan, D. B. & Hockings, M. The performance and potential of protected areas. *Nature.* **515**, 67–73 (2014).
16. Somanathan, E., Prabhakar, R. & Mehta, B. S. Decentralization for cost-effective conservation. *Proc. Natl Acad Sci. USA* **106**, 4143–4147 (2009).
17. Terborgh, J. & Peres, C. A. Do community-managed forests work? A biodiversity perspective. *Land* **6**, 2–22 (2017).
18. Richardson, V. A. & Peres, C. A. Temporal decay in timber species composition and value in Amazonian logging concessions. *PLoS ONE* **11**, 0159035 (2016).
19. Cox M., Arnold G., Tomás S. V. A review of design principles for community-based natural resource management. *Ecol Soc*. https://doi.org/10.5751/ES-03704-150438 (2010).
20. Ostrom, E. A general framework for analyzing sustainability of social-ecological systems. *Science.* **325**, 419–422 (2009).
21. Campos-Silva, J. V., Hawes, J. E., Freitas, C. T., Andrade, P. C., & Peres, C. A. Community-based management of amazonian biodiversity assets. in *Participatory Biodiversity Conservation*. 99–111 (Springer, Cham, 2020).
22. Castello, L. et al. Lessons from integrating fishers of arapaima in small-scale fisheries management at the Mamirauá Reserve, Amazon. *Environ. Manag.* **43**, 197–209 (2009).
23. Campos-Silva, J. V. & Peres, C. A. Community-based management induces rapid recovery of a high-value tropical freshwater fishery. *Sci. Rep.* **6**, 34745 (2016).
24. Petersen, T. A. et al. Recovery of Arapaima sp. populations by community-based management in floodplains of the Purus River, Amazon. *J. Fish. Biol.* **89**, 241–248 (2016).
25. Campos-Silva et al. Community-based population recovery of overexploited Amazonian wildlife. *Perspect. Ecol. Conserv.* **15**, 266–270 (2017).
26. Campos-Silva et al. Unintended multispecies co-benefits of an Amazonian community-based conservation programme. *Nat. Sustain.* **1**, 650–656 (2018).
27. Freitas, C. T. et al. Co-management of culturally important species: a tool to promote biodiversity conservation and human well-being. *People Nat.* **2**, 61–81 (2020a).
28. Freitas, C. T. et al. Resource co-management as a step towards gender equity in fisheries. *Ecol Econ.* **176**, 106709 (2020b).
29. Castro Dias, T. C. A., da Cunha, A. C. & da Silva, J. M. C. Return on investment of the ecological infrastructure in a new forest frontier in Brazilian Amazonia. *Biol. Conserv.* **194**, 184–193 (2016).
30. Angelo, H. et al. Analysis of the non-timber forest products market in the Brazilian Amazon. *J. Crop Sci.* **12**, 1640 (2018).
31. Bernardes, C. & Gunther, W. M. R. Generation of domestic solid waste in rural areas: case study of remote communities in the Brazilian Amazon. *Hum. Ecol.* **42**, 617–623 (2014).
32. Oliveira, B. O. S. & Medeiros, G. A. Evolução e desafios no gerenciamento dos resíduos sólidos urbanos nos estados da região norte, Brasil. *Rev. Valore* **4**, 749–761 (2019).
33. Bueno, G. W. et al. Implementation of aquaculture parks in Federal Government waters in Brazil. *Rev. Aquac.* **7**, 1–12 (2015).
34. Dong, L. et al. Recent progress on innovative urban infrastructures system towards sustainable resource management. *Resour. Conserv. Recycl.* **128**, 355–359 (2018).
35. Brasil. Lei n° 12.305, de 02 de agosto de 2010. *Política Nacional de Resíduos Sólidos. Brasília [National policy for solid wastes]*, DF. http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/lei/l12305.htm (2010).
36. Campos-Silva, J. V. et al. Community-Based Management of Amazonian Biodiversity Assets. in *Participatory Biodiversity Conservation*. 99-111 (Springer, Cham, 2020).
37. Newton, P., Watkinson, A. R. & Peres, C. A. Determinants of yield in a non-timber forest product: Copaifera oleoresin in Amazonian extractive reserves. *For. Ecol. Manag.* **261**, 255–264 (2011).
38. PMC—Prefeitura Municipal de Carauari. *Plano Municipal de Saneamento Básico e de Gestão Integrada de Resíduos Sólidos do município de Carauari-AM*. Associação Amazonense de Municípios e Secretaria de Meio Ambiente e Desenvolvimento Sustentável do Governo do Estado do Amazonas (Municipal Plan for Basic Sanitation and Integrated Solid Waste Management in the municipality of Carauari-AM), Carauari-AM, 424 pp. (2012).
39. IDESAM, Instituto de Conservação e Desenvolvimento Sustentável da Amazônia. *Manejo Florestal: cadeias produtivas de andiroba e mururumuru no médio Juruá (Forest Management: production chains of andiroba and mururumuru in the middle Jurua River)*. https://idesam.org/projeto-cadeias-produtivas-de-andiroba-e-mururumuru-no-medio-jurua-apresenta-resultados (2013).

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AUTHOR CONTRIBUTIONS

M.X.P., J.V.C.S. and J.A.P.O. participated in all stages of the work (conceptualization, methodology, data acquisition, writing, and review).

COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

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