UNIVERSIDADE FEDERAL DE ALAGOAS
INSTITUTO DE CIÊNCIAS BIOLÓGICAS E DA SAÚDE
Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos

ANA CARLA RODRIGUES

SERVIÇOS AMBIENTAIS E BENEFÍCIOS DA NATUREZA PARA AS PESSOAS DO MAIOR ARRANJO DE CONSERVAÇÃO DE BASE COMUNITÁRIA NA AMAZÔNIA BRASILEIRA

MACEIÓ - ALAGOAS
Setembro/2024

ANA CARLA RODRIGUES

SERVIÇOS AMBIENTAIS E BENEFÍCIOS DA NATUREZA PARA AS PESSOAS DO MAIOR ARRANJO DE CONSERVAÇÃO DE BASE COMUNITÁRIA NA AMAZÔNIA BRASILEIRA

Tese apresentada ao Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos, Instituto de Ciências Biológicas e da Saúde. Universidade Federal de Alagoas, como requisito para obtenção do título de Mestre/Doutor em CIÊNCIAS BIOLÓGICAS, área de concentração em Conservação da Biodiversidade Tropical.

Orientador: Prof. Dr. João Vitor Campos e Silva
Coorientadora: Profa. Dra. Ana Claudia Mendes Malhado

MACEIÓ - ALAGOAS
Setembro/2024

Catalogação na Fonte
Universidade Federal de Alagoas
Biblioteca Central
Divisão de Tratamento Técnico
Bibliotecário: Marcelino de Carvalho Freitas Neto – CRB-4 - 1767

R696s Rodrigues, Ana Carla.
Serviços ambientais e benefícios da natureza para as pessoas do maior arranjo de conservação de base comunitária na Amazônia brasileira / Ana Carla Rodrigues. – 2024.
115 f. : il.

Orientador: João Vitor Campos e Silva.
Co-orientadora: Ana Claudia Mendes Malhado.
Tese (Doutorado em Ciências Biológicas) – Universidade Federal de Alagoas. Instituto de Ciências Biológicas e da Saúde. Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos. Maceió, 2024.

Inclui bibliografias.
Apêndices: f. 110-115.

1. Amazônia. 2. Pirarucu - Manejo. 3. Biodiversidade - Conservação. I. Título.

CDU: 504(811/812.1/.2)

Folha de aprovação

Ana Carla Rodrigues

SERVIÇOS AMBIENTAIS E BENEFÍCIOS DA NATUREZA PARA AS PESSOAS DO MAIOR ARRANJO DE CONSERVAÇÃO DE BASE COMUNITÁRIA NA AMAZÔNIA BRASILEIRA

Tese apresentada ao Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos, Instituto de Ciências Biológicas e da Saúde. Universidade Federal de Alagoas, como requisito para obtenção do título de Doutor(a) em CIÊNCIAS BIOLÓGICAS na área da Biodiversidade.

Tese aprovada em 03 de setembro de 2024.

Documento assinado digitalmente
JOAO VITOR CAMPOS E SILVA
Data: 25/09/2024 15:36:53-0300
Verifique em https://validar.iti.gov.br

Dr.(ª) – João Vitor Campos e Silva
(orientador)

Documento assinado digitalmente
ANA CLAUDIA MENDES MALHADO
Data: 26/09/2024 08:14:03-0300
Verifique em https://validar.iti.gov.br

Dra. Ana Claudia Mendes Malhado/UFAL
(Coorientadora)

Documento assinado digitalmente
GUILHERME RAMOS DEMETRIO FERREIRA
Data: 25/09/2024 16:39:11-0300
Verifique em https://validar.iti.gov.br

Dr. (ª) Guilherme Ramos Demétrio Ferreira

Documento assinado digitalmente
ROBSON GUIMARAES DOS SANTOS
Data: 23/10/2024 15:11:33-0300
Verifique em https://validar.iti.gov.br

Dr. (ª) Robson Guimarães dos Santos

Documento assinado digitalmente
SIMONE FERREIRA DE ATHAYDE
Data: 27/09/2024 19:11:07-0300
Verifique em https://validar.iti.gov.br

Dr. (ª) Simone Athayde

Documento assinado digitalmente
GUSTAVO HALLWASS
Data: 25/09/2024 16:00:57-0300
Verifique em https://validar.iti.gov.br

Dr. (ª) Gustavo Hallwass

MACEIÓ - AL

Setembro/ 2024

DEDICATÓRIA

Dedico este trabalho à minha mãe, Lúcia, e ao meu irmão, Antônio,
pelo amor e apoio incondicionais, que sempre foram minha força e inspiração.

Aos meus avós, Antônio e Helena,
por suas bênçãos que superam o tempo e a distância.

AGRADECIMENTOS

Primeiramente, gostaria de honrar a Universidade Federal de Alagoas, uma universidade nordestina, pública e de qualidade. Quero agradecer aos queridos professores do DIBICT, que se tornaram amigos e acolheram nossa turma em meio ao caos da pandemia. Destaco também a força e a inspiração de sete mulheres incríveis da turma de 2020, que foram tão resilientes ao longo desse trajeto.

A cada um do Laboratório de Conservação no Século 21 (Lacos21), agradeço o acolhimento, abraços, discussões, cafés e brincadeiras, que foram verdadeiros momentos salvadores. Vocês tornaram essa jornada ainda mais especial.

Ao meu orientador e amigo, Jota (João Campos-Silva), um brilhante pesquisador, poeta, cantor, sambista, compositor e otimista, tão necessário e fundamental neste mundo, muito obrigada! Agradeço muito por me incentivar, me ensinar tanto, me corrigir tão docemente, e por me permitir dividir os momentos dessa jornada. Me ensinou a também a confiar — confiar que as coisas vão dar certo, que as coisas ficarão lindas, também a sempre pensar, aproveitar e apreciar as belezas da vida.

Não posso deixar de dizer o quanto fui agraciada por ter também a Ana Malhado como orientadora nessa jornada. Sempre me acolheu com palavras de carinho e motivação. Esteve ao meu lado nas perdas e nas alegrias, acompanhando tantas maluquices da vida e tornando tudo mais leve. Cada reunião, cada conversa, foram recargas que me ajudaram a continuar. Um dos grandes orgulhos dessa jornada foi ter sido orientada por uma mulher, mãe e pesquisadora incrível! Que sorte imensa a minha!

Ao Prof. Richard, tantos momentos interessantes, como ver um inglês abraçando, aprendendo a tocar “Evidências” para os Lacoricos e sendo ele um dos maiores pesquisadores do mundo, contribuindo com nossa formação.

Meu agradecimento ao Prof. Eduardo Brondízio, que me recebeu tão bem na Indiana University, me proporcionando uma experiência profissional e pessoal inimaginável, e a oportunidade de fazer tantos amigos no Lab. Casel. Nesse mesmo caminho surpreendente, tive a alegria de encontrar as “Cientistas em Bloomington”, que tornaram o período sanduíche nos EUA especial, com um companheirismo imenso e muito amor.

A Maceió, esse paraíso que me acalentou com sua beleza, me permitiu reencontrar amigos e fazer amizades que se tornaram família. Sou grata por cada dia nesse lugar incrível, que me mostrou com ser mais leve e que a vida pode ser assim.

Nesse período, me despedi de um grande incentivador, apoiador, cuidador e verdadeiro pai que tive: meu avô Antônio do Leôncio. Ele sempre acreditou nos meus sonhos, assim como minha avó Helena, que também já me olha lá de cima. Agradeço muito a eles, com todo meu amor, pois sempre me apoiaram e oraram bastante para que eu realizasse meus planos e sonhos. Além deles, contei com a garra, determinação, força, esperança, companheirismo e amor da minha mãe Lúcia, que sempre uniu todas as forças do universo e enfrentou todas as adversidades para que eu chegasse até aqui. Uma incansável motivadora em todas as minhas jornadas. Eu te amo muito, mãe! Eu agradeço ao meu irmão Toninho (Antônio), biólogo também, que me disse na época do vestibular que a biologia era uma paixão, não apenas uma profissão. Essa fala sempre me acompanhou, especialmente diante dos muitos desafios que enfrentei como profissional, mas que também me fez ver que minha paixão só aumentaria. Agradeço a vocês pelos incentivos, motivações, lutas e orações. Eu consegui graças a vocês e eu os amo muito! Muito obrigada!

E ao meu Chico, que não pôde estar fisicamente comigo nesta reta final, não poderia deixar de agradecê-lo por todo amor e companheirismo que me ofereceu durante dezesseis anos da minha vida, desde a graduação até o doutorado.

Aos meus sobrinhos Olívia, Antonela e Inácio, e à minha cunhada Mirelle, muito obrigada pelo carinho e quando possível, atravessaram o país para acalentar a saudade e me renovar. Minha gratidão e espero estar cada vez mais presente! Também expresso minha gratidão a toda a minha família, aos meus tios, primos e primas-irmãs, que a todo momento perguntavam: “Quando você vem?!” e que continuaram a me motivar, sempre dizendo para eu terminar tudo logo, para nosso encontro no Corozinho.

Ao meu companheiro Hugo, com todo meu amor, agradeço por mais essa jornada, talvez uma das mais loucas que tivemos. A vida nos trouxe a Maceió, repleta de desafios, e ele sempre esteve ao meu lado. Choramos juntos de saudade da família, de medo da pandemia, e celebramos juntos cada conquista. Nossas discussões científicas sempre renderam muito. Hugo, além de ser o meu parceiro de vida, é um cientista formidável, e tenho muito orgulho e me sinto honrada de trabalharmos juntos. Obrigada por todos os momentos lindos e de conquistas! Seguimos realizando nossos sonhos juntos! Estendo também meus agradecimentos a Gil, Neri e Bruno, que sempre estiveram ao nosso lado nas nossas decisões.

Minha grande amiga Allinne talvez nem imagina o quanto me ajudou durante esse tempo. Agradeço de coração o apoio incondicional e por sempre “aceitar” a minha distância e, ainda assim, continuar sempre presente ao meu lado. Às minhas Cumadis do início (e para sempre) das aventuras amazônicas — Viviane, Vanessa e Letícia — agradeço por sempre me ajudarem a “ajeitar os cabelos” e por fazerem parte da minha vida. Obrigada por estarem comigo sempre! “Just as long as you stand, stand by me!”

Nessas jornadas de graduações tiveram muitas mãos (mães) envolvidas, na verdade, “mães” de coração que sempre estarão marcadas em meu coração por toda a ajuda que nos deram, a mim e à minha mãe em vários momentos. “As mulheres são como águas; crescem quando se encontram.” Minha gratidão por terem nos tornados mais fortes.

Um professor, e agora amigo, sempre diz: “Daqui vão surgir grandes amizades para toda a vida.” E realmente, aqui eu encontrei amizades muito necessárias e especiais. Agradeço ao nosso quinteto formado por mim — Evellynne, Thainá, Carolina Neves e Anna Ludmilla — por tornarem esse caminho mais lindo, iluminado e leve, por enxugarem as lágrimas e por proporcionarem tantas diversões e alegrias. Ao Gaio, sou grata por todos os momentos de longas conversas, descontrações, broncas e carinho.

Por fim, sinto uma gratidão imensa a tantas pessoas queridas do Médio Juruá! Foram tantas conversas sobre vida, resiliência, união, luta e inspiração. Agradeço também pela confiança em compartilhar seus imensos conhecimentos para que possamos lutar por um futuro. Além disso, agradeço por mostrar as belezas e esperanças de uma Amazônia inspiradora. Meu coração é repleto de amor e gratidão. Nunca vou esquecer a expedição de campo pós-vacinação - Covid-19, em que participamos de uma primeira festa na comunidade: às margens do Rio Juruá, com uma lua cheia linda nascendo sobre a floresta, e do outro lado, as pessoas alegres comemorando os reencontros. Aquele momento foi a energia de esperança necessária, e, a cada sorriso, a certeza de que dias melhores viriam.

"Foi um rio que passou em minha vida
E meu coração se deixou levar"
(Paulinho da Viola)

RESUMO

Os trópicos estão enfrentando as maiores taxas de degradação florestal globalmente, impulsionadas pela produção de commodities, silvicultura, agricultura de commodities e incêndios florestais, resultando em apenas 20% de florestas intocadas. Além disso, a superexploração de peixes e vertebrados terrestres pode levar à síndrome de floresta vazia, prejudicando os serviços ecossistêmicos. A contínua perda de cobertura florestal e espécies animais ameaça a segurança alimentar de milhões de pessoas que dependem da caça e pesca. Esta crise de biodiversidade, aliada à pobreza e desigualdade social, desafia a criação de novos caminhos de desenvolvimento que alinhem a conservação da biodiversidade com a melhoria do bem-estar local. A Amazônia, representando mais de 50% das florestas tropicais remanescentes, é crucial para a regulação do clima e a manutenção da biodiversidade global. Embora as Áreas Protegidas sejam fundamentais para a preservação, muitas unidades de conservação amazônicas carecem de estrutura e gestão adequadas, e terras indígenas enfrentam invasões e exploração ilegal. Iniciativas de manejo comunitário dos recursos naturais que acomodam múltiplos interesses locais estão surgindo como ferramentas poderosas para recuperar populações de espécies historicamente superexploradas na Amazônia. A pesca manejada do pirarucu (*Arapaima gigas*) é um exemplo de sucesso, no entanto, desafios como monopólio pesqueiro, pesca ilegal, logística e remuneração justa para os manejadores persistem. Esta tese, explora a pesca manejada do pirarucu no Rio Juruá, oeste da Amazônia Brasileira, através de entrevistas com gestores, presidentes de associações e pescadores, para investigar a multidimensionalidade dessa atividade na proteção territorial, organização social e contribuição da natureza para as pessoas. Observamos que o manejo comunitário do pirarucu apresenta um sistema de governança policêntrico e adaptativo para promover tomadas de decisão participativas e que apresentou um aumento de inclusão e aperfeiçoou os mecanismos de monitoramento e sanções de punição ao longo do tempo, o que pode inspirar outros modelos de bioeconomia para a Amazonia. Adicionalmente, a proteção comunitária dos lagos para a pesca manejada promove diferentes percepções locais sobre a contribuição da natureza para as pessoas principalmente na criação e manutenção de habitats, qualidade do ar, materiais e preservação de recursos genéticos. Demonstramos que o mapeamento das rotas de vigilância percorridas pelos manejadores é substancialmente superior a área de interesse direto para o manejo (área do lago). Porém, os custos associados à proteção são desproporcionais aos benefícios gerados por essa atividade que pode ser valorizada por mecanismos de pagamentos por serviços ambientais para melhor remuneração dos manejadores.

Palavras-chave: Amazônia, co-manejo, conservação.

ABSTRACT

The tropics are facing the highest rates of forest degradation globally, driven by commodity production, forestry, agricultural commodities, and forest fires, resulting in only 20% pristine forests remaining. Additionally, the overexploitation of wildlife can lead to the empty forest syndrome, impairing ecosystem services. The continued loss of forest cover and animal species jeopardize the food security of millions of people who depend on hunting and fishing. This biodiversity crisis, coupled with poverty and social inequality, challenges the creation of new development pathways that align biodiversity conservation with the improvement of local well-being. The Amazon, representing over 50% of the remaining tropical forests, is crucial for climate regulation and the maintenance of global biodiversity. Although Protected Areas are fundamental for preservation, many Amazonian Protected Areas lack adequate structure and management, and indigenous lands face invasions and illegal exploitation. Community-based natural resource management initiatives that accommodate multiple local interests are emerging as powerful tools to recover historically overexploited species populations in the Amazon. Community-based Arapaima (Arapaima gigas) fisheries is a success story; however, challenges such as fishing monopolies, illegal fishing, logistics, and fair compensation for managers persist. This thesis explores the managed fisheries of Arapaima in the Juruá River, western Brazilian Amazon, through interviews with managers, association presidents, and fishers, to investigate the multidimensionality of this activity in territorial protection, social organization, and the contribution of nature to people. We observed that community management of pirarucu presents a polycentric and adaptive governance system to promote participatory decision-making, which has led to increased inclusion and improved monitoring and punishment mechanisms over time. This model can inspire other bioeconomy models for the Amazon. Additionally, the community protection of lakes for managed fishing promotes different local perceptions of nature's contribution to people, mainly in the creation and maintenance of habitats, air quality, materials, and the preservation of genetic resources. We demonstrate that the mapping of surveillance routes taken by managers substantially exceeds the area of direct interest for management (lake area). However, the costs associated with protection are disproportionate to the benefits generated by this activity, which can be valued through payment mechanisms for environmental services to better compensate managers.

Key-word: Amazon, co-management, conservation.

LISTA DE FIGURAS

LISTA DE TABELAS

SUMÁRIO

APRESENTAÇÃO

Os trópicos atualmente experimentam as maiores taxas de degradação florestal em todo o mundo. A produção de commodities, a silvicultura, a agricultura itinerante e os incêndios florestais são os principais motores do desmatamento (Curtis et al. 2018), restando apenas 20% de florestas intocadas. Além disso, a superexploração de peixes e de vertebrados terrestres pode levar a uma síndrome de floresta vazia, carente de serviços ecossistêmicos (Wilkie et al. 2011; Antunes et al. 2016). O declínio contínuo da cobertura florestal e de espécies animais coloca em risco a segurança alimentar de milhões de pessoas indígenas e não indígenas que dependem da caça e da pesca como principais fontes de proteínas, gorduras, calorias e micronutrientes (Tregidgo et al. 2020). A crise da biodiversidade, combinada com altos níveis de pobreza e desigualdade social, impõe às sociedades contemporâneas o desafio de estabelecer novos caminhos de desenvolvimento que alinhem a conservação da biodiversidade com a melhoria do bem-estar local (Nobre et al. 2016; Campos-Silva et al. 2021).

A Amazônia representa mais de 50% das florestas tropicais remanescentes e é um ambiente crucial para a regulação do clima (Malhi et al. 2008) e para a manutenção da biodiversidade em escala global (Pimm et al. 2014). A substituição de florestas por agricultura mecanizada de commodities, pecuária e instalação de hidrelétricas em grande escala tem sido historicamente responsável pelo desmatamento massivo da Amazônia, que alcançou 838.600 km² até o final de 2022. Além disso, 38% da floresta remanescente está atualmente degradada por incêndios, efeitos de borda, extração de madeira e secas extremas (Lapola et al. 2023), aproximando-se do limiar de não retorno de 40% de desmatamento (Sampaio et al. 2007; Lovejoy e Nobre 2019). Embora as Áreas Protegidas sejam o principal obstáculo contra a perda de habitat e biodiversidade, a maioria das reservas amazônicas carece de estrutura adequada, gestão e monitoramento. Um terço de todas as terras indígenas amazônicas ainda não completou seu processo de demarcação física e 85% enfrentam regularmente invasões por grileiros, extração ilegal de madeira e mineração, que degradam a estrutura florestal e os recursos naturais essenciais para seus ocupantes legítimos.

Iniciativas de base-comunitária que acomodam os interesses de múltiplos atores locais estão emergindo como uma poderosa ferramenta para recuperar populações de várias espécies historicamente superexploradas em toda a bacia amazônica (Campos-Silva et al. 2017). A pesca manejada do pirarucu (*Arapaima gigas*) praticada em Unidades de Conservação, Terras Indígenas e em áreas de Acordos de Pesca é o caso de maior sucesso de manejo comunitário dos recursos naturais. Além dos benefícios de conservação para este icônico peixe amazônico, o manejo do pirarucu também se tornou uma grande oportunidade para melhorar o bem-estar da população rural amazônida podendo ser replicado em diversas bacias hidrográficas e de diferentes contextos sociais. Os principais desafios para essa cadeia produtiva são a quebra do monopólio pesqueiro, o combate à pesca ilegal, logística, infraestrutura e a remuneração justa para o manejador na beira do lago.

Para construir essa tese naveguei pelo Rio Juruá, no oeste da Amazônia Brasileira e entrevistei gestores, presidentes de associações, pescadores e pescadoras para entender a multidimensionalidade dessa atividade na proteção territorial, organização social e na contribuição da natureza para as pessoas em comunidades manejadoras e não manejadoras de pirarucu. Ela é composta por três capítulos em formatos de artigos científicos que se complementam de maneira cronológica na implementação dessa atividade.

“Você consegue fazer tudo sozinho aqui no Médio Juruá, menos manejar. Você precisa ter uma comunidade organizada! O manejo começa impactando a organização social das famílias…” Essas frases de Manoel Cunha, liderança do Médio Juruá ilustram muito bem o que apresento no primeiro capítulo intitulado: “ The community management of Arapaima (*Arapaima gigas*) in an Amazonian bright spot: a history of institutional strengthening” . Nele, descrevo o histórico da implementação do manejo do pirarucu no rio Juruá, o sistema policêntrico de governança e analisamos as modificações nos regimentos internos das comunidades manejadoras ao longo do tempo de acordo com os princípios propostos por Elinor Ostrom para o manejo de recursos comuns. Manoel segue com sua fala: **“Depois, traz uma colaboração e um impacto também na biodiversidade, se protege um lago para tirar uma ou duas espécies, mas acaba ficando protegido todo aquele ecossistema dentro daquele ambiente, né? Até a floresta, porque não se pode**

derrubar uma árvore nem para tirar uma abelha (mel) sequer na redondeza desses lagos de manejo, porque algum peixe daquele ambiente se alimenta daquela fruta…”. Inspirada nessas palavras, o capítulo 2 “Community-based conservation catalyzes multidimensional nature’s contributions to people”, revela como o manejo do pirarucu é uma atividade mantenedora de serviços ecossistêmicos através da comparação das percepções locais antes e depois da implementação da atividade para comunidades manejadoras de pirarucu, que são contrastadas com as percepções atuais de comunidades não manejadoras de pirarucu. Por fim, Fernanda Moraes, moradora e liderança feminina da comunidade Lago Serrado é minha grande inspiração para o capítulo 3: **“ Se um dia eu pudesse ter contato com alguém de fora, e que se alimenta do peixe que tem no nosso lago, eu gostaria de dizer: - Olha, você está comendo fruto de união, de um cuidado que as pessoas têm para que esse alimento chegue até você! Você está tendo o privilégio de se alimentar de um peixe que engloba amor, cuidado, proteção e união juntos.”.** Nesse artigo, Intitulado “Community-based fisheries management exert a vast value-added effective protection footprint in Amazonian forests” mapeei as rotas de vigilância percorridas pelos manejadores de pirarucu e descobri que a área localmente protegida por eles é substancialmente maior do que a área de interesse direta para o manejo (área do lago), no entanto todos os custos associados à vigilância são pagos pelos próprios manejadores, o que é desproporcional aos benefícios gerados por essa atividade. Por isso, discuto que mecanismos de pagamentos por essa atividade devem ser desenvolvidos para melhor valorização do pirarucu de manejo e consequente melhor remuneração para o pescador na beira do lago. Boa leitura!

REFERÊNCIAS

Antunes, A.P., Fewster, R.M., Venticinque, E.M., Peres, C.A., Levi, T., Rohe, F., Shepard, G.H., 2016. Empty forest or empty rivers? A century of commercial hunting in Amazonia. Sci Adv 2. https://doi.org/10.1126/sciadv.1600936

Campos-Silva, J.V., Peres, C.A., Amaral, J.H.F., Sarmento, H., Forsberg, B., Fonseca, C.R., 2021. Fisheries management influences phytoplankton biomass of Amazonian floodplain lakes. Journal of Applied Ecology 58, 731–743. https://doi.org/10.1111/1365-2664.13763

Campos-Silva, J.V., Peres, C.A., Antunes, A.P., Valsecchi, J., Pezzuti, J., 2017. Community-based population recovery of overexploited Amazonian wildlife. Perspect Ecol Conserv 15, 266–270. https://doi.org/10.1016/j.pecon.2017.08.004

Curtis, P.G., Slay, C.M., Harris, N.L., Tyukavina, A., Hansen, M.C., 2018. Classifying drivers of global forest loss. Science (1979) 361, 1108–1111. https://doi.org/10.1126/science.aau3445

Lapola, D.M., Pinho, P., Barlow, J., Aragão, L.E.O.C., Berenguer, E., Carmenta, R., Liddy, H.M., Seixas, H., Silva, C.V.J., Silva, C.H.L., Alencar, A.A.C., Anderson, L.O., Armenteras, D., Brovkin, V., Calders, K., Chambers, J., Chini, L., Costa, M.H., Faria, B.L., Fearnside, P.M., Ferreira, J., Gatti, L., Gutierrez-Velez, V.H., Han, Z., Hibbard, K., Koven, C., Lawrence, P., Pongratz, J., Portela, B.T.T., Rounsevell, M., Ruane, A.C., Schaldach, R., da Silva, S.S., von Randow, C., Walker, W.S., 2023. The drivers and impacts of Amazon forest degradation. Science (1979) 379. https://doi.org/10.1126/science.abp8622

Lovejoy, T.E., Nobre, C., 2019. Amazon tipping point: Last chance for action. Sci Adv 5. https://doi.org/10.1126/sciadv.aba2949

Malhi, Y., Roberts, J.T., Betts, R.A., Killeen, T.J., Li, W., Nobre, C.A., 2008. Climate Change, Deforestation, and the Fate of the Amazon. Science (1979) 319, 169–172. https://doi.org/10.1126/science.1146961

Pimm, S.L., Jenkins, C.N., Abell, R., Brooks, T.M., Gittleman, J.L., Joppa, L.N., Raven, P.H., Roberts, C.M., Sexton, J.O., 2014. The biodiversity of species and their rates of extinction, distribution, and protection. Science (1979) 344. https://doi.org/10.1126/science.1246752

Sampaio, G., Nobre, C., Costa, M.H., Satyamurty, P., Soares-Filho, B.S., Cardoso, M., 2007. Regional climate change over eastern Amazonia caused by pasture and soybean cropland expansion. Geophys Res Lett 34. https://doi.org/10.1029/2007GL030612

Tregidgo, D., Barlow, J., Pompeu, P.S., Parry, L., 2020. Tough fishing and severe seasonal food insecurity in Amazonian flooded forests. People and Nature 2, 468–482. https://doi.org/10.1002/pan3.10086

Wilkie, D.S., Bennett, E.L., Peres, C.A., Cunningham, A.A., 2011. The empty forest revisited. Ann N Y Acad Sci 1223, 120–128. https://doi.org/10.1111/j.1749-6632.2010.05908.x.

1. REVISÃO DA LITERATURA

1.1 As várzeas amazônicas

As zonas úmidas são ecossistemas globalmente importantes para a conservação da biodiversidade e para o bem-estar humano ((Butchart et al., 2010; Junk et al., 2014a). Apesar de cobrirem somente 0.8% da superfície terrestre, esses ecossistemas abrigam cerca de um terço de todas as espécies de vertebrados, além de sustentarem diretamente os meios de vida de milhões de pessoas pela exploração de peixes e vertebrados, solos férteis para agricultura, água potável, ciclagem de nutrientes e regulação do clima (Groot et al., 2012). A Amazônia corresponde a mais de 50% dos remanescentes de florestas tropicais sendo que uma vasta proporção de sua área é formada por mosaicos de paisagens naturais de áreas úmidas inseridas dentro de uma matriz de florestas de terra firme sob solos geralmente pobres em nutrientes e acima do nível máximo da água das planícies aluviais adjacentes(Tuomisto et al., 1995). As planícies aluviais amazônicas compreendem uma variedade de habitats, incluindo florestas alagadas, savanas hidromórficas, áreas úmidas costeiras, florestas de maré e florestas sazonalmente alagadas. Essas áreas úmidas amazônicas são classificadas de acordo com suas características climáticas, edáficas e florísticas (Junk et al., 2014b, 2011). Com base nesses critérios, dois grandes grupos de áreas úmidas podem ser distinguidos: aquelas com níveis de água (i) relativamente estáveis ou (ii) oscilantes (Junk et al., 2011).

As zonas úmidas amazônicas de nível de água variável podem ser sazonalmente alagadas por rios de água branca, como o Solimões, Madeira, Japurá e Juruá, de águas pretas como o Negro, Tefé e Jutaí, ou ainda por rios de águas claras como o Tocantins, Tapajós e Xingú (Wittmann et al., 2006). Os rios de águas brancas são ricos em nutrientes, pois possuem as suas nascentes na Cordilheira dos Andes (Junk et al., 2011) que depositam anualmente sedimentos em suas águas. As florestas sazonalmente alagadas por rios de água branca são conhecidas como várzeas, que são as zonas úmidas mais ricas em espécies de árvores no mundo, compartilhando muitas espécies com as florestas de terra firme, além de possuir um alto número de espécies endêmicas adaptadas para sobreviver ao longo período de inundação (Wittman et al., 2017). A alternância anual entre períodos de inundação e de seca é a principal responsável por moldar as formas de sobrevivência das espécies nas diferentes épocas do ano (Costa et al., 2018). A fácil acessibilidade de transporte pelos rios, a provisão de solos férteis para plantio durante a estação seca e a alta produtividade pesqueira favorecem a ocupação das várzeas pelas comunidades humanas rurais (Junk et al., 2011; Wittmann et al., 2006).

1.2 Serviços Ecossistêmicos e Contribuição da Natureza para as Pessoas

Os ecossistemas dão suporte à vida no planeta(Corvalan et al., 2005; Costanza, 2020; Costanza et al., 1997). As funções ecossistêmicas são conceituadas como serviços ecossistêmicos (SE) quando trazem ideias de valor, saúde, bem-estar, meios de subsistência e sobrevivência para o ser humano (Daily and Matson, 2008). Estas funções provêm benefícios às pessoas, gerando soluções econômicas e sociais devido ao uso direto e indireto dos recursos naturais (COSTANZA et al., 2017). Através dos SE é possível medir a integridade ecológica de um ecossistema, e sua capacidade em realizar as funções de regulação, produtividade e resiliência (Groot et al., 2002).

O conceito de SE se transformou ao longo do tempo objetivando unir a ciência, os recursos naturais, e questões sociais para que fosse possível interligar as políticas ambientais e socioeconômicas. Seguindo o conceito de SE, a Plataforma Intergovernamental de Políticas Científicas sobre Biodiversidade e os Serviços de Ecossistema (IPBES) desenvolveu o conceito de "Contribuição da Natureza para as Pessoas" (NCP – nature's contribution to people - em inglês) (Díaz et al., 2015). Este conceito surgiu para ampliar pontos abordados pelos serviços ecossistêmicos, com a inclusão das partes interessadas, perspectivas e conhecimentos de populações tradicionais e indígenas. Assim, o NCP inclui as relações (positivas ou negativas) das pessoas com a natureza, e as relaciona com a diversidade de ecossistemas e à qualidade de vida (Díaz et al., 2018).

Neste contexto, a valoração de NCP (daqui em diante substitui o conceito de serviços ecossistêmicos) significa qualificar e quantificar os serviços da natureza que estão sendo usados e percebidos pelas atividades humanas. Com isso é possível verificar o quão melhor ou pior estão os recursos naturais e o bem-estar das pessoas envolvidas em determinado período (Pascual et al., 2017). Ou seja, através das medidas adequadas, a valoração será capaz de mostrar quais são os NCPs que estão em evidência para o bem-estar humano (Pascual et al., 2017)

A valoração dos NCPs é uma importante ferramenta para ser utilizada no planejamento de estratégias de conservação de modo que combinem adequadamente proteção e formulação de planos que garantam a sustentabilidade e a qualidade de vida dos povos locais (Díaz et al., 2018; Pascual et al., 2017). Quando se usa a mensuração dos NCPs em valores monetários, pode-se tornar mais palpável a utilidade daquele recurso utilizado pela sociedade, direta ou indiretamente (Costanza, 2001), de acordo com os modelos de mercado. Desta forma, isto poderá auxiliar no entendimento de como ocorre o declínio dos NCPs para evitar declínios e prejuízos futuros (Carpenter et al., 2009; Corvalan et al., 2005). Sendo assim, a valoração, não só a monetária, integrada à percepção da sociedade sobre os recursos naturais visa reconhecer a diversidade de valores existentes a partir dos sistemas de conhecimento locais, entendendo o valor social dos NCPs e como são utilizados. Porém, além das valorações de mercado, que são baseadas em moedas de mercado, há uma necessidade de reconhecer também valores não monetários, que também são de grande valia para o funcionamento dos ecossistemas e bem-estar da população mundial.

Há uma grande lacuna de conhecimento sobre os NCPs e sua valoração na Amazônia, especialmente sob a perspectiva das comunidades locais (Strand et al., 2018) Reconhecer e integrar esses conhecimentos é essencial para desenvolver políticas ambientais e socioeconômicas que sustentem esses serviços a longo prazo (Kiker et al., 2005). A valoração dos recursos naturais é crucial, pois estima os fluxos desses recursos para identificar os impactos ou melhorias da natureza no bem-estar humano (Chan et al., 2016; Díaz et al., 2018).

As comunidades locais possuem um entendimento profundo e específico do ecossistema, que pode complementar os dados científicos e contribuir para estratégias de conservação mais abrangentes (Brondízio et al., 2021). A colaboração entre cientistas, formuladores de políticas e comunidades locais pode levar a soluções mais sustentáveis e equitativas para a gestão dos recursos naturais na Amazônia. Assim, a integração de conhecimentos científicos e locais não só preserva a biodiversidade, mas também promove o bem-estar humano ao garantir que os benefícios dos recursos naturais sejam compartilhados de maneira justa e sustentável (Campos-Silva and Peres, 2016). Não obstante, a inclusão das comunidades locais no processo de valoração é fundamental para garantir que as políticas sejam eficazes e justas.

Nesse contexto, o pagamento por serviço ambiental (PSA) surge como uma ferramenta eficaz para a conservação e a sustentabilidade. Os primeiros programas de PSA na Amazônia foram iniciados por volta dos anos 2000 e se destacam pela aplicabilidade e pelas lições aprendidas a longo prazo. Um exemplo notável é o Programa de Desenvolvimento Socioambiental da Produção Familiar (Proambiente), que prevê pagamentos pela redução do desmatamento, programas de sequestro e carbono evitado, diminuição ou finalização do uso de agrotóxicos, redução de queimadas, conservação do solo, água e da biodiversidade (Onishi, 2019). Esses programas demonstram como incentivos econômicos podem alinhar os interesses das comunidades locais com objetivos de conservação, promovendo práticas sustentáveis que beneficiam tanto o meio ambiente quanto as populações que dependem dele.

Os programas de PSA mais frequentes globalmente incluem o sequestro de carbono ou a emissão evitada de gases carbônicos na atmosfera. Para a implementação desses programas, são necessários trabalhos técnicos para obter estimativas de quanto carbono seria emitido e evitado, estabelecer metas de redução de emissão e calcular o carbono sequestrado por áreas de floresta protegidas ou reflorestadas. Embora os projetos do REDD+ (Reducing Emissions from Deforestation and Degradation) sejam amplamente reconhecidos, é importante notar que o foco aqui está na ampla aplicabilidade dos PSAs (Matthews et al., 2014; Parker et al., 2008).

Um exemplo no estado do Amazonas é o Programa Bolsa Floresta (PBF) que oferece apoio e fomento para comunidades tradicionais, visando contribuir com a conservação das florestas e a melhoria da qualidade de vida. Para assessorar essas comunidades, o programa promove diferentes medidas que visam desde o fortalecimento da participação, autonomia e protagonismo de grupos populares até o desenvolvimento do empreendedorismo e da capacidade de autogestão mantendo a floresta conservada. Atualmente, o benefício abrange cerca de 35 mil pessoas distribuídas nas Unidades de Conservação do Estado do Amazonas (Cisneros et al., 2022).

De acordo com (Campos-Silva and Peres, 2016), no Rio Juruá, o manejo do pirarucu aumenta a receita anual média das comunidades para US $10.601 ao ano em lagos protegidos, aumentando os benefícios financeiros locais, incluindo melhorias nas condições de vida da população, fortalecendo os valores culturais e a conservação da biodiversidade. Os PSAs promovem a conservação ambiental, aumentam a consciência global sobre a importância dos serviços ecossistêmicos e incentivam novas formas de sustentabilidade. Ao valorizar economicamente os serviços prestados pelos ecossistemas, os PSAs oferecem um modelo sustentável que pode ser replicado em diferentes contextos, adaptando-se às necessidades específicas de cada região e comunidade(Pascual et al., 2014; Wunder, 2015).

1.3. A pesca do pirarucu (*Arapaima gigas*)

A pesca é um importante meio de subsistência em todo mundo, principalmente para as comunidades de baixa renda. Na Amazônia é a principal fonte de aquisição de proteína, tornando a população dependente deste recurso. No entanto, e a pesca comercial desregrada resulta muitas vezes na superexploração e no colapso dos estoques pesqueiros (Darimont et al., 2015; Tregidgo et al., 2020). Esse colapso, também resultante da alta demanda comercial, tem sido uma preocupação para a conservação da biodiversidade e para economia local, principalmente pela exploração de pescados de maior tamanho e reprodução lenta, como o pirarucu , (Arapaima gigas) (Campos-Silva and Peres, 2016; Castello et al., 2009; Petersen et al., 2016).

De acordo com as instruções normativas do IBAMA n. 34, de 18 de junho de 2004 e n.º 001, de 01 de junho de 2005, a pesca, o transporte, a armazenagem e comercialização do pirarucu são proibidos em todo o Estado do Amazonas, exceto se proveniente de manejo de lagos. Tais instruções dão suporte ao decreto n.º 36.083 de 23/07/2015 que regulamenta a pesca manejada do pirarucu no Estado em Unidades de Conservação Estaduais, Áreas de Relevante Interesse Socioambiental e em Áreas de Acordo de Pesca, instituídas pelo órgão estadual competente. Os acordos de pesca estabelecem regras de regulação para as práticas pesqueiras entre comunidades de pescadores locais, podendo ser de subsistência e comercial, buscando lidar com os conflitos de pressão sobre os recursos pesqueiros e com sanções a serem aplicadas aos infratores (Castro and McGrath, 2001). Nestes acordos de pesca, os lagos são divididos em três categorias: I) lagos abertos à pesca comercial; II) lagos de subsistência para as comunidades; III) lagos protegidos pela comunidade para a recuperação populacional do pirarucu e das demais espécies de pescado. Neste último, a cota de retirada de arapaima é de 30% ao ano para cada lago, porcentagem que é determinada pelo IBAMA a partir da contagem feita nos mesmos lagos no ano anterior (Castello et al., 2009; decreto do Amazonas N.º 36.083, 23 de julho de 2015).

Na década de 1990 na Reserva de Desenvolvimento Sustentável Mamirauá, a pesca manejada do pirarucu foi implementada e devido ao alto nível de engajamento comunitário tem se replicado em todo o Estado do Amazonas. Esta atividade representa um raro exemplo onde a conservação da biodiversidade está alinhada à melhoria da qualidade de vida. Tais benefícios incluem a recuperação populacional dessa espécie historicamente super explorada, regulação das cadeias tróficas nos lagos, a proteção dos ambientes de várzea, melhorias nas condições de vida, promoção da equidade de gênero na pesca fortalecimento dos valores culturais e aumento da geração de renda (Campos-Silva et al., 2019; Campos-Silva and Peres, 2016; Freitas et al., 2020).

REFERÊNCIAS

Brondízio, E.S., Aumeeruddy-Thomas, Y., Bates, P., Carino, J., Fernández-Llamazares, Á., Ferrari, M.F., Galvin, K., Reyes-García, V., McElwee, P., Molnár, Z., Samakov, A., Shrestha, U.B., 2021. Locally Based, Regionally Manifested, and Globally Relevant: Indigenous and Local Knowledge, Values, and Practices for Nature. Annu Rev Environ Resour 46, 481–509. https://doi.org/10.1146/annurev-environ-012220-012127

Butchart, S.H.M., Walpole, M., Collen, B., Strien, A. v, Scharlemann, J.P.W., Almond, R.E.A., Baillie, J.E.M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K.E., Carr, G.M., Chanson, J., Chenery, A.M., Csirke, J., Davidson, N.C., Dentener, F., Foster, M., Galli, A., Galloway, J.N., Genovesi, P., Gregory, R.D., Hockings, M., Kapos, V., Lamarque, J.-F., Leverington, F., Loh, J., McGeoch, M.A., McRae, L., Minasyan, A., Morcillo, M.H., Oldfield, T.E.E., Pauly, D., Quader, S., Revenga, C., Sauer, J.R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S.N., Symes, A., Tierney, M., Tyrrell, T.D., Vié, J.-C., Watson, R., In, 2010. Global Biodiversity: Indicators of. Science (1979) 328, 1164–1168.

Campos-Silva, J.V., Hawes, J.E., Peres, C.A., 2019. Population recovery, seasonal site fidelity, and daily activity of pirarucu (Arapaima spp.) in an Amazonian floodplain mosaic. Freshw Biol 64, 1255–1264. https://doi.org/10.1111/fwb.13301

Campos-Silva, J.V., Peres, C.A., 2016. Community-based management induces rapid recovery of a high-value tropical freshwater fishery. Sci Rep 6, 1–13. https://doi.org/10.1038/srep34745

Carpenter, S.R., Mooney, H.A., Agard, J., Capistrano, D., Defries, R.S., Diaz, S., Dietz, T., Duraiappah, A.K., Oteng-Yeboah, A., Pereira, H.M., Perrings, C., Reid, W. V., Sarukhan, J., Scholes, R.J., Whyte, A., 2009. Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. Proc Natl Acad Sci U S A 106, 1305–1312. https://doi.org/10.1073/pnas.0808772106

Castello, L., Viana, J.P., Watkins, G., Pinedo-Vasquez, M., Luzadis, V.A., 2009. Lessons from integrating fishers of arapaima in small-scale fisheries management at the mamirauá reserve, amazon. Environ Manage 43, 197–209. https://doi.org/10.1007/s00267-008-9220-5

Castro, F. De, McGrath, D.G., 2001. O manejo comunitário de lagos na Amazônia, Parcerias Estratégicas.

Chan, K.M.A., Balvanera, P., Benessaiah, K., Chapman, M., Díaz, S., Gómez-Baggethun, E., Gould, R., Hannahs, N., Jax, K., Klain, S., Luck, G.W., Martín-López, B., Muraca, B., Norton, B., Ott, K., Pascual, U., Satterfield, T., Tadaki, M., Taggart, J., Turner, N., 2016. Why protect nature? Rethinking values and the environment. Proc Natl Acad Sci U S A 113, 1462–1465. https://doi.org/10.1073/pnas.1525002113

Cisneros, E., Börner, J., Pagiola, S., Wunder, S., 2022. Impacts of conservation incentives in protected areas: The case of Bolsa Floresta, Brazil. J Environ Econ Manage 111, 102572. https://doi.org/10.1016/j.jeem.2021.102572

Corvalan, C., Hales, Simon., McMichael, A., Butler, C., Campbell-Lendrum, D., Confalonieri, U., Leitner, K., Lewis, N., Patz, J., Polson, K., Scheraga, J., Woodward, A., Younes, M., 2005. Ecosystems and human well-being: Health Synthesis- A Report of the Millennium. World Health Organization 1–59.

Costa, H.C.M., Peres, C.A., Abrahams, M.I., 2018. Seasonal dynamics of terrestrial vertebrate abundance between Amazonian flooded and unflooded forests. PeerJ 2018. https://doi.org/10.7717/peerj.5058

Costanza, R., 2020. Valuing natural capital and ecosystem services toward the goals of efficiency, fairness, and sustainability. Ecosyst Serv 43, 101096. https://doi.org/10.1016/j.ecoser.2020.101096

Costanza, R., 2001. Visions, values, valuation, and the need for an ecological economics. Bioscience 51, 459–468. https://doi.org/10.1641/0006-3568(2001)051[0459:VVVATN]2.0.CO;2

Costanza, R., D'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. LK - https://royalroads.on.worldcat.org/oclc/4592801201, Nature TA - TT -.

Daily, G.C., Matson, P.A., 2008. Ecosystem services: From theory to implementation. Proc Natl Acad Sci U S A 105, 9455–9456. https://doi.org/10.1073/pnas.0804960105

Darimont, C.T., Fox, C.H., Bryan, H.M., Reimchen, T.E., 2015. The unique ecology of human predators. Science (1979) 349, 858–860. https://doi.org/10.1126/science.aac4249

de Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., ten Brink, P., van Beukering, P., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosyst Serv 1, 50–61. https://doi.org/10.1016/j.ecoser.2012.07.005

De Groot, R.S., Wilson, M.A., Boumans, R.M.J., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41, 393–408. https://doi.org/10.1016/S0921-8009(02)00089-7

Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., Larigauderie, A., Adhikari, J.R., Arico, S., Báldi, A., Bartuska, A., Baste, I.A., Bilgin, A., Brondizio, E., Chan, K.M.A., Figueroa, V.E., Duraiappah, A., Fischer, M., Hill, R., Koetz, T., Leadley, P., Lyver, P., Mace, G.M., Martin-Lopez, B., Okumura, M., Pacheco, D., Pascual, U., Pérez, E.S., Reyers, B., Roth, E., Saito, O., Scholes, R.J., Sharma, N., Tallis, H., Thaman, R., Watson, R., Yahara, T., Hamid, Z.A., Akosim, C., Al-Hafedh, Y., Allahverdiyev, R., Amankwah, E., Asah, T.S., Asfaw, Z., Bartus, G., Brooks, A.L., Caillaux, J., Dalle, G., Darnaedi, D., Driver, A., Erpul, G., Escobar-Eyzaguirre, P., Failler, P., Fouda, A.M.M., Fu, B., Gundimeda, H., Hashimoto, S., Homer, F., Lavorel, S., Lichtenstein, G., Mala, W.A., Mandivenyi, W., Matczak, P., Mbizvo, C., Mehrdadi, M., Metzger, J.P., Mikissa, J.B., Moller, H., Mooney, H.A., Mumby, P., Nagendra, H., Nesshover, C., Oteng-Yeboah, A.A., Pataki, G., Roué, M., Rubis, J., Schultz, M., Smith, P., Sumaila, R., Takeuchi, K., Thomas, S., Verma, M., Yeo-Chang, Y., Zlatanova, D., 2015. The IPBES Conceptual Framework - connecting nature and people. Curr Opin Environ Sustain 14, 1–16. https://doi.org/10.1016/j.cosust.2014.11.002

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R.T., Molnár, Z., Hill, R., Chan, K.M.A., Baste, I.A., Brauman, K.A., Polasky, S., Church, A., Lonsdale, M., Larigauderie, A., Leadley, P.W., Van Oudenhoven, A.P.E., Van Der Plaat, F., Schröter, M., Lavorel, S., Aumeeruddy-Thomas, Y., Bukvareva, E., Davies, K., Demissew, S., Erpul, G., Failler, P., Guerra, C.A., Hewitt, C.L., Keune, H., Lindley, S., Shirayama, Y., 2018. Assessing nature's contributions to people: Recognizing culture, and diverse sources of knowledge, can improve assessments. Science (1979) 359, 270–272. https://doi.org/10.1126/science.aap8826

Freitas, C.T., Espírito-Santo, H.M.V., Campos-Silva, J.V., Peres, C.A., Lopes, P.F.M., 2020. Resource co-management as a step towards gender equity in fisheries. Ecological Economics 176. https://doi.org/10.1016/j.ecolecon.2020.106709

Junk, W.J., Piedade, M.T.F., Lourival, R., Wittmann, F., Kandus, P., Lacerda, L.D., Bozelli, R.L., Esteves, F.A., Nunes da Cunha, C., Maltchik, L., Schöngart, J., Schaeffer-Novelli, Y., Agostinho, A.A., 2014a. Brazilian wetlands: Their definition, delineation, and classification for research, sustainable management, and protection. Aquat Conserv 24, 5–22. https://doi.org/10.1002/aqc.2386

Junk, W.J., Piedade, M.T.F., Lourival, R., Wittmann, F., Kandus, P., Lacerda, L.D., Bozelli, R.L., Esteves, F.A., Nunes da Cunha, C., Maltchik, L., Schöngart, J., Schaeffer-Novelli, Y., Agostinho, A.A., 2014b. Brazilian wetlands: Their definition, delineation, and classification for research, sustainable management, and protection. Aquat Conserv 24, 5–22. https://doi.org/10.1002/aqc.2386

Junk, W.J., Piedade, M.T.F., Schöngart, J., Cohn-Haft, M., Adeney, J.M., Wittmann, F., 2011. A classification of major naturally-occurring amazonian lowland wetlands. Wetlands 31, 623–640. https://doi.org/10.1007/s13157-011-0190-7

Kiker, G.A., Bridges, T.S., Varghese, A., Seager, P.T.P., Linkov, I., 2005. Application of multicriteria decision analysis in environmental decision making. Integr Environ Assess Manag 1, 95–108. https://doi.org/10.1897/IEAM_2004a-015.1

Onishi, C.M., 2019. Implantação De Programas De Pagamento Por Serviços Ambientais (Psa) Como Estratégia De Conservação Do Patrimônio Natural: a Contribuição Do Setor Empresarial.

Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E., Stenseke, M., Watson, R.T., Başak Dessane, E., Islar, M., Kelemen, E., Maris, V., Quaas, M., Subramanian, S.M., Wittmer, H., Adlan, A., Ahn, S.E., Al-Hafedh, Y.S., Amankwah, E., Asah, S.T., Berry, P., Bilgin, A., Breslow, S.J., Bullock, C., Cáceres, D., Daly-Hassen, H., Figueroa, E., Golden, C.D., Gómez-Baggethun, E., González-Jiménez, D., Houdet, J., Keune, H., Kumar, R., Ma, K., May, P.H., Mead, A., O'Farrell, P., Pandit, R., Pengue, W., Pichis-Madruga, R., Popa, F., Preston, S., Pacheco-Balanza, D., Saarikoski, H., Strassburg, B.B., van den Belt, M., Verma, M., Wickson, F., Yagi, N., 2017. Valuing nature's contributions to people: the IPBES approach. Curr Opin Environ Sustain 26–27, 7–16. https://doi.org/10.1016/j.cosust.2016.12.006

Pascual, U., Phelps, J., Garmendia, E., Brown, K., Corbera, E., Martin, A., Gomez-Baggethun, E., Muradian, R., 2014. Social equity matters in payments for ecosystem services. Bioscience 64, 1027–1036. https://doi.org/10.1093/biosci/biu146

Petersen, T.A., Brum, S.M., Rossoni, F., Silveira, G.F.V., Castello, L., 2016. Recovery of Arapaima sp. populations by community-based management in floodplains of the Purus River, Amazon. J Fish Biol 89, 241–248. https://doi.org/10.1111/jfb.12968

Strand, J., Soares-Filho, B., Costa, M.H., Oliveira, U., Ribeiro, S.C., Pires, G.F., Oliveira, A., Rajão, R., May, P., van der Hoff, R., Siikamäki, J., da Motta, R.S., Toman, M., 2018. Spatially explicit valuation of the Brazilian Amazon Forest's Ecosystem Services. Nat Sustain 1, 657–664. https://doi.org/10.1038/s41893-018-0175-0

Tregidgo, D., Barlow, J., Pompeu, P.S., Parry, L., 2020. Tough fishing and severe seasonal food insecurity in Amazonian flooded forests. People and Nature 2, 468–482. https://doi.org/10.1002/pan3.10086

Tuomisto, H., Ruokolainen, K., Kalliola, R., Linna, A., Danjoy, W., Rodriguez, Z., 1995. Dissecting amazonian biodiversity. Science (1979) 269, 63–66. https://doi.org/10.1126/science.269.5220.63

Wittman, H., Chappell, M.J., Abson, D.J., Kerr, R.B., Blesh, J., Hanspach, J., Perfecto, I., Fischer, J., 2017. A social–ecological perspective on harmonizing food security and biodiversity conservation. Reg Environ Change 17, 1291–1301. https://doi.org/10.1007/s10113-016-1045-9

Wittmann, F., Schöngart, J., Montero, J.C., Motzer, T., Junk, W.J., Piedade, M.T.F., Queiroz, H.L., Worbes, M., 2006. Tree species composition and diversity gradients in white-water forests across the Amazon Basin. J Biogeogr 33, 1334–1347. https://doi.org/10.1111/j.1365-2699.2006.01495.x

Wunder, S., 2015. Revisiting the concept of payments for environmental services. Ecological Economics 117, 234–243. https://doi.org/10.1016/j.ecolecon.2014.08.016

2. THE COMMUNITY MANAGEMENT OF ARAPAIMA (*Arapaima gigas*) IN AN AMAZONIAN BRIGHT SPOT: A HISTORY OF INSTITUTIONAL STRENGTHENING

Revista pretendida: Land Use Policy

Ana Carla Rodrigues, Adevaldo Dias, Richard James Ladle, Ana Claudia Mendes Malhado, João Vitor Campos-Silva, Eduardo Sonnewend Brondizio

2.1 Abstract

Management of common-pool resources is important for sustainability and community well-being, particularly in complex socio-ecological systems like the Amazon. However, developing effective systems of resource management is challenging, and there are few successful examples that can be used as model systems. Here, we describe one such success story, the co-management of pirarucu (Arapaima gigas) in the Middle Juruá River. We explore the factors that have led to its success, focusing on polycentric governance, institutional design principles and socioeconomic impacts. We carried out open and semi-structured interviews with different actors involved in co-management. Furthermore, we collected the registered internal regulations of the communities involved in co-management. We observed significant changes that involved decentralization, increased inclusion and improved monitoring and sanctioning mechanisms. These adjustments reflect an adaptive approach to arapaima management, incorporating local needs and promoting participatory decision-making. Collaborative management of pirarucu serves as a model for other natural resource systems in the Amazon, illuminating ways to reconcile the protection of biodiversity while generating diverse benefits for local communities.

Keywords: common-pool resources, polycentric governance, co-management, socio-bioeconomy, sustainability, community management

2.2 Introduction

The Amazon basin is a critical conservation and cultural region due to its unparalleled biodiversity, sociolinguistic diversity, and numerous ecosystem services (Levis et al., 2020). Water resources, represented by the Amazon River and its vast network of tributaries, streams, lakes, and floodplains, are fundamental to ecological processes and the food security and well-being of indigenous peoples, local communities, and urban populations (Lopes et al., 2021). These bodies of water support high biodiversity, serving as habitat for many species and maintaining hydrological and climatic cycles (Junk et al., 2007). They are also vital for fishing, agriculture, and subsistence of riverside and indigenous communities, in addition to serving transportation and communication needs. The conservation of these resources is crucial for environmental preservation and the continuity of the life and culture of Amazonian populations (Castello et al., 2013). However, environmental protection policies in Brazil focus more on terrestrial environments, making scientific support essential for the protection of Amazonian aquatic environments (Castello et al., 2013).

Sustainable management of natural resources is fundamental for the preservation of ecosystems and the well-being of local communities (Brondizio & Le Tourneau, 2016). In the vastness of the Amazon, community management of Arapaima (Arapaima gigas), also known as pirarucu or paiche, is a model of success (Campos-Silva & Peres, 2016). The involvement of fishers in management processes has played a fundamental role in the conservation of small-scale fisheries in various ways, consolidating institutions over time (Ostrom, 1990). The commercial overexploitation of arapaima in recent decades has brought the species' population to the brink of extinction. The response to this crisis began to emerge in the 1990s, marked by the launch of the Pirarucu Project in Mamirauá, a Sustainable Development Reserve in Amazonas. Since its creation in 1999, the project has actively involved local communities in practices regulated by the Brazilian Natural Resources Agency (IBAMA), establishing standards for fishing seasons, minimum sizes, and annual quotas.

Co-management of the Arapaima in the Amazon is an example of community-based natural resource management that has been successful in conserving this important species (Campos-Silva & Peres, 2016). The co-management process involves the active participation of local communities in monitoring, surveillance, fishing, and selling the fish (Castello et al., 2009). In addition, these communities participate in decision-making together with federal and state institutions, NGOs, universities, and associations. The communities usually establish agreements categorizing the lakes into areas for fish reproduction only, subsistence fishing lakes, and Arapaima management lakes. Besides the agreements signed between communities and regulatory institutions, there are restrictions on access to certain fishing areas and the establishment of quotas that can be fished. One of the benefits of the co-management of the Arapaima is that it contributes to food security and the subsistence of the local communities, which depend on the fish for their diet, and its sale results in income generation. These goods and services, subject to different levels of exclusion, subtraction, and overlapping types of property regimes in their production or consumption (Mcginnis, 2012; Ostrom, 1990), reflect the complexity of relationships between local communities and the co-management of the Arapaima in the Amazon.

Community-Based Management (CBM) is notable because of its ability to actively engage local communities in decision-making processes and implementing sustainable practices (Brosius et al., 1998). This approach promotes the conservation of ecosystems, social sustainability, and improved quality of life. The success of Community-Based Management combines traditional knowledge and the active participation of communities in natural resource management processes (Berkes, 2009; Ostrom, 2008). This pioneering project in the Mamirauá Sustainable Development Reserve has served as a model for implementing Arapaima management in other regions, such as the Juruá River. These initiatives have positively impacted the conservation of the species and the development of social organizations, both within and between local communities (Campos-Silva et al., 2018).

The management of Arapaima in the Juruá River is deeply intertwined with economic phases, historical influences, and power dynamics that have shaped the region. This CBM is the result of the economic and social scenarios that culminated in the first fishing agreements and moulded the evolution of institutions over time. The trajectory of communities in the Juruá River region, influenced by the rubber cycles and the economic transformations of the 1980s, highlights the resilience and adaptability of local populations in the face of historical and environmental challenges. In this dynamic context, the creation of the Médio Juruá Extractive Reserve (Resex) in the 1990s was a fundamental milestone. In addition to preserving the environment, the Resex redefined social relationships, granting collective rights and promoting sustainable practices.

The trajectory of the communities in the Rio Juruá region was influenced by the rubber cycles and the economic transformations of the 1980s. This highlights the resilience and organizational capacity of the local populations in the face of the historical challenges of exploitation. With the process of community organization also came the social pressure to create the Médio Juruá Extractive Reserve (Resex) in the 1990s. This directly contributed to conserving the environment, redefined social relations, granted collective rights and promoted sustainable practices. The community organizations, state organizations, conservation units, and NGOs, formed a broad collaborative network to develop comprehensive solutions to local challenges. A relevant example of social organization is the Association of Rural Producers of Carauari (ASPROC), which brought together approximately 800 families from 55 riverside communities, becoming an important link between partner institutions and conservation units.

In addition to relations between communities, ASPROC also extends to partnerships with research institutions and NGOs, further strengthening the organization's capacity. This synergy between the community, scientific, and non-governmental sectors contribute to sustainable management, highlighting the importance of interdisciplinary cooperation and the exchange of knowledge in the development of effective management practices. These partnerships expand the spectrum of influences, allowing a more holistic approach to promoting sustainable Arapaima management in the Juruá River region.

The success of Arapaima management on the Juruá River will be evaluated through institutional principles, with the active participation of community members in decision-making processes. Applying Ostrom's design principles can provide valuable guidance for developing effective community management systems. This approach can help increase the resilience and adaptive capacity of local communities involved in the co-management of natural resources. This analytical tool is particularly useful for examining changes in various categories of rules and the social-organizational co-management processes involved in crafting them as social groups cooperate. Organizing these social dynamics as “action situations” provides us with analytical resources “that can be used to describe, analyses, predict and explain behavior within groups of institutional arrangements” (Ostrom, 2005). In this way, the design principles help us organize institutional characteristics to determine the tensions, contradictions, limitations, and catalysts of collective action at various levels. We must recognize that the design principles seek to understand how the governance structure of CBM can be maintained in the long term and replicated in other regions, as it has been a successful case of co-management.

Despite the clear success of co-management of Arapaima, there are still nuances to be understood and strengths to be leveraged. This study explores how the community-based institution has organized itself for the management of arapaima and how governance structures have been established. By analyzing the integration of Elinor Ostrom's design principles in management activities, we evaluate the relationships among institutions throughout the management process. Our goal is to further strengthen and replicate the successful model of Arapaima management, providing a robust foundation for effective natural resource management policies and practices worldwide.

2.3 Methods

2.3.1 Study Area and socioecological context of Jurua River

The Juruá River is notable for its extensive, highly productive floodplains, supporting hundreds of indigenous and non-indigenous human settlements. The landscape consists of seasonally flooded (várzea) forests throughout the floodplain and adjacent upland (terra firme) forests (Junk et al., 2011). The Juruá, particularly its middle section, played a crucial role during the rubber boom, when thousands of people from northeastern Brazil migrated to the Amazon to work as rubber tappers. These individuals lived under conditions akin to slavery, without social rights, and often suffered from severe poverty, debt patronage, tropical diseases, and lack of access to healthcare and education (D'Almeida, 2006). With the assistance of the Catholic Church and the environmental movement that emerged around the social activist Chico Mendes, these local communities began a process of self-organization to secure essential social and land rights (Fearnside, 1989). In this context, two large sustainable-use protected areas were established in this region. The federally managed Médio Juruá Extractive Reserve (ResEx Médio Juruá; 5°33′54″S, 67°42′47″W) was created in 1997 and hosts approximately 700 people distributed across 13 villages within its 253,227 hectares. The state-managed Uacari Sustainable Development Reserve (RDS de Uacari; 5°43′58″S, 67°46′53″W) was created in 2005, is home to about 1200 residents living in 32 communities within its 632,949 hectares. The local economy in both reserves is sustained by fisheries, slash-and-burn agriculture, and non-timber forest products such as oil seeds and palm fruits (Newton et al. 2011) and supported by payments for environmental services (Alves-Pinto et al., 2018). However, two examples of community-based management (CBM) stand out for generating significant social and economic benefits for rural communities: the CBM of arapaima and freshwater turtles.

Arapaima management

The Arapaima (Arapaima gigas) is the largest freshwater scaled fish, reaching up to 3 meters in length and over 200 kilograms in weight (Nelson, 1994). This iconic species has been crucial for subsistence in the Amazon since pre-Columbian times (Prestes-Carneiro et al., 2016). However, in the past century, arapaima populations have plummeted due to intense commercial fishing, leading to their local extinction in many areas (Castello et al., 2015). Despite a ban by the Brazilian government, illegal fishing persisted, hindering recovery efforts (Castello & Stewart, 2010; Cavole et al., 2015). In response, local communities, experienced fishers, and researchers initiated a community-based management (CBM) model in 1999 at the Mamirauá Sustainable Development Reserve (Castello et al., 2009, 2011).

The arapaima adapted to anoxic lake environments by developing a swim bladder suitable for breathing air (Brauner et al., 2004). Consequently, arapaima frequently surface to breathe, allowing trained fishers to visually count them using a standardized protocol (Castello, 2004). This unique trait facilitates reliable population estimates, enabling the government to assign a harvest quota of up to 30% of adult individuals per CBM unit (Castello et al., 2011). Another vital aspect of the CBM approach is that local communities must zone their water bodies, designating protected no-take lakes and ensuring surveillance against poaching. This initiative has been highly successful (Castello et al., 2009), and CBM schemes for arapaima have since expanded throughout the Amazon.

Research has demonstrated that arapaima CBM yields significant outcomes for both biodiversity conservation and the well-being of rural communities (Campos-Silva & Peres, 2016; Castello et al., 2009; Petersen et al., 2016). Along the Juruá River in the western Brazilian Amazon, community-based lake protection has led to a remarkable 425.2% increase in arapaima populations over 11 years (Campos-Silva et al., 2019). Even outside protected areas, populations have shown a 397.5% annual increase (Campos-Silva et al., 2019). A single protected lake can host over 2800 individuals, compared to an average of just nine in unprotected lakes (Campos-Silva et al., 2019; Campos-Silva & Peres, 2016). Similar patterns have been observed in other river basins, where arapaima have also recovered significantly (Castello et al., 2009; Petersen et al., 2016). Additionally, the protection of lakes benefits numerous co-occurring species, including caimans, freshwater turtles, and other fish species (Arantes & Freitas, 2016; Campos-Silva & Peres, 2016; Miorando et al., 2013).

Beyond ecological benefits, arapaima CBM has driven substantial social transformations in Amazonian communities. Protected lakes provide a steady annual income for rural residents who often lack other cash-earning opportunities. This financial security allows for savings and emergency expenditures, such as urgent healthcare (Campos-Silva and Peres 2016). Profits from the harvest also contribute to improving basic infrastructure and living conditions within households and communities (Campos-Silva & Peres, 2016). Other significant social benefits reported by participants in arapaima CBM include enhanced food security, community pride, cultural preservation, and a more equitable distribution of fishery profits (Campos-Silva & Peres, 2016).

2.3.2 Data Collection and Analysis

First, we conducted open and semi-structured interviews with the main leaders who led the implementation process of Arapaima management at Juruá River. These interviews aimed to elucidate the different actors involved in the arrangements, the governance, and the decision-making structure. Secondly, we collected all the recorded internal regulations of the communities engaged in co-management within the Juruá River region. These internal regulations delineate guidelines, norms, and rules governing the utilization and conservation of resources associated with Arapaima co-management. As part of the updating process, each community convened individual focus meetings to propose modifications to the existing regulations. The regiments were organized, initially, by sector, reflecting the structure of the groups of communities that collaborated. The initial regulations underwent review and adjustments in 2014 and complete reformulation in 2023.

Based on the standardized principles for the co-management of Arapaima, we carried out a quantitative and qualitative accounting of the changes that have occurred over time in the internal regulations, in addition to a textual analysis approach based on analytical reference and coding of the elements of the internal regulations. We used Ostrom's design principles to guide the analysis process and synthetically capture the conditions that define the configuration of the communities' institutional arrangements. Subsequently, the texts were coded according to thematic categories, using design principles in textual analysis, which enabled the quantitative analysis of the data. After collecting data from the internal regulations, a radar plot was created to illustrate the evolution of the internal regulations (Figure 1). Furthermore, we included data on people's perceptions of improvements in nature over time, as well as data on arapaima counts in the lakes during the regime periods.

Following Ostrom's design principles for managing common-pool resources, we implemented the following evaluation strategies:

(1) Clearly Defined Boundaries: It is essential to establish clear and well-defined boundaries for the common resource so that users understand their rights and responsibilities. In our case, the allocation of lakes among communities is explicitly defined, specifying which lakes are designated for fishing, breeding, or management.

(2) Adaptive Rules: Resource usage rules must be flexible and responsive to the changing needs of the community. Our evaluation allows for adaptive rules, where community members can propose changes, and institutions act as intermediaries to facilitate these adjustments. This ensures that the allocation and use of lakes can be renegotiated as needed.

(3) User Participation and Involvement: Active participation of users in the management and decision-making processes is crucial. In our model, management is entirely carried out by community members, who collectively determine participation in various management activities, ensuring that decisions are made inclusively and transparently.

(4) Monitoring: Continuous monitoring of common resources and institutional compliance is necessary to ensure rules are followed and issues are promptly addressed. This involves regular checks and assessments of the resources and the governance structures in place.

(5) Graduated Sanctions: Effective and appropriate sanctions must be in place for those who violate resource usage rules. For instance, in cases of unauthorized lake usage or failure to fulfill management responsibilities, community-defined sanctions are enforced to maintain order and compliance.

(6) Conflict Resolution Mechanisms: There must be fair and efficient mechanisms for resolving conflicts among users. Our framework includes defined processes for conflict resolution, involving relevant stakeholders to ensure equitable and timely outcomes.

(7) Recognition of User Rights: The rights of users must be recognized and respected concerning the common resource. This includes clearly delineated rights

about which fish can be caught and the quantities allowed, ensuring sustainable use and equity among users.

(8) Supportive External Authorities: Involvement of external bodies such as state agencies and NGOs can enhance resource management. For instance, fishing quotas regulated by the state ensure that the resource is used sustainably.

In addition, we applied the polycentric governance framework to analyze organizational structures and their contributions to co-management (Ostrom, 1990, 2010; Schröder, 2018). Data collection involved interviews with local community members, community leaders, and organization representatives to gather insights into the implementation of management practices and current activities.

2.4 Results and discussion

2.4.1 Implementation history

The community-based management of Arapaima on the Juruá River benefited from a history of community-led protection of lakes supported by the catholic church in the 1970s. These actions strengthened social organization and, critically, resulted in the exclusion of large commercial boats. The spatial zoning of lakes and an experimental harvesting quota was initially initiated in São Raimundo, an emblematic local community with strong social organization and the presence of respected regional leaders. After the implementation success at São Raimundo, several rural communities adopted the same model in an attempt to replicate the same rules and dynamics.

Local community leaders played a crucial role in the implementation of Arapaima arrangement at Juruá River. Their intimate understanding of local contexts, cultural norms, and community dynamics enabled them to mobilize and engage community members. As trusted figures, they acted as a bridge between external conservation agencies and local populations, ensuring that conservation strategies are culturally sensitive and locally relevant. By advocating for sustainable practices and facilitating transparent communication, local leaders also helped foster a sense of ownership and responsibility towards conservation efforts. Their leadership ensured that the stated conservation goals aligned with the community's needs and aspirations, thereby enhancing the sustainability and impact of conservation programs. Furthermore, local leaders also mentored future generations, building a legacy of environmental stewardship and community resilience that supported the long-term success of the project.

2.4.2 Polycentric governance

Territorial governance along the Juruá River can be examined through the lens of polycentric governance (Ostrom, 2010), which involves multiple decision-making entities governing a resource within defined boundaries and includes a variety of organizations, scales, autonomies, and non-hierarchical processes (Figure 1). Along the river, several decision-making centers engage multiple stakeholders, from individuals to various organizations such as community associations, non-profits, universities, government institutions, and private companies (e.g., from the cosmetics industry). This collaborative approach fostered a democratic decision-making system and numerous opportunities for knowledge co-production. This multi-sector partnership aims to conserve natural resources, improve rural community well-being, and integrate local people into profitable and accountable value chains for processing diverse aquatic and terrestrial resources, including managed fish, agricultural produce, palm fruits, and natural plant oils used in the cosmetics industry. Each decision-making center operates with a high degree of autonomy, reflecting diverse cultural backgrounds and spatial scales. In this context, community meetings are essential to improve local rules and ensure high levels of compliance. If the communities face stronger or unexpected challenges, local assemblies of grassroots associations provide a platform for them to voice their concerns and demands for collective action. If a local issue cannot be addressed at this level, it can be taken up at broader decision-making centers. For instance, the Mid-Juruá Territory Forum brings together multiple stakeholders to implement comprehensive programs that expand the scale of local projects or single community interventions.

The Rio Juruá Ramsar site, designated in 2019, exemplifies wetland conservation through international legislation aligned with local aspirations. Protected areas also have their own decision-making centers, which help implement federal and state government rules and plans. Each protected area hosts a management council, a highly participatory body composed of diverse local actors that determines territorial priorities. Although these decision-making centers operate at different levels and spatial scales, they are interconnected around the common goal of conserving natural resources and enhancing rural community well-being.

Another decision-making body that is configured as an axis of polycentric governance is the Pirarucu Collective. The Pirarucu Collective (PC) is a network of community-based organizations, supporting NGOs and government agencies involved in the management of the Arapaima. This network was created by communities that successfully managed the Arapaima to address larger-scale processes that influence the value chain, ultimately determining the price paid to fishers for the Arapaima. The PC became a decision-making platform to coordinate efforts and interventions along the value chain to strengthen and recognize local participation, transforming it into a socially and economically fair chain that promotes biodiversity conservation. Currently, the PC is composed of community-based organizations representing 20 management units and nearly 2500 families. The network operates according to principles of trust and mutual understanding between members, humility, collaboration, and respect for the autonomy of participating organizations. The PC also helps to create and strengthen public policies such the Arapaima minimum price, which is a policy created by the Brazilian government to ensure fairer commercial relationships. Undoubtedly, the results achieved by this network reflect the relationship between its members and the collaborative environment.

As a result of the existence of the PC, individual experience and knowledge have been shared among members improving their management and commercial practices. At the individual level, peer recognition allows members to gain more confidence and restore a sense of identity and local pride. It also empowers community-based organizations and NGOs to have a voice in political and technical forums, often negotiating sensitive issues as a group instead of as a lone organization. Moreover, the

PC allowed decisions and interventions to be implemented simultaneously at several sites, affecting the value chain at a regional scale. Among its main achievements is the strengthening of different public policies and the creation of a collective brand called "Gosto da Amazônia" ("the taste of the Amazon" in English) (www.gostodaamazonia.com.br). This still embryonic collective brand raised the price of managed Arapaima from 50% to 85% higher than the average in the state, depending on where the Arapaima is sold (in the community, in the nearest city, or in the state capital, Manaus).

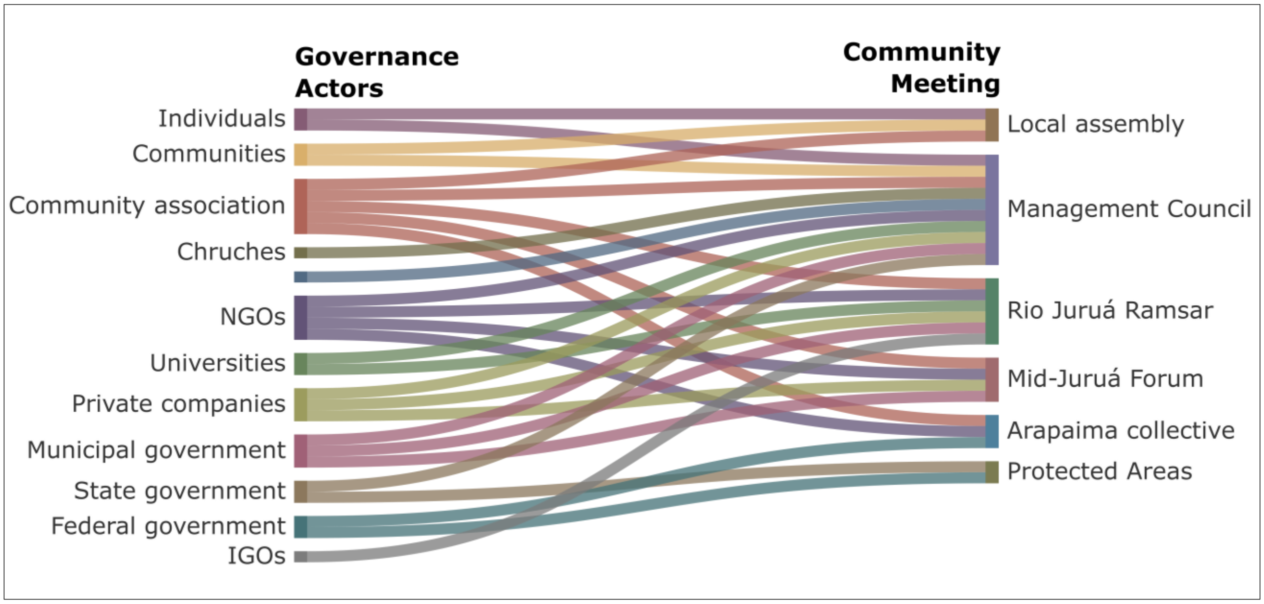

Figure 1. Territorial governance along the Juruá River examined through the lens of polycentric governance. This approach involves multiple decision-making entities managing resources within defined boundaries, encompassing diverse organizations, scales, autonomies, and non-hierarchical processes.

2.4.3 A positive example of common pool resource management

The management of Arapaima at Jurua River involves the complex use of a network of resources and social-ecological systems. As such, these activities related to arapaima management exemplify a situation of Common-Pool Resources (CPR's)(Ostrom, 2005). Specifically, the resources used in arapaima co-management activities are characteristic of common resources (subsistence fishing and fish sales), highlighting the role of subsistence fishing and trade among communities. Furthermore, administrative management has been achieved through the implementation of community-based normative institutions. The complexity resulting from the expansion of co-management is also highlighted, adding institutional and socioeconomic complexity to the management of CRP (Stronza, 2010).

The co-management of Arapaima, strongly shaped by the communities, demonstrates participatory development in the creation of institutions aimed at developing a participatory and multi-level governance system. Natural resource management can illustrate the application of Common-Pool Resources (CPR’s) principles in natural resource management. CPR theory can be applied to understand how institutions play roles in the management of natural resources. The sustainable management of Arapaima has led to the creation of effective organizations that coordinate and facilitate joint decision-making among the involved parties. Continuous monitoring of agreements and regulations is essential to ensure adherence to institutional rules and to identify and resolve any issues or violations that may arise. Additionally, community-based organizations promote cooperation among different groups and institutions involved in Arapaima management. The creation of cooperative networks and the establishment of agreements between organizations are fundamental to ensuring an integrated and collaborative approach to resource management. These organizations actively promote and participate in local community dynamics, assisting in the formation of institutions, and in the development and adjustment of norms and regulations in line with the communities' needs and demands. This involves discussing and negotiating agreements that consider the needs and perspectives of all stakeholders.

This process usually involves establishing effective communication mechanisms, such as dialogue forums and discussion spaces, where different actors within the organizations exchange knowledge, experiences, and relevant information for management. In summary, the CPR framework can be applied to organizational development, highlighting the importance of joint decision-making, the establishment of agreements, and the implementation of effective monitoring mechanisms within and between organizations. Therefore, the management of Arapaima involves the complex use of natural resources in conjunction with an extensive network of socio-ecological systems. As such, these activities related to Arapaima management exemplify a common-pool resources (CPR’s) situation.

2.4.4 . Regulations and Institutional Effectiveness in Community Management of Arapaima: An Analysis through Design Principles

This study provides a comprehensive overview of the presence of design principles (Ostrom, 1990) and their effectiveness within Arapaima co-management regulations. The evolution of these regulations reflects practical adjustments based on experiences from management activities over three periods. Initially, the regulations were defined by sector when the communities joined the management process. In the second phase, around 2014, changes to these regulations were introduced and formalized in response to community demands. Finally, in the third phase, in 2023, regulations were individualized by community rather than by sector, as the areas within the Extractive Reserves (Resex) and Sustainable Development Reserves (RDS) had previously been divided (Figure 2).

The main changes in the regulations, in relation to design principles, were notably the decentralization of the regulations during these review and reformulation periods. In the third revision, each set of regulations was tailored to the preferences of the respective community. However, this introduced new challenges for local families and communities, necessitating the development of testable sets of rules and norms that may require complex adjustments in the future: (1) Boundaries: The most significant changes in boundary definitions involved decisions and adjustments related to lakes, often due to logistical reasons or agreements between communities and management facilities. (2) Local Rules: The most notable modifications to local rules involved changes in who could participate in management activities, the conditions of rights and duties, and the timing for new members to gain full management rights. (3) Recent updates have also emphasized the inclusion of women, elders, and youth in management activities, reflecting a shift towards more inclusive and adaptive rulemaking. (4). Monitoring: The changes in monitoring involved enhancing the oversight of compliance with community agreements and management activities. Monitoring now focuses on ensuring that members adhere to established roles and responsibilities, with more robust mechanisms for tracking adherence to community and management agreements. (5). Changes in sanctions for non-compliance with management activities and community regulations became more pronounced. Additionally, gradual sanctions were introduced, including temporary suspension of management profits, restrictions on fishing in certain lakes, and even expulsion from the community. (6) Conflict Resolution: conflict resolution continues to rely on dialogue, community expulsion, and notifications from the management of the RDS and Resex. (7) Recent revisions have refined the recognition of user rights concerning resource use, quantities, and qualities. Specific increases in fish catches and sales in the community lakes may occur due to food shortages, financial crises, or health issues within the community. Additionally, the use of the community financial fund may be required to address such needs critics. (8). Multiple Layers: Various entities are involved and continue to participate in management actions, including bureaucratic processes, sanctions, regulations, and associations that address members' demands. NGOs providing scientific and technical support are also involved. Notably, there was an increase from Period 1 to Period 2, likely due to the growing number of NGOs and the creation of community associations.

Regulations influence the behavioral processes associated with claims and use of natural resources, thereby impacting all aspects of resource management and its outcomes. The rules and norms established by institutions at various organizational levels help reduce uncertainties among the population and contribute to mediating competing actions and the values that individuals and groups bring to biodiversity management.

This analysis is rooted in a holistic approach to examining collective actions; it considers how individuals and communities operate within shared contexts of rules and constraints related to the use of biophysical, political, cultural, and economic resources (Ostrom et al., 1994). The design principles framework reveals how institutions are defined in relation to participants, existing rules, and proposed changes in co-management activities, evaluating the different types of design principles (Ostrom et al., 1994).

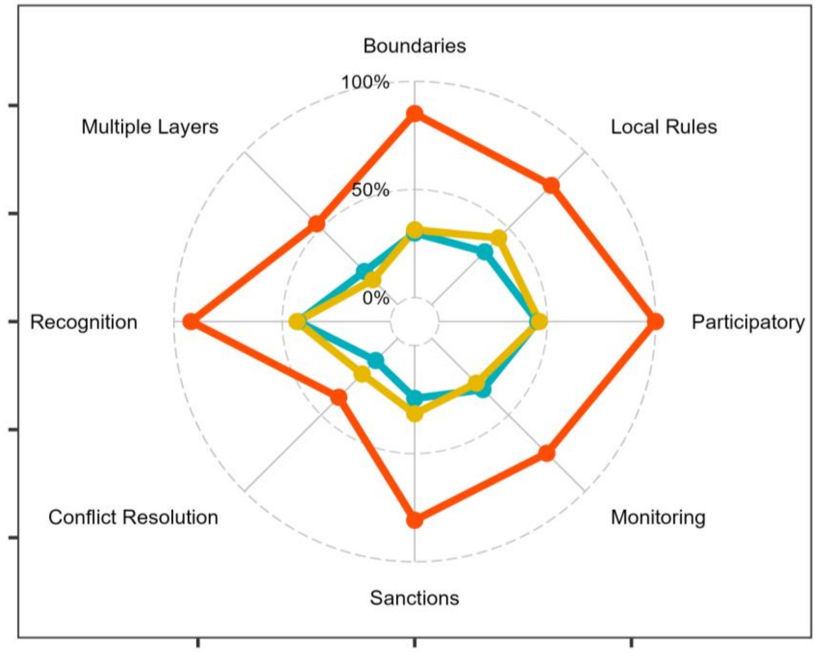

Figure 2. The evolution of design principles (DPs) and their main features across three periods: T1, Initial Phase: Sector-based regulations established as communities joined the management process (blue). T2, Second Phase, around 2014: Regulations revised, and f formalized in response to community demands (yellow). T3, Third Phase, 2023: Regulations individualized by community (red)

Ostrom's (1990) design principles outline the characteristics of institutional systems involved in the management of common-pool resources. These principles have practical applications in guiding the creation and management of governance systems aimed at ensuring the sustainable use of common resources. Specifically, the principles can help design institutions that support the sustainable use of resources and establish effective mechanisms for monitoring, enforcing, and discussing rules and norms among stakeholders. This approach can help increase the resilience and adaptive capacity of local communities involved in the management of various resources.

Based on the review of the internal regulations of the communities and following the application of the design principles, it is assumed that the presence of clear rules, active community participation in decision-making, effective monitoring, and the existence of sanction mechanisms are correlated with the success of natural resource management and the sustainability of resources in the Amazon region. In the context of Arapaima management, the implementation of clear rules, such as fishing seasons, minimum catch sizes, and controlled catch quotas, reflects efficient mechanisms to ensure the sustainability and oversight of common resource management in the Amazon.

2.4.5 Arapaima as a symbol of the new Amazonian sociobioeconomy

The formation of the institutions described above resulted from a participatory process of joint decision-making, within local communities and with intra-organizational support. In addition, the strengthening of social organizations, such as fisher's associations and community cooperatives, emphasizes the importance of social organization in strengthening the effective management of resources, helping with external bureaucratic processes and contacts with other organizations and bodies. The interaction between the implementation of the Arapaima management institution and the strengthening of social organizations in the collaboration illustrates the principles of the CPR, demonstrating the orientation and effectiveness of this governance model in the Amazon context.

Using design principles, organizations manage and protect common pool resources (CPRs), ranging from the creation and application of participatory rules, adjusted to the local reality for the use of common resources, monitoring and enforcing these norms and rules, acting in managed decision-making with active and participatory decisions to resolve bottlenecks and conflicts in the institutions. Even so, the multi-level management of CPRs, as in this case of co-management, allows for greater use of resources by ensuring that the rules and policies are fair and effective for all stakeholders. In this way, CPRs prevent ecosystems from collapsing by using them in ways that don't deplete them, guaranteeing common resources for the communities that depend on them, as well as the resources originated and used by the cascade effect.

The inclusion of all organizations in different decision-making environments increases the resilience of the entire model, ensuring solutions for various bottlenecks throughout the value chain. The strategy based on the design principles can be replicated for many other value chains implemented by similar actors. Several aspects of this governance model are based on knowledge and social organization, agreed upon by community members over many decades of resource scarcity, exploitation, and lack of technical support. Currently, they may have inspired the use of common-pool resources in remote regions, where infrastructure and logistics needs were absent. The sociobioeconomy has become a target strategy to align biodiversity protection and wellbeing in Amazonia.

There are several challenges in terms of a consolidation of an Amazonian concept of sociobioeconomy beyond the monetary dimension (Vatn et al., 2024). In this context, the community management of Arapaima serves as a model that can inspire new bioeconomic models, illuminating pathways to reconcile biodiversity protection, local well-being, and strong governance structures in previously disadvantaged environments.

Referências

Alves-Pinto, H.N., Hawes, J.E., Newton, P., Feltran-Barbieri, R., Peres, C.A., 2018. Economic Impacts of Payments for Environmental Services on Livelihoods of Agro-extractivist Communities in the Brazilian Amazon. Ecological Economics 152, 378–388. https://doi.org/10.1016/j.ecolecon.2018.05.016

Arantes, M.L., Freitas, C.E.C., 2016. Effects of fisheries zoning and environmental characteristics on population parameters of the tambaqui (Colossoma macropomum) in managed floodplain lakes in the Central Amazon. Fish Manag Ecol 23, 133–143. https://doi.org/10.1111/fme.12164

Berkes, F., 2009. Evolution of co-management: Role of knowledge generation, bridging organizations and social learning. J Environ Manage 90, 1692–1702. https://doi.org/10.1016/j.jenvman.2008.12.001

Brauner, C.J., Matey, V., Wilson, J.M., Bernier, N.J., Val, A.L., 2004. Transition in organ function during the evolution of air-breathing;insights from Arapaima gigas, an obligate air-breathing teleost from the Amazon. Journal of Experimental Biology 207, 1433–1438. https://doi.org/10.1242/jeb.00887

Brosius, J.P., Tsing, A.L., Zerner, C., 1998. Representing communities: Histories and politics of community-based natural resource management. Soc Nat Resour 11, 157–168. https://doi.org/10.1080/08941929809381069

Campos-Silva, J.V., Hawes, J.E., Peres, C.A., 2019. Population recovery, seasonal site fidelity, and daily activity of pirarucu (Arapaima spp.) in an Amazonian floodplain mosaic. Freshw Biol 64, 1255–1264. https://doi.org/10.1111/fwb.13301

Campos-Silva, J.V., Peres, C.A., 2016. Community-based management induces rapid recovery of a high-value tropical freshwater fishery. Sci Rep 6, 1–13. https://doi.org/10.1038/srep34745

Campos-Silva, J. V., Hawes, J.E., Andrade, P.C.M., Peres, C.A., 2018. Unintended multispecies co-benefits of an Amazonian community-based conservation programme. Nat Sustain 1, 650–656. https://doi.org/10.1038/s41893-018-0170-5

Castello, L., 2004. A Method to Count Pirarucu Arapaima gigas : Fishers, Assessment, and Management. N Am J Fish Manag 24, 379–389. https://doi.org/10.1577/M02-024.1

Castello, L., Arantes, C.C., Mcgrath, D.G., Stewart, D.J., De Sousa, F.S., 2015. Understanding fishing-induced extinctions in the Amazon. Aquat Conserv 25, 447–458. https://doi.org/10.1002/aqc.2491

Castello, L., Mcgrath, D.G., Hess, L.L., Coe, M.T., Lefebvre, P.A., Petry, P., Macedo, M.N., Renó, V.F., Arantes, C.C., 2013. The vulnerability of Amazon freshwater ecosystems. Conserv Lett 6, 217–229. https://doi.org/10.1111/conl.12008

Castello, L., Stewart, D.J., 2010. Assessing CITES non-detriment findings procedures for Arapaima in Brazil. Journal of Applied Ichthyology 26, 49–56. https://doi.org/10.1111/j.1439-0426.2009.01355.x

Castello, L., Viana, J.P., Pinedo-Vasquez, M., 2011. Participatory Conservation and Local Knowledge in the Amazon Várzea: The Pirarucu Management Scheme in Mamirauá, in: The Amazon Várzea. Springer Netherlands, Dordrecht, pp. 259–273. https://doi.org/10.1007/978-94-007-0146-5_18

Castello, L., Viana, J.P., Watkins, G., Pinedo-Vasquez, M., Luzadis, V.A., 2009. Lessons from integrating fishers of arapaima in small-scale fisheries management at the mamirauá reserve, amazon. Environ Manage 43, 197–209. https://doi.org/10.1007/s00267-008-9220-5

Cavole, L.M., Arantes, C.C., Castello, L., 2015. How illegal are tropical small-scale fisheries? An estimate for arapaima in the Amazon. Fish Res 168, 1–5. https://doi.org/10.1016/j.fishres.2015.03.012

D'Almeida, B.G.D., 2006. Os Acordos De Pesca Na Amazônia: Uma Perspectiva Diferenciada De Gestão Das Águas, XV Encontro Preparatório do CONPEDI/UNICAP.

Fearnside, P.M., 1989. Extractive reserves in Brazilian Amazonia.

Junk, W.J., Piedade, M.T.F., Schöngart, J., Cohn-Haft, M., Adeney, J.M., Wittmann, F., 2011. A classification of major naturally-occurring amazonian lowland wetlands. Wetlands 31, 623–640. https://doi.org/10.1007/s13157-011-0190-7

Junk, W.J., Soares, M.G.M., Bayley, P.B., 2007. Freshwater fishes of the Amazon River basin: Their biodiversity, fisheries, and habitats. Aquat Ecosyst Health Manag 10, 153–173. https://doi.org/10.1080/14634980701351023

Levis, C., Flores, B.M., Mazzochini, G.G., Manhães, A.P., Campos-Silva, J.V., Borges de Amorim, P., Peroni, N., Hirota, M., Clement, C.R., 2020. Help restore Brazil's governance of globally important ecosystem services. Nat Ecol Evol. https://doi.org/10.1038/s41559-019-1093-x

Lopes, P.F.M., de Freitas, C.T., Hallwass, G., Silvano, R.A.M., Begossi, A., Campos-Silva, J.V., 2021. Just Aquatic Governance: The Amazon basin as fertile ground for aligning participatory conservation with social justice. Aquat Conserv 31, 1190–1205. https://doi.org/10.1002/aqc.3586

Mcginnis, M., 2012. How to Use the IAD Framework.

Miorando, P.S., Rebêlo, G.H., Pignati, M.T., Brito Pezzuti, J.C., 2013. Effects of Community-Based Management on Amazon River Turtles: A Case Study of Podocnemis sextuberculata in the Lower Amazon Floodplain, Pará, Brazil. Chelonian Conservation and Biology 12, 143–150. https://doi.org/10.2744/CCB-1011.1

Nelson, J.S., 1994. Fishes of the world, #rd ed. ed. Wiley, New York.

Ostrom, E., 2008. The challenge of common-pool resources. Environment 50, 8–21. https://doi.org/10.3200/ENVT.50.4.8-21

Ostrom, E., 2005. Understanding institutional diversity, Princeton University Press. Princeton, NJ. https://doi.org/10.1093/oso/9780190672492.003.0008

Ostrom, E., 1990. Governing the commons: the evolution of institutions for collective action, Governing the commons: the evolution of institutions for collective action. Cambridge University Press, New York. https://doi.org/10.2307/3146384

Ostrom, E., Gardner, R., James Walker, 1994. Rules, Games, and Common-Pool Resources, Environmental and Natural Resource Economics: An Encyclopedia. The University of Michigan Press.

Petersen, T.A., Brum, S.M., Rossoni, F., Silveira, G.F.V., Castello, L., 2016. Recovery of Arapaima sp. populations by community-based management in floodplains of the Purus River, Amazon. J Fish Biol 89, 241–248. https://doi.org/10.1111/jfb.12968

Prestes-Carneiro, G., Béarez, P., Bailon, S., Py-Daniel, A.R., Neves, E.G., 2016. Subsistence fishery at Hatahara (750–1230 CE), a pre-Columbian central Amazonian village. ournal of Archaeological Science: Reports 8, 454–462. https://doi.org/https://doi.org/10.1016/j.jasrep.2015.10.033.

Schröder, N.J.S., 2018. The lens of polycentricity: Identifying polycentric governance systems illustrated through examples from the field of water governance. Environmental Policy and Governance 28, 236–251. https://doi.org/10.1002/eet.1812

Stronza, A.L., 2010. Commons management and ecotourism: ethnographic evidence from the Amazon. Int J Commons 4, 56–77.

3. COMMUNITY-BASED CONSERVATION CATALYZES MULTIDIMENSIONAL NATURE CONTRIBUTIONS FOR PEOPLE

Revista pretendida: People and Nature

Ana Carla Rodrigues, Hugo C. M. Costa, Eduardo Sonnewend Brondizio, Adevaldo Dias, José Alves de Moraes, Richard James Ladle, Ana Claudia Mendes Malhado, João Vitor Campos-Silva

3.1 Abstract

The Amazon rainforest and its ecological processes significantly contribute to ecosystem services for humanity. As human activities threaten its maintenance, the Amazon sustain of traditional indigenous and non-indigenous communities that intimately connect to their surroundings and play a vital conservation role. The Arapaima co-management is a successful example of the recognition of a social technology that enhance local protagonism in conservation. The benefits of Arapaima co-management are clear, encompassing ecological, economic, and social aspects. However, it is necessary to understand and value the relationships between communities and nature, revealing their diverse values. This study aims to elucidate the benefits of sustainable community-based activities as a tool to improve the quality of life and protect the Amazon rainforest. Interviews with 186 expert fishermen and fisherwomen from 39 communities along the Juruá River, western Brazilian Amazon, were conducted to collect data based on their perceptions over time about high commercial-value and ecologically important species, in addition to social aspects from their communities. Each response was classified within the Nature's Contributions to People (NCP) framework and Ecosystem Services (IPBES). We compared benefits generated and restored in nature between Arapaima-managing communities and non-Arapaima-management communities. The results show significant differences between the contributions of nature among communities that do and do not practice Arapaima co-management. Co-management activities have unintentionally increased the abundance of economically valuable hard wood species aiding in climate change mitigation. Arapaima-managing communities also perceive higher catch-per unit effort in fisheries and increased and high-value economic species like Tambaqui (*Colossoma macropomum*). Additionally, these communities report more intangible contributions, such as cultural revival and strengthening. This study reinforces that Arapaima co-management has led to the recovery and maintenance of nature's benefits in the Amazon. It also highlights the importance of recognizing and economically compensating the benefits provided by communities, incentivizing the continuation of practices that sustain these benefits.

Keywords: Ecosystem services**,** traditional ecological knowledge, common pool resources

3.2 Introduction

Indigenous and non-indigenous people have cultivated deep interactions with and detailed perceptions of biodiversity throughout history. Human communities' understanding of the forest acknowledges the dynamics that generate well-being and quality of life, intrinsically linked through social interactions, cultural norms, practices, and beliefs (Braga-Pereira et al., 2024; Díaz et al., 2018; Pascual et al., 2017; Schröder, 2018). However, various human activities have caused profound changes in the global ecological dynamic, leading to severe crises, including climate change, deforestation, and biodiversity loss (Pörtner et al., 2023). Such changes severely impact socio-ecological systems, where local communities heavily depend on natural resources. Therefore, profound and immediate changes in decision-making processes and public planning are imperative to build more just and sustainable futures for socio-ecological systems (Campos-Silva et al., 2021).

The Brazilian Amazon stands out as an exemplary ecological system due to its immense size, exceptional primary productivity, and highly variable spatial and climatic conditions. Its vast expanse, coupled with diverse age structures and stable ecosystems maintained over long periods, has fostered an unparalleled level of biodiversity. As one of the most species-rich regions on the planet, the Amazon plays a critical role in global ecological processes and biodiversity conservation (Hubbs and Nelson, 1978; Malhado et al., 2013). The Amazon region is characterized by a diversity of traditional communities, each intimately connected to the environmental conservation of their surroundings. These communities play a vital role in conservation efforts, driven by their historical resilience to external pressures and the pressing sociopolitical dynamics of their social and cultural contexts, territorial claims, and organizational structures (Davis and Wagner, 2006). In the Brazilian Amazon, natural resources, including fruits, medicinal plants, hunting, fishing, and timber, are indispensable for the subsistence of local communities. These resources support daily survival and sustain important cultural practices (Camilotti et al., 2020). The effective and sustainable management of these resources by local communities is crucial for their well-being and the preservation of the region's rich ecological systems (Albuquerque et al., 2024; Mori et al., 2013).

The Amazon represents over 50% of remaining tropical forests and is a crucial environment for regulating climate (Malhi et al., 2008) and sustaining biodiversity on a global scale (Pimm et al., 2014; Sullivan et al., 2020). Replacing forests with mechanised commodity agriculture, cattle ranching, and large-scale hydropower generation has historically led to massive deforestation, which reached 846,640,600 km² by late 2023 (INPE, 2022). Furthermore, 38% of the remaining forest is currently degraded by fire, edge effects, timber extraction, and extreme drought (Lapola et al., 2023), approaching the no-return threshold of 40% deforestation (Lovejoy and Nobre, 2019; Sampaio et al., 2007). The ongoing decline of both forest cover and wildlife jeopardizes food security for millions of indigenous and non-indigenous people who rely on bushmeat and fish as major sources of protein, fats, calories, and micronutrients (Tregidgo et al., 2020)

Protected Areas (PAs) cover more than 28.4 million square kilometers worldwide and represent the major strategy to ensure biodiversity conservation, protection of ecological processes, and ecosystem services (Folke and Berkes, 2002; Palomo et al., 2014; Watson et al., 2014). Most Brazilian PAs are in the Amazon and represent the key strategy against tropical biodiversity loss and deforestation (Bruner et al., 2001; Mori et al., 2013a; Ricketts et al., 2010) Currently, sustainable-use PAs and Indigenous Lands compose an important and promising strategy to increase local governance, contributing to the broad sustainable goals of the socio-environmentalist movement (Brondízio et al., 2021). Therefore, beyond its conservation value, PAs are in constant evolution in terms of conception, goals, and management strategy (Watson et al., 2014). In tropical countries, where poverty alleviation is also imperative, PAs (especially those for sustainable use) face the additional challenge of integrating the goals of biodiversity conservation and social aspiration (Naughton-Treves et al., 2005). Education, health, and minimum income are, therefore, still imperative. There have been incontestable advances with the creation of the PAs system in Brazil, but important concerns regarding its implementation remain. In fact, it has been suggested that many of the world's PAs exist only as 'paper parks' (Dudley and Stolton, 1999), lacking human resources, funding, and infrastructure, and failing to deliver effective conservation (Joppa et al., 2008). In a constant shortage of funding and human resources, the future of the Amazon cannot rely solely on the implementation of protected areas. In this context, community-based conservation emerges as a window of opportunity to align biodiversity protection and social needs (Albuquerque et al., 2024).

Community-based initiatives that accommodate the interests of multiple local stakeholders are proving to be a powerful tool in the recovery of several historically overexploited species throughout the Amazon basin (Campos-Silva et al., 2017). These initiatives promote gender equity in fisheries (Freitas et al., 2020), enhance local livelihoods, and reduce rural exodus among youth (Campos-Silva et al., 2021) Additionally, they strengthen governance structures and contribute to the protection of territories. To achieve this, it is necessary to include the most diverse social groups in decision-making processes, especially rural communities, to ensure that a wide range of values and perceptions are expressed and considered (Brondizio et al., 2021; Vatn et al., 2024). Including and recognizing all stakeholders in decision-making processes ensures the identification of various values of nature, surpassing evaluations limited to only monetary values.

Negotiations that exclude local and indigenous communities, favoring other groups and considering only market values in decision-making processes, result in crises in the use of natural resources. Thus, it is urgent to identify the diversity of values, including different worldviews, social conditions, and distinct relationships with nature, as these elements are fundamental for the creation and implementation of strategic actions that promote sustainable changes (Bennett et al., 2021; Fischer and Riechers, 2019; Malmborg et al., 2022). Ecosystem services are the functions and resources provided by nature that influence human well-being, giving rise to the idea of Nature's Contributions to People (NCPs) (Díaz et al., 2018; Pascual et al., 2017). NCPs expand the concepts of ecosystem services to include local and indigenous knowledge, allowing for a deeper understanding of the interactions between nature and humans (Kadykalo et al., 2019). Strategies based on NCPs transcend ecological, economic, and social analyses, providing a holistic understanding of the benefits this knowledge can offer (Díaz et al., 2018; Pascual et al., 2017; Quintas-Soriano et al., 2018).

Local Communities and Indigenous People possess profound knowledge about the use of their territories (Brondízio et al., 2021), which is reflected in substantially lower deforestation rates in their areas. This significantly contributes to the preservation of NCPs (Corlett, 2015). Additionally, local communities have demonstrated the capacity to protect areas much larger than those directly used for sustainable community-based management of Arapaima (Arapaima gigas), highlighting the effectiveness of their lake protection systems and, consequently, vast forest expanses. The co-management of Arapaima stands out as a symbol of significant change in conservation actions in the Amazon basin. This activity has ecological benefits, recovering the Arapaima population by up to 425% in 11 years, including the increase of other species (Campos-Silva et al., 2019; Campos-Silva and Peres, 2016; Castello et al., 2009; Petersen et al., 2016). Additionally, the model provides socioeconomic benefits, such as financial resources for local communities, improving infrastructure, and promoting the inclusion of women in fisheries management (Campos-Silva and Peres, 2016; Freitas et al., 2020)

Despite the evident ecological, economic, and social benefits, it is necessary to understand the nuances of NCPs in co-management. This is essential to value the relationships between communities and nature, revealing the diverse values associated with activities like Arapaima co-management (Quintas-Soriano et al., 2018). Therefore, it is crucial to understand other benefits and values, including the new and emerging ones in this context (Kadykalo et al., 2019). Here, we evaluated the benefits generated and restored in nature, based on the perceptions of local communities that practice Arapaima co-management and those that do not. By analyzing these perceptions, we aim to provide a comprehensive understanding of the benefits of sustainable community-based activities as a tool to improve people's quality of life and protect the Amazon rainforest.

3.3 Methods

3.3.1 Study Area

The study was conducted in the mid-section of the Juruá River, located in the state of Amazonas, which is one of the main tributaries of the Solimões River, in rural communities within and outside two contiguous Extratctive Reserves: the Uacari Sustainable Development Reserve (RDS Uacari, 5º43'58"S, 67º46'53"W), covering an area of 632,949 hectares, and the Médio Juruá Extractive Reserve (ResEx Médio Juruá, 5º33'54"S, 67º42'47"W), with an area of 253,227 hectares. The ResEx Médio Juruá and RDS Uacari were officially established in 1997 and 2005, respectively, and currently house approximately 4,000 inhabitants spread across 74 communities along 800 km. These communities were located mainly near the river channel, but also included those situated along tributary streams and lakeshores (Figure 1) (Newton et al., 2012).

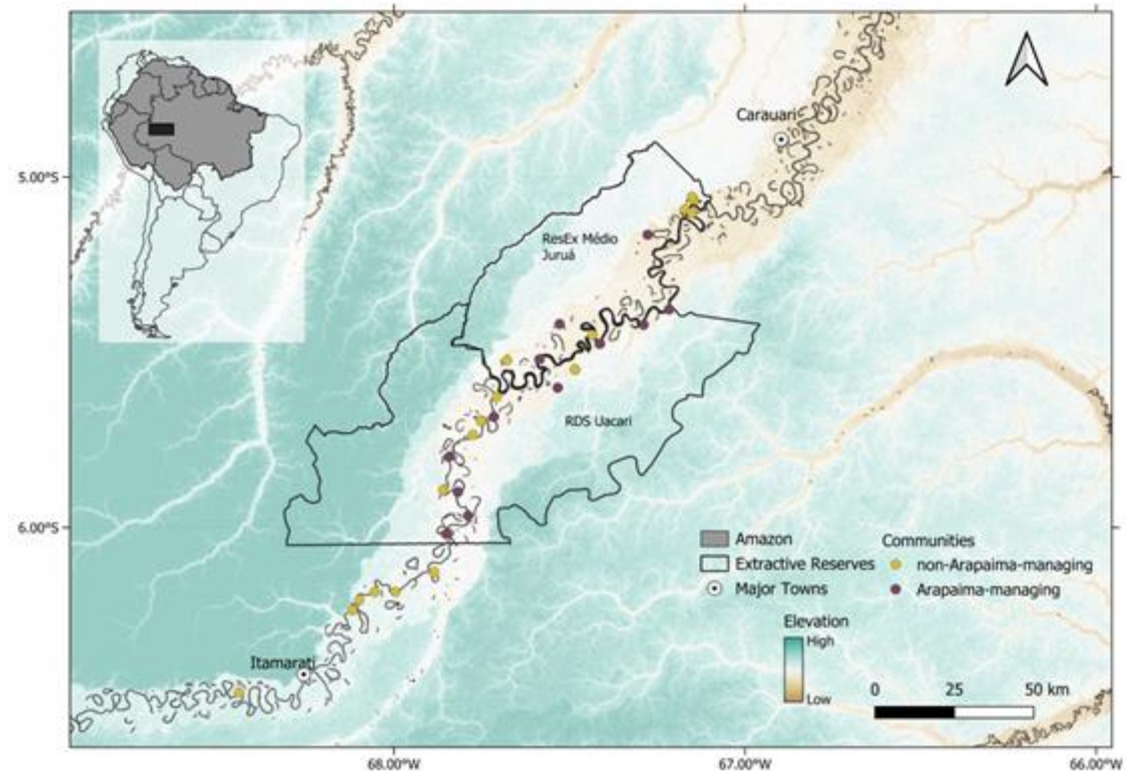

Figure 1. Study area, mid-section of Juruá River, western Brazilian Amazonia. Arapaima-managing and non-Arapaima-managing communities interviewed during this study are represented by purple and yellow dots respectively.

3.3.2 Data collection

We conducted a survey consisting of 15 questions with experienced fishermen and women from the sampled communities. The responses were recorded on a modified Likert scale ranging from 0 to 10, where 0 represents the lowest possible value or total disagreement, and 10 represents the highest possible grade or total agreement (Table 1.). We chose this scale because it is commonly used in rural primary schools, making it easier for participants to understand and provide accurate responses. The answers were supplemented with open-ended comments about each question, which were either recorded or transcribed during the interviews. This approach allowed for a deeper understanding of the nuances of co-management in each community and local specificities (Maia et al., 2004). We used these additional comments to identify and classify each response within the 18 Nature's Contributions to People (NCP) framework from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Díaz et al., 2018; Pascual et al., 2017).

The questions addressed perceptions of various factors, including the abundance of high-value timber species, fisheries catch-per-unit-effort (CPUE), Arapaima abundance in both protected and unprotected lakes, and the abundance of Tambaqui (*Colossoma macropomum*), the most valuable Amazonian fish and a key seed predator and disperser. Additionally, the questions explored aspects such as group celebrations, cultural revival and strengthening, learning opportunities, community cohesion, and whether the Arapaima could symbolize life in the Juruá River Basin (Table 1.). Respondents from communities engaged in Arapaima management reported their perceptions of both the period before the implementation of co-management and the present day. In contrast, communities not engaged in Arapaima management reported only their current perceptions.

Table 1. Questions asked to fishermen and women from Arapaima-managing and non-Arapaima-managing communities along the Juruá River in the western Brazilian Amazon regarding local perceptions of Nature's Contribution to People before and after Arapaima management implementation, as well as current perceptions.

Question	Local communities	Time Frame	Nature's Contribution to People
How do you perceive the abundance of Assacú (*Hura crepitans*), surrounding the community's lakes?	Arapaima-managing	Before and after Arapaima management implementation	Habitat Creation and Maintenance Air quality Climate Regulation Materials Genetic Resources
How do you perceive the abundance of Louro-mamuri (*Ocotea cymbarum*), surrounding the community's lakes?	Arapaima-managing	Before and after Arapaima management implementation	Habitat Creation and Maintenance Air quality Climate Regulation Materials Genetic Resources
How do you perceive the abundance of Macacaúba (*Platymiscium trinitatis*), surrounding the community's lakes?	Arapaima-managing	Before and after Arapaima management implementation	Habitat Creation and Maintenance Air quality Climate Regulation Materials Genetic Resources
How do you perceive the abundance of Copaíba (*Copaífera longsdorffii*), surrounding the community 's lakes?	Arapaima-managing	Before and after Arapaima management implementation	Habitat Creation and Maintenance Air quality Climate Regulation Materials Genetic Resources
How do you perceive fisheries CPUE in community's lakes?	Arapaima-	Before and after Arapaima	Food

	managing	management implementation	
How do you perceive Arapaima (*Arapaima gigas*) abundance in the community's lakes?	Arapaima-managing	Before and after Arapaima management implementation	Habitat creation and Maintenance Freshwater Quality Food Physical and Psychological Experiences Maintenance of options
How do you perceive Tambaqui (*Colossoma macropomum*) abundance in the community's lakes?	Arapaima-managing	Before and after Arapaima management implementation	Habitat creation and Maintenance Pollination and Dispersal Food Maintenance of options
How do you perceive Arapaima (*Arapaima gigas*) abundance in unprotected lakes?	Arapaima-managing and Non-Arapaima-managing	Current	Habitat creation and Maintenance Freshwater Quality Food Physical and Psychological Experiences Maintenance of options
Fisheries can be considered as a recreational activity	Arapaima-managing and Non-Arapaima-managing	Current	Physical and Psychological Experiences Supporting Identities
Group celebrations are common in your community	Arapaima-managing and Non-Arapaima-managing	Current	Learning and Inspiration Physical and Psychological Experiences Supporting Identities

Culture and traditions are not being lost in your community	Arapaima-managing and Non-Arapaima-managing	Current	Learning and Inspiration Physical and Psychological Experiences Supporting Identities
Current inhabitants from your community are reviving traditions and cultural behaviors from your ancestors	Arapaima-managing and Non-Arapaima-managing	Current	Learning and Inspiration Physical and Psychological Experiences Supporting Identities
The Arapaima can be used as symbol to represents livelihoods in the Juruá	Arapaima-managing and Non-Arapaima-managing	Current	Learning and Inspiration Physical and Psychological Experiences Supporting Identities
You have experienced opportunities to learn new techniques and good practices in fisheries	Arapaima-managing and Non-Arapaima-managing	Current	Learning and Inspiration
Inhabitants of your community are very uniting	Arapaima-managing and Non-Arapaima-managing	Current	Supporting Identities

3.3.3 Analysis

To understand the Nature's Contributions to People (NCPs) provided by Arapaima co-management, we first performed a paired t-test on the local communities engaged in managed fisheries. This analysis utilised respondents' perceptions, comparing periods before and after the implementation of Arapaima management in each community. Next, we compared the current local perceptions of NCPs between Arapaima-managing communities and non-Arapaima-managing communities using a Student’s t-test. Both t-tests had their assumptions validated. Finally, we assigned one or more of the 18 NCPs to each response and its additional comments to identify which NCPs contributed most to differences in perceived NCPs between non-Arapaima-managing communities and Arapaima-managing communities using a Principal Component Analysis (PCA) with the vegan package in R (Oksanen et al., 2022). All analyses were conducted in R version 4.4.1 (R Core Team 2024).

3.4 Results

We interviewed 186 people from 39 different communities along the Juruá River, comprising 15 Arapaima-managing communities and 24, non-Arapaima-managing communities. Respondents from Arapaima-managing communities perceived a higher abundance of high-value hardwood tree species after the implementation of Arapaima management, specifically Assacú (*Hura crepitans*), Louro-mamuri (*Ocotea cymbarum*), and Macacaúba (*Platymiscium trinitatis*), with statistically significant differences ($p < 0.05$). Although Copaíba (*Copaífera longsdorffii*) was perceived to have increased in value after the implementation of co-management, this difference was not confirmed by the t-test. Oxbow lakes used by Arapaima-managing communities showed higher CPUE for daily fisheries, greater Arapaima abundance, and higher Tambaqui abundance after the implementation of Arapaima management, compared to the periods before implementation (Figure 2). When compared with non-Arapaima-managing communities, fishermen and women from Arapaima-managing communities perceived lower Arapaima abundance in unprotected lakes. Additionally, communities engaged in co- management perceived fisheries as a recreational activity, experienced a higher frequency of group celebrations, and reported stronger community unity. Arapaima co-management also promoted cultural revival and strengthening, along with the introduction of new techniques and learning opportunities. Despite the notable differences mentioned, all interviewees agreed that the Arapaima could be used as an icon to represent livelihoods in the Juruá River (Figure 3).

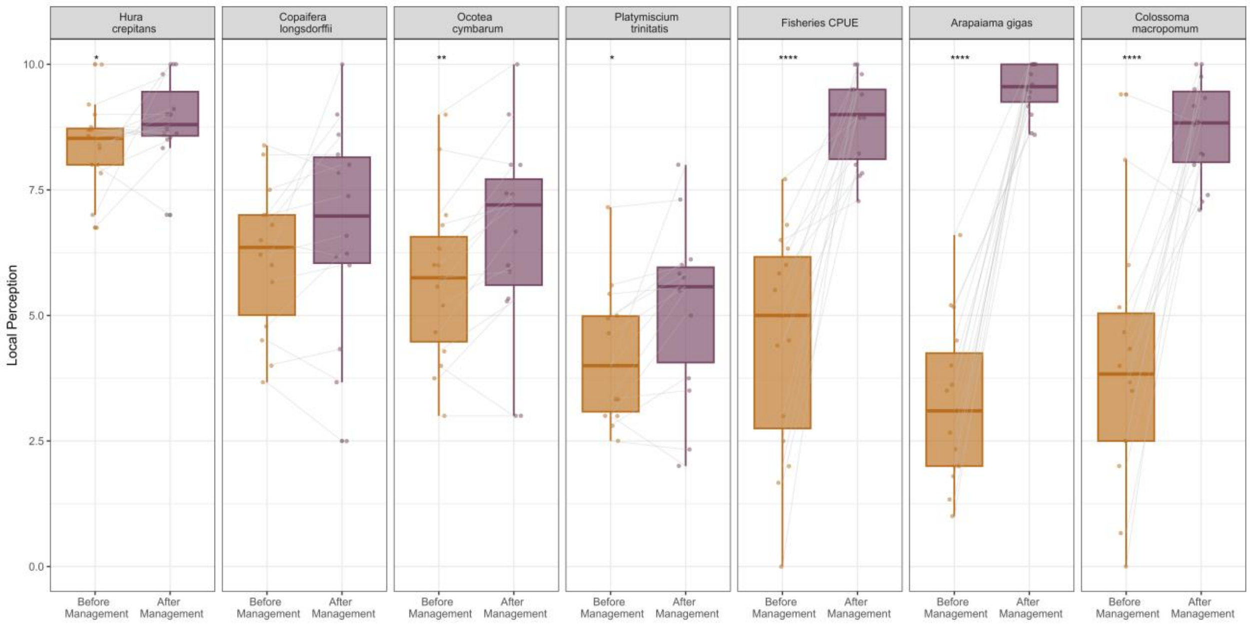

Figure 2. Boxplots comparing local perceptions of hard-wood species abundance (Hura crepitans, Copaifera longsdorffii, Ocotea cymbarum, and Platymiscium trinitatis), fisheries CPUE, Arapaima gigas, and Colossoma macropomum abundance from rural communities along the Juruá River before and after Araparaima co-management implementation. Paired t-test statistical significance is denoted as: *p < 0.05, **p < 0.01, ***p < 0.001 and **** p < 0.0001.

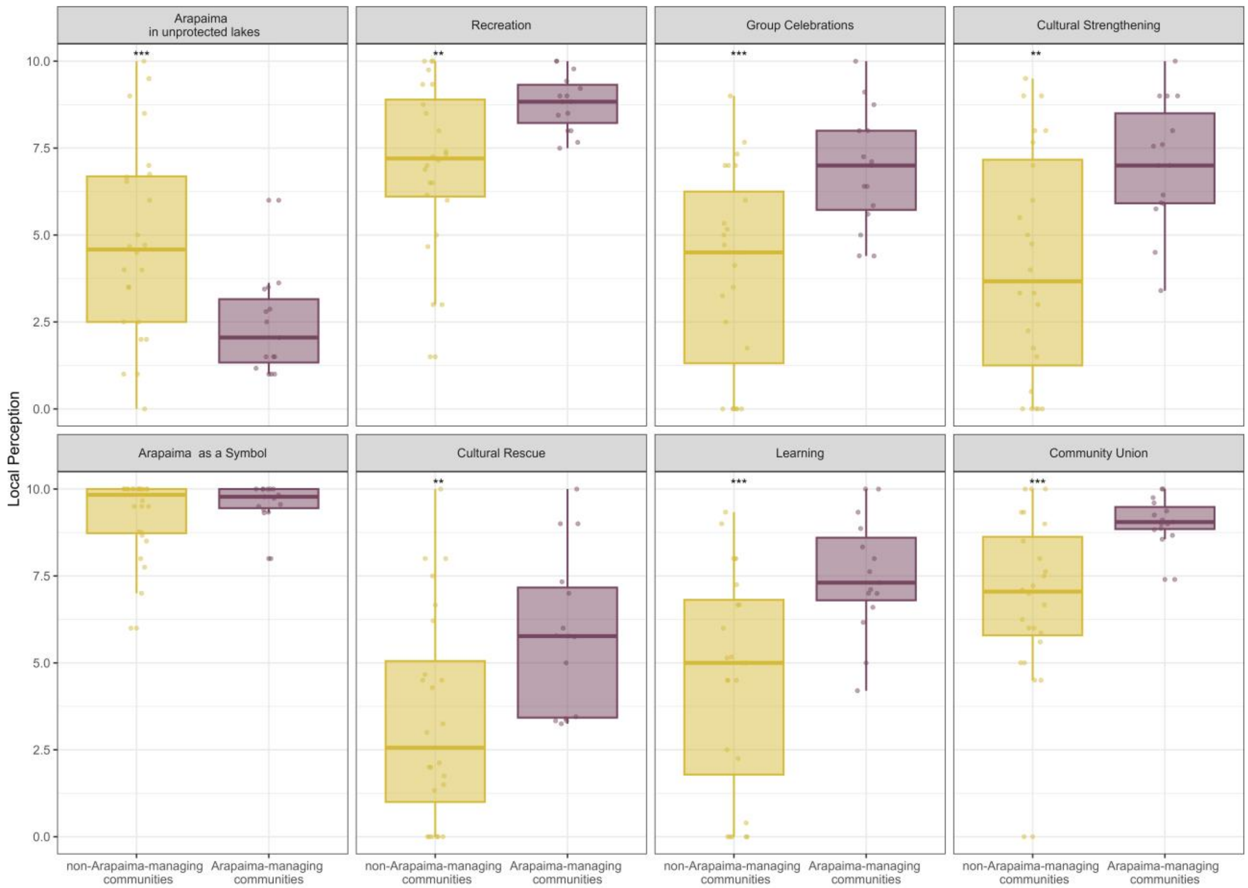

Figure 3. Boxplots represent local perceptions from both non-Arapaima managing and Arapaima-managing communities about Arapaima abundance in unprotected lakes, fisheries as a recreational activity, frequency of group celebrations, Arapaima as an icon to represent local livelihoods, cultural strengthening and revival, learning opportunities and community union. t-test statistical significance is denoted as: *p < 0.05, **p < 0.01 and ***p < 0.001.

Principal Component Analysis revealed that non-Arapaima-managing communities occupied a broad spectrum in the multivariate space showing that this group of communities perceive NCPs differently from each other. In contrast, Arapaima managing communities occupies a small area in the multivariate space being more concise and related to each other which clearly separates the two groups. PC1 captured 51 % of data variance being Habitat creation and maintenance the most influential NCP in distinguishing the two groups, followed by air quality, climate regulation, materials, and genetic resources (Figure 4).

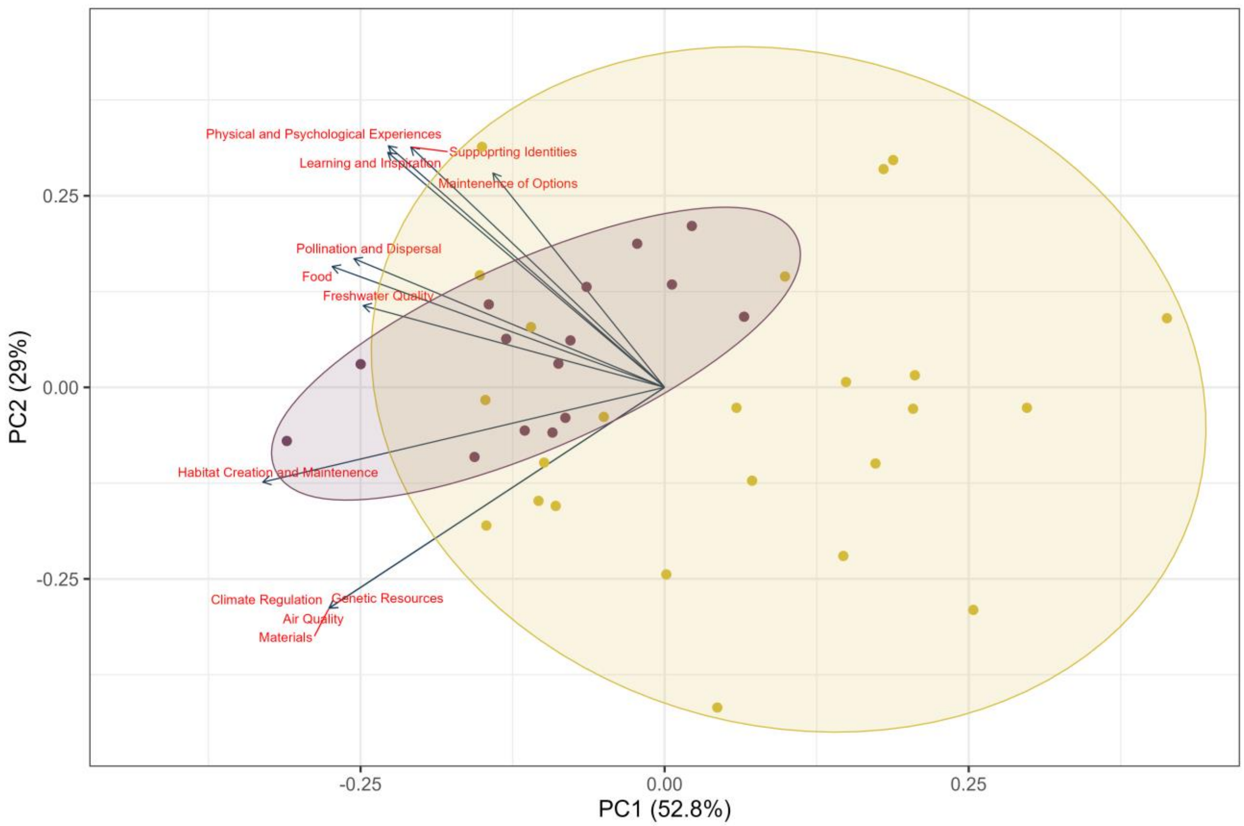

Figure 4. Principal Component Analysis (PCA) of rural communities along the Juruá River in western Brazilian Amazônia and Nature Contributions to People Perceptions. The biplot displays the first two principal components (PC1 and PC2), which explain 52% and 29% of the variance, respectively. Purple dots represent Arapaima-managing communities while non-Arapaima-managing communities are represented in yellow. Arrows represent the loadings of the original variables, showing their contribution to the principal components.

3.5 Discussion

Co-management of arapaima has led to the creation and recovery of ecosystem services in the western Amazon. By integrating local knowledge from communities and scientific approaches, we can reveal valuable insights and benefits to nature. Community members' perceptions of improvements in nature's contributions to people highlight the importance of recognizing and economically compensating the community efforts to sustain community-based conservation arrangements, thereby incentivizing the continuation of sustainable practices (Díaz et al., 2018).

The co-management of arapaima has brought significant benefits to local communities, especially related to socioeconomic improvements and population recovery of target species (Campos-Silva et al., 2018). Our studies amplify the range of benefits, spot lightening outcomes that are very important for local wellbeing. Among these benefits is the increase in Tambaqui (*Colossoma macropomum*), a species that was rare before co-management but has now become an important source of protein for local families, enhancing food security. The sustainable sale of Tambaqui and arapaima has also increased family incomes (Isaac et al., 2015). Additionally, there has been a noted growth in the availability of lower commercial value fish that are consumed daily and are quite essential for food security specially during intermittent periods of scarcity (Tregidgo et al., 2020).

Community members have also observed the recovery of high value tree species such as Assacú (*Hura crepitans*), Louro-mamuri (*Ocotea cymbarum*), Macacaúba (*Platymiscium trinitatis*), and Copaíba (*Copaífera longsdorffii*), which were previously heavily exploited. This demonstrates a cascading effect of management practices, benefiting several non-target species (Campos-Silva, 2017). The recovery of these tree species plays an important role in mitigating climate change, as the increased abundance of trees contributes to carbon sequestration, benefiting global sustainability (Mori et al., 2013, Peres et al 2016).

A diverse range of methods is needed to discern the values of nature, reflecting its complexities and multidimensionality (Scholte et al., 2015). In the case of co-management, it is crucial to involve diverse forms of valuation with financial implications and consider the diverse potential impacts on the values of communities and natural resources. Current asymmetries in natural resource management can result in simplistic valuations based solely on financial criteria, undermining a pluralistic and comprehensive approach (Dasgupta and Srikanth, 2020). For example, the unity and sense of cooperation between people in co-management activities can ensure participation even without direct financial rewards (Brites and Morsello, 2018). Non-monetary valuations have shown that a sense of belonging within communities engaged in co-management improves outcomes (Yates et al., 2010). Considering local perceptions in community management activities provides a more realistic and in-depth understanding of the benefits of these initiatives. Integrating local community perspectives strengthens natural resource management and promotes sustainable and equitable development (Braga-Pereira et al., 2024). Community involvement in resource management can increase the effectiveness of co-management programs, improve resource conservation, and foster local economic development (Malmborg et al., 2022; Wiseman, 2006).

Community-based conservation is a powerful global force for protecting and sustainably managing ecosystems and species (Kothari et al., 2013). In the Brazilian Amazon, it has played a crucial role in safeguarding large forest areas and reproduction sites for historically overexploited species (Campos-Silva et al., 2017), demonstrating the effectiveness of local management. Local communities have successfully protected lake areas averaging 47.4 ha and “terra-firme” areas averaging 11,188 ha. This conservation effort extends well beyond the pirarucu fishing lakes, highlighting the broad impact of community-managed initiatives. These communities' capacity to implement effective conservation strategies underscores their vital role in ecosystem-wide protection, significantly benefiting both biodiversity and community well-being (Rodrigues et al., 2024).

Amazon floodplain communities employ co-management strategies, integrating traditional knowledge with collective agreements to sustain fish productivity and minimise conflicts over aquatic resources. This approach has enhanced fish abundance, and fisheries yields in tropical floodplain lakes, thereby supporting fisheries sustainability and food security in dam-affected areas (Silvano et al., 2014). Co-management not only boosts ecological benefits, such as increased species abundance and habitat availability, but also improves outcomes by enhancing the diversity and quantity of fish catches (d’Armengol et al., 2018). Effective co-management relies on social cohesion and well-regulated territories, which bolster subsistence fishing for local communities (Gutiérrez et al., 2011; Tregidgo et al., 2020). Co-management practices for Arapaima in Amazon floodplain lakes have positively impacted fish assemblage structure and composition, leading to greater fish richness, biomass, and improved household income and livelihoods (Donda, 2017). By facilitating species recolonization, co-management enhances the abundance, size, and biomass of high-value fish species. The positive effects of co-management on fish assemblages have been observed in protected lakes, reinforcing its benefits for both ecological and socio-economic dimensions (Medeiros-Leal et al., 2021; Silvano et al., 2014).

Biodiversity conservation can ensure food security for local communities (Naughton-Treves et al., 2005; Tregidgo et al., 2020). However, public policies in many countries treat food security and biodiversity conservation as contradictory goals. The productivism discourse argues that to improve food security, it is necessary to increase food availability, but this negatively impacts biodiversity (Mooney and Hunt, 2009). Local initiatives in the Brazilian Amazon can promote regional sustainability by fostering changes in production systems, adding value, providing access to markets, and strengthening local governance arrangements (Brondizio et al., 2021). Community-based management is democratic and collaborative, resulting in a greater sense of belonging and responsibility within communities. This approach integrates social, economic, and environmental objectives, promoting resilience and adaptability within communities (Ostrom, 1990). Traditional ecological knowledge (TEK) is an invaluable resource for sustainable resource management, encompassing generations of experience and a deep understanding of local ecosystems (Berkes, 2009; Brondízio et al., 2021). Co-management also promotes the transmission and sharing of traditional knowledge, ensuring its preservation for future generations (Hossain and Ballardini, 2021).

Non-material values such as trust, joy, increased recreational opportunities, new learning experiences, and the strengthening of traditional knowledge and unity are inherent in co-management. Consequently, cultural recovery, appreciation, and reinforcement help protect socio-biodiversity. This array of benefits demonstrates that co-management transcends the economic resources it generates. Additionally, it fosters empowerment and enhances social cohesion, improves collaborative efforts, increases unity, and encourages active participation in decision-making processes. The reinforcement of social organisation, alongside traditional ecological knowledge, promotes equity and social justice (Albuquerque et al., 2024).

There is a need to strengthen assessments of the relationships between society and nature, as well as the use of its resources, based on the perception of local communities. This is essential to avoid the simplification of assessments and valuations made by groups that focus only on the economic and unsustainable use of natural resources (Vatn et al., 2024). The perception of local communities in the protection of areas of global importance, such as the Amazon, reveals immense diversity in the perceptions of the benefits of nature, where there is a great consensus between human perception and changes in natural resources (Braga-Pereira et al., 2024). For example, the perception of experienced fishers confirmed the evident notion that local fish populations have increased (Campos-Silva et al., 2017). Participatory and deliberative methods in the assessment of the perception of NCPs are essential to ensure that the values and interests of local communities are included in decision-making processes. Such approaches value natural resources and their sustainable uses, and promote a sense of belonging and commitment among those involved in the use and conservation of resources (Hausmann et al., 2016)

Community unity can be one of the strongest drivers of local involvement in co-management (Brites and Morsello, 2018). Changes in people’s beliefs about the impacts of human activity on natural resources can ensure community participation in co-management activities. Recognizing increased unity, sharing the importance of conservation actions, and improving community well-being can increase and ensure community participation rates. Strengthening policies that support co-management arrangements for arapaima is crucial to increasing adaptive capacity and overall performance, allowing continued activity even in adverse circumstances. These community-based arrangements, involving active local participation in resource management, have been shown to be effective in preserving biodiversity and improving quality of life (Campos-Silva and Peres, 2016; Ostrom, 1990) Strengthening these arrangements increases the capacity of communities to face future environmental and socioeconomic challenges, as well as promoting equitable and inclusive management of natural resources (Folke and Berkes, 2002). Therefore, policies that support and expand these arrangements are essential for long-term sustainability and increased resilience.

Implementing policies to strengthen sustainable community management can lead to the growth and strengthening of local institutions and better relationships with other stakeholders (Villamayor-Tomas and García-López, 2018). Empowering policies can improve collective decision-making by making it more inclusive and participatory, recognizing and transmitting traditional ecological knowledge, and promoting economic autonomy. Community management supported by effective policies can ensure better performance, especially when integrated and strategic policies are in place to support it.

Alternative sources of support for conservation activities and community engagement may include compensatory payments for conservation actions that reflect global benefits (Akers, 2019). These compensations may be provided by governments or other public and private organizations (Ezzine-de-Blas et al. 2016). Partner organizations may provide infrastructure support to significantly boost conservation efforts by stabilizing activities and building larger coalitions (Osewe et al, 2023). Policies and programs aimed at strengthening activities can increase the connection between institutions and the resilience of local communities (Nieratkaa et al., 2015). Community members are essential in identifying priorities for improvement in activities, and supportive policies may include investments in infrastructure, such as territorial surveillance. These investments improve relationships within and between communities and other institutions, increasing the resilience of activities (Wiseman, 2006).

Conservation science has often argued that biodiversity conservation and social needs are, at worst, incompatible and, at best, difficult to deliver simultaneously (McShane et al., 2011). However, few initiatives have tested these ideas in established sustainable-use systems. Empowered communities can decentralize natural resource management, generating significant sources of self-development while ensuring ecological outcomes, as we observed in our study case. There is still a long way to go to properly recognize the efforts of local communities in protecting nature and ensure a fairer financial return that covers the costs and fairly compensates those communities. Nevertheless, highlighting conservation successes can boost optimism, a crucial asset in addressing contemporary socioecological challenges, which is often in shortage among conservationists in many developing countries (Cvitanovic and Hobday, 2018).

Referências

Akers, J.F., Yasué, M., 2019. Motivational Crowding in Payments for Ecosystem Service Schemes: A Global Systematic Review. Conservation and Society 17, 377–389. https://doi.org/10.4103/cs.cs_18_90

Albuquerque, U.P., Maroyi, A., Ladio, A.H., Pieroni, A., Abbasi, A.M., Toledo, B.A., Dahdouh-Guebas, F., Hallwass, G., Soldati, G.T., Odonne, G., Vandebroek, I., Vallès, J., Hurrell, J.A., Pardo de Santayana, M., La Torre-Cuadros, M. de los Á., Silva, M.T.P., Jacob, M.C.M., da Fonseca-Kruel, V.S., Ferreira Júnior, W.S., 2024. Advancing ethnobiology for the ecological transition and a more inclusive and just world: a comprehensive framework for the next 20 years. J Ethnobiol Ethnomed 20, 1–9. https://doi.org/10.1186/s13002-024-00661-4

Bennett, E.M., Biggs, R., Peterson, G.D., Gordon, L.J., 2021. Patchwork Earth: navigating pathways to just, thriving, and sustainable futures. One Earth 4, 172–176. https://doi.org/10.1016/j.oneear.2021.01.004

Berkes, F., 2009. Evolution of co-management: Role of knowledge generation, bridging organizations and social learning. J Environ Manage 90, 1692–1702. https://doi.org/10.1016/j.jenvman.2008.12.001

Braga-Pereira, F., Mayor, P., Morcatty, T.Q., Pérez-Peña, P.E., Bowler, M.T., de Mattos Vieira, M.A.R., Alves, R.R. da N., Fa, J.E., Peres, C.A., Tavares, A.S., Mere-Roncal, C., González-Crespo, C., Bertsch, C., Rodriguez, C.R., Bardales-Alvites, C., von Muhlen, E., Paim, F.P., Tamayo, J.S., Valsecchi, J., Gonçalves, J., Torres-Oyarce, L., Lemos, L.P., Gilmore, M.P., Correa, M.A., Perez, N.C.A., Puertas, P., El Bizri, H.R., 2024. Predicting animal abundance through local ecological knowledge: An internal validation using consensus analysis. People and Nature 6, 535–547. https://doi.org/10.1002/pan3.10587

Brites, A.D., Morsello, C., 2018. Effects of Economic Dependence and Cooperative Behavior Over Participation in Monitoring the Impacts of Natural Resource Trade. Ecological Economics 147, 365–372. https://doi.org/10.1016/j.ecolecon.2018.01.033

Brondizio, E.S., Andersson, K., de Castro, F., Futemma, C., Salk, C., Tengö, M., Londres, M., Tourne, D.C., Gonzalez, T.S., Molina-Garzón, A., Russo Lopes, G., Siani, S.M., 2021. Making place-based sustainability initiatives visible in the Brazilian Amazon. Curr Opin Environ Sustain 49, 66–78. https://doi.org/10.1016/j.cosust.2021.03.007

Brondízio, E.S., Aumeeruddy-Thomas, Y., Bates, P., Carino, J., Fernández-Llamazares, Á., Ferrari, M.F., Galvin, K., Reyes-García, V., McElwee, P., Molnár, Z., Samakov, A., Shrestha, U.B., 2021. Locally Based, Regionally Manifested, and Globally Relevant: Indigenous and Local Knowledge, Values, and Practices for Nature. Annu Rev Environ Resour 46, 481–509. https://doi.org/10.1146/annurev-environ-012220-012127

Bruner, A.G., Gullison, R.E., Rice, R.E., Da Fonseca, G.A.B., 2001. Effectiveness of parks in protecting tropical biodiversity. Science (1979) 291, 125–128. https://doi.org/10.1126/science.291.5501.125

Camilotti, V.L., Pinho, P., Brondízio, E.S., Escada, M.I.S., 2020. The Importance of Forest Extractive Resources for Income Generation and Subsistence among Caboclos and Colonists in the Brazilian Amazon. Hum Ecol 48, 17–31. https://doi.org/10.1007/s10745-020-00127-7

Campos-Silva, J.V., Hawes, J.E., Peres, C.A., 2019. Population recovery, seasonal site fidelity, and daily activity of pirarucu (Arapaima spp.) in an Amazonian floodplain mosaic. Freshw Biol 64, 1255–1264. https://doi.org/10.1111/fwb.13301

Campos-Silva, J.V., Peres, C.A., 2016. Community-based management induces rapid recovery of a high-value tropical freshwater fishery. Sci Rep 6, 1–13. https://doi.org/10.1038/srep34745

Campos-Silva, J.V., Peres, C.A., Antunes, A.P., Valsecchi, J., Pezzuti, J., 2017. Community-based population recovery of overexploited Amazonian wildlife. Perspect Ecol Conserv 15, 266–270. https://doi.org/10.1016/j.pecon.2017.08.004

Campos-Silva, J. V., Hawes, J.E., Andrade, P.C.M., Peres, C.A., 2018. Unintended multispecies co-benefits of an Amazonian community-based conservation programme. Nat Sustain 1, 650–656. https://doi.org/10.1038/s41893-018-0170-5

Campos-Silva, J. V., Peres, C.A., Hawes, J.E., Haugaasen, T., Freitas, C.T., Ladle, R.J., Lopes, P.F.M., 2021. Sustainable-use protected areas catalyze enhanced livelihoods in rural Amazonia. Proc Natl Acad Sci U S A 118. https://doi.org/10.1073/pnas.2105480118

Castello, L., Viana, J.P., Watkins, G., Pinedo-Vasquez, M., Luzadis, V.A., 2009. Lessons from integrating fishers of arapaima in small-scale fisheries management at the mamirauá reserve, amazon. Environ Manage 43, 197–209. https://doi.org/10.1007/s00267-008-9220-5

Corlett, R.T., 2015. The Anthropocene concept in ecology and conservation. Trends Ecol Evol 30, 36–41. https://doi.org/10.1016/j.tree.2014.10.007

Cvitanovic, C., Hobday, A.J., 2018. Building optimism at the environmental science-policy-practice interface through the study of bright spots. Nat Commun. https://doi.org/10.1038/s41467-018-05977-w

d’Armengol, L., Prieto Castillo, M., Ruiz-Mallén, I., Corbera, E., 2018. A systematic review of co-managed small-scale fisheries: Social diversity and adaptive management improve outcomes. Global Environmental Change 52, 212–225. https://doi.org/10.1016/j.gloenvcha.2018.07.009

Dasgupta, P., Srikanth, K., 2020. Valuing Development, Environment and Conservation: Creating Values that Matter. Conservation and Society 18, 68. https://doi.org/10.4103/cs.cs_19_121

Davis, A., Wagner, J., 2006. A right to fish for a living? The case for coastal fishing people's determination of access and participation. Ocean Coast Manag 49, 476–497. https://doi.org/10.1016/j.ocecoaman.2006.04.007

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R.T., Molnár, Z., Hill, R., Chan, K.M.A., Baste, I.A., Brauman, K.A., Polasky, S., Church, A., Lonsdale, M., Larigauderie, A., Leadley, P.W., Van Oudenhoven, A.P.E., Van Der Plaat, F., Schröter, M., Lavorel, S., Aumeeruddy-Thomas, Y., Bukvareva, E., Davies, K., Demissew, S., Erpul, G., Failler, P., Guerra, C.A., Hewitt, C.L., Keune, H., Lindley, S., Shirayama, Y., 2018a. Assessing nature's contributions to people: Recognizing culture, and diverse sources of knowledge, can improve assessments. Science (1979) 359, 270–272. https://doi.org/10.1126/science.aap8826

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R.T., Molnár, Z., Hill, R., Chan, K.M.A., Baste, I.A., Brauman, K.A., Polasky, S., Church, A., Lonsdale, M., Larigauderie, A., Leadley, P.W., Van Oudenhoven, A.P.E., Van Der Plaat, F., Schröter, M., Lavorel, S., Aumeeruddy-Thomas, Y., Bukvareva, E., Davies, K., Demissew, S., Erpul, G., Failler, P., Guerra, C.A., Hewitt, C.L., Keune, H., Lindley, S., Shirayama, Y., 2018b. Assessing nature's contributions to people: Recognizing culture, and diverse sources of knowledge, can improve assessments. Science (1979) 359, 270–272. https://doi.org/10.1126/science.aap8826

Donda, S., 2017. Who benefits from fisheries co-management? A case study in Lake Chiuta, Malawi. Mar Policy 80, 147–153. https://doi.org/10.1016/j.marpol.2016.10.018

Dudley, N., Stolton, S., 1999. Conversion of paper parks to effective management: developing a target. Report to the WWF-World Bank Alliance from the IUCN/WWF Forest Innovation Project. The World Conservation Union (IUCN), Gland.

Ezzine-De-Blas, D., Wunder, S., Ruiz-Pérez, M., Del Pilar Moreno-Sanchez, R., 2016. Global patterns in the implementation of payments for environmental services. PLoS One 11, 1–16. https://doi.org/10.1371/journal.pone.0149847

Fischer, J., Riechers, M., 2019. A leverage points perspective on sustainability. People and Nature 1, 115–120. https://doi.org/10.1002/pan3.13

Folke, C., Berkes, F., 2002. Back to the future: ecosystem dynamics and local knowledge, in: L. H. Gunderson, & C.S.H. (Ed.), Panarchy: Understanding Transformations in Human and Natural Systems. Island Press, Washington DC, pp. 121–146.

Freitas, C.T., Espírito-Santo, H.M.V., Campos-Silva, J.V., Peres, C.A., Lopes, P.F.M., 2020. Resource co-management as a step towards gender equity in fisheries. Ecological Economics 176. https://doi.org/10.1016/j.ecolecon.2020.106709

Gutiérrez, N.L., Hilborn, R., Defeo, O., 2011. Leadership, social capital and incentives promote successful fisheries. Nature 470, 386–389. https://doi.org/10.1038/nature09689

Hausmann, A., Slotow, R., Burns, J.K., Di Minin, E., 2016. The ecosystem service of sense of place: Benefits for human well-being and biodiversity conservation. Environ Conserv 43, 117–127. https://doi.org/10.1017/S0376892915000314

Hossain, K., Ballardini, R.M., 2021. Protecting Indigenous Traditional Knowledge Through a Holistic Principle-Based Approach. Nord J Hum Rights 39, 51–72. https://doi.org/10.1080/18918131.2021.1947449

Hubbs, C.L., Nelson, J.S., 1978. Fishes of the World., #rd ed. ed, Systematic Zoology. Wiley, New York. https://doi.org/10.2307/2412830

INPE, 2022. Programa de Monitoramento da Amazônia e Demais Biomas [WWW Document]. Instituto Nacional de Pesquisas Espaciais. URL http://terrabrasilis.dpi.inpe.br/downloads/ (accessed 2.7.24).

Isaac, V.J., Almeida, M.C., Giarrizzo, T., Deus, C.P., Vale, R., Klein, G., Begossi, A., 2015. Food consumption as an indicator of the conservation of natural resources in riverine communities of the Brazilian Amazon. An Acad Bras Cienc 87, 2229–2242. https://doi.org/10.1590/0001-3765201520140250

Joppa, L.N., Loarie, S.R., Pimm, S.L., 2008. On the protection of “protected areas.” Proc Natl Acad Sci U S A 105, 6673–6678. https://doi.org/10.1073/pnas.0802471105

Kadykalo, A.N., López-Rodriguez, M.D., Ainscough, J., Droste, N., Ryu, H., Ávila-Flores, G., Le Clec’h, S., Muñoz, M.C., Nilsson, L., Rana, S., Sarkar, P., Sevecke, K.J., Harmáčková, Z. V., 2019. Disentangling ‘ecosystem services’ and ‘nature’s contributions to people.’ Ecosystems and People 15, 269–287. https://doi.org/10.1080/26395916.2019.1669713

Kothari, A., Camill, P., Brown, J., 2013. Conservation as if people also mattered: Policy and practice of community-based conservation. Conservation and Society 11, 1–15. https://doi.org/10.4103/0972-4923.110937

Lapola, D.M., Pinho, P., Barlow, J., Aragão, L.E.O.C., Berenguer, E., Carmenta, R., Liddy, H.M., Seixas, H., Silva, C.V.J., Silva, C.H.L., Alencar, A.A.C., Anderson, L.O., Armenteras, D., Brovkin, V., Calders, K., Chambers, J., Chini, L., Costa, M.H., Faria, B.L., Fearnside, P.M., Ferreira, J., Gatti, L., Gutierrez-Velez, V.H., Han, Z., Hibbard, K., Koven, C., Lawrence, P., Pongratz, J., Portela, B.T.T., Rounsevell, M., Ruane, A.C., Schaldach, R., da Silva, S.S., von Randow, C., Walker, W.S., 2023. The drivers and impacts of Amazon forest degradation. Science (1979) 379. https://doi.org/10.1126/science.abp8622

Lovejoy, T.E., Nobre, C., 2019. Amazon tipping point: Last chance for action. Sci Adv 5. https://doi.org/10.1126/sciadv.aba2949

Maia, A.G., Reydon, B.P., Ie, D., 2004. metodologias e recomendações Valoração de recursos ambientais – metodologias e recomendações. IE/UNICAMP.

Malhado, A.C.M., Ladle, R., Whittaker, R., Neto, A., Malhi, Y., Ter Steege, H., 2013. The ecological biogeography of Amazonia. Front Biogeogr 5. https://doi.org/10.21425/f5fbg13314

Malhi, Y., Roberts, J.T., Betts, R.A., Killeen, T.J., Li, W., Nobre, C.A., 2008. Climate change, deforestation, and the fate of the Amazon. Science (1979) 319, 169–172. https://doi.org/10.1126/science.1146961

Malmborg, K., Enfors-Kautsky, E., Schultz, L., Norström, A. V., 2022. Embracing complexity in landscape management: Learning and impacts of a participatory resilience assessment. Ecosystems and People 18, 241–257. https://doi.org/10.1080/26395916.2022.2061596

McShane, T.O., Hirsch, P.D., Trung, T.C., Songorwa, A.N., Kinzig, A., Monteferri, B., Mutekanga, D., Thang, H. Van, Dammert, J.L., Pulgar-Vidal, M., Welch-Devine, M., Peter Brosius, J., Coppolillo, P., O'Connor, S., 2011. Hard choices: Making trade-offs between biodiversity conservation and human well-being. Biol Conserv 144, 966–972. https://doi.org/10.1016/j.biocon.2010.04.038

Medeiros-Leal, W.M., Castello, L., Freitas, C.E.C., Siqueira-Souza, F.K., 2021. Single-Species Co-management Improves Fish Assemblage Structure and Composition in a Tropical River. Front Ecol Evol 9. https://doi.org/10.3389/fevo.2021.604170

Mooney, P.H., Hunt, S.A., 2009. Food Security: The Elaboration of Contested Claims to a Consensus Frame*. Rural Sociol 74, 469–497. https://doi.org/10.1111/j.1549-0831.2009.tb00701.x

Mori, A.S., Furukawa, T., Sasaki, T., 2013a. Response diversity determines the resilience of ecosystems to environmental change. Biological Reviews 88, 349–364. https://doi.org/10.1111/brv.12004

Mori, A.S., Spies, T.A., Sudmeier-Rieux, K., Andrade, A., 2013b. Reframing ecosystem management in the era of climate change: Issues and knowledge from forests. Biol Conserv 165, 115–127. https://doi.org/10.1016/j.biocon.2013.05.020

Naughton-Treves, L., Holland, M.B., Brandon, K., 2005. The role of protected areas in conserving biodiversity and sustaining local livelihoods. Annu Rev Environ Resour 30, 219–252. https://doi.org/10.1146/annurev.energy.30.050504.164507

Nieratkaa, L., Bray, D., Mozumder, P., 2015. Can Payments for Environmental Services Strengthen Social Capital, Encourage Distributional Equity, and Reduce Poverty? Conservation and Society 13, 345–355. https://doi.org/10.4103/0972-4923.179880

Oksanen, J., Simpson Gavin, Blanchet F, Kindt Roeland, Legendre Pierre, Minchin Peter, O'Hara R.B., Solymos, P., Stevens, M., Szoecs, E., Wagner, H., Barbour Matt, Bedward Michael, Bolker Ben, Borcard Daniel, Carvalho Gustavo, Chirico Michael, De Caceres Miquel, Durand Sebastien, Evangelista Heloisa, FitzJohn Rich, Friendly Michael, Furneaux Brendan, Hannigan Geoffrey, Hill Mark O, Lahti Leo, McGlinn Dan, Ouellette Marie-Helene, Ribeiro Cunha Eduardo, Smith Tyler, Stier Adrian, Ter Braak Cajo, Weedon James, 2022. Vegan: Community Ecology Package. R package version 2.6-4. Community ecology package.

Osewe, I., Hălălișan, A.F., Talpă, N., Popa, B., 2023. Critical Analysis of Payments for Ecosystem Services: Case Studies in Kenya, Uganda and Tanzania. Forests 14. https://doi.org/10.3390/f14061209

Ostrom, E., 1990. Governing the commons: the evolution of institutions for collective action, Governing the commons: the evolution of institutions for collective action. Cambridge University Press, New York. https://doi.org/10.2307/3146384

Palomo, I., Montes, C., Martín-López, B., González, J.A., García-Llorente, M., Alcorlo, P., Mora, M.R.G., 2014. Incorporating the social-ecological approach in protected areas in the anthropocene. Bioscience 64, 181–191. https://doi.org/10.1093/biosci/bit033

Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E., Stenseke, M., Watson, R.T., Başak Dessane, E., Islar, M., Kelemen, E., Maris, V., Quaas, M., Subramanian, S.M., Wittmer, H., Adlan, A., Ahn, S.E., Al-Hafedh, Y.S., Amankwah, E., Asah, S.T., Berry, P., Bilgin, A., Breslow, S.J., Bullock, C., Cáceres, D., Daly-Hassen, H., Figueroa, E., Golden, C.D., Gómez-Baggethun, E., González-Jiménez, D., Houdet, J., Keune, H., Kumar, R., Ma, K., May, P.H., Mead, A., O'Farrell, P., Pandit, R., Pengue, W., Pichis-Madruga, R., Popa, F., Preston, S., Pacheco-Balanza, D., Saarikoski, H., Strassburg, B.B., van den Belt, M., Verma, M., Wickson, F., Yagi, N., 2017. Valuing nature's contributions to people: the IPBES approach. Curr Opin Environ Sustain 26–27, 7–16. https://doi.org/10.1016/j.cosust.2016.12.006

Peres, C.A., Emilio, T., Schietti, J., Desmoulière, S.J.M., Levi, T., 2016. Dispersal limitation induces long-term biomass collapse in overhunted Amazonian forests. Proc Natl Acad Sci U S A 113, 892–897. https://doi.org/10.1073/PNAS.1516525113/SUPPL_FILE/PNAS.201516525SI.PDF

Petersen, T.A., Brum, S.M., Rossoni, F., Silveira, G.F.V., Castello, L., 2016. Recovery of Arapaima sp. populations by community-based management in floodplains of the Purus River, Amazon. J Fish Biol 89, 241–248. https://doi.org/10.1111/jfb.12968

Pimm, S.L., Jenkins, C.N., Abell, R., Brooks, T.M., Gittleman, J.L., Joppa, L.N., Raven, P.H., Roberts, C.M., Sexton, J.O., 2014. The biodiversity of species and their rates of extinction, distribution, and protection. Science (1979) 344. https://doi.org/10.1126/science.1246752

Pörtner, H.O., Scholes, R.J., Arneth, A., Barnes, D.K.A., Burrows, M.T., Diamond, S.E., Duarte, C.M., Kiessling, W., Leadley, P., Managi, S., McElwee, P., Midgley, G., Ngo, H.T., Obura, D., Pascual, U., Sankaran, M., Shin, Y.J., Val, A.L., 2023. Overcoming the coupled climate and biodiversity crises and their societal impacts. Science (1979) 380. https://doi.org/10.1126/science.abl4881

Quintas-Soriano, C., Brandt, J.S., Running, K., Baxter, C. V., Gibson, D.M., Narducci, J., Castro, A.J., 2018. Social-ecological systems influence ecosystem service perception: A programme on ecosystem change and society (PECS) analysis. Ecology and Society 23, art3. https://doi.org/10.5751/ES-10226-230303

Ricketts, T.H., Soares-Filho, B., da Fonseca, G.A.B., Nepstad, D., Pfaf, A., Petsonk, A., Anderson, A., Boucher, D., Cattaneo, A., Conte, M., Creighton, K., Linden, L., Maretti, C., Moutinho, P., Ullman, R., Victurine, R., 2010. Indigenous lands, protected areas, and slowing climate change. PLoS Biol 8, e1000331. https://doi.org/10.1371/journal.pbio.1000331

Rodrigues, A.C., Costa, H., Carlos, P., Brondizio, E., Dias, A., Dias, J., Constantino, P., Ladle, R., Malhado, A.C., Campos-Silva, J. V., 2024. Community-based fisheries management exert a vast value-added effective protection footprint in Amazonian forests. Nature Sustainability - In press 1–26. https://doi.org/10.21203/rs.3.rs-3782947/v1

Sampaio, G., Nobre, C., Costa, M.H., Satyamurty, P., Soares-Filho, B.S., Cardoso, M., 2007. Regional climate change over eastern Amazonia caused by pasture and soybean cropland expansion. Geophys Res Lett 34. https://doi.org/10.1029/2007GL030612

Scholte, S.S.K., van Teeffelen, A.J.A., Verburg, P.H., 2015. Integrating socio-cultural perspectives into ecosystem service valuation: A review of concepts and methods. Ecological Economics 114, 67–78. https://doi.org/10.1016/j.ecolecon.2015.03.007

Schröder, N.J.S., 2018. The lens of polycentricity: Identifying polycentric governance systems illustrated through examples from the field of water governance. Environmental Policy and Governance 28, 236–251. https://doi.org/10.1002/eet.1812

Silvano, R.A.M., Hallwass, G., Lopes, P.F., Ribeiro, A.R., Lima, R.P., Hasenack, H., Juras, A.A., Begossi, A., 2014. Co-management and spatial features contribute to secure fish abundance and fishing yields in tropical floodplain lakes. Ecosystems 17, 271–285. https://doi.org/10.1007/s10021-013-9722-8

Sullivan, M.J.P., Lewis, S.L., Affum-Baffoe, K., Castilho, C., Costa, F., Sanchez, A.C., Ewango, C.E.N., Hubau, W., Marimon, B., Monteagudo-Mendoza, A., Qie, L., Sonké, B., Martinez, R.V., Baker, T.R., Brienen, R.J.W., Feldpausch, T.R., Galbraith, D., Gloor, M., Malhi, Y., Aiba, S.I., Alexiades, M.N., Almeida, E.C., De Oliveira, E.A., Dávila, E.Á., Loayza, P.A., Andrade, A., Vieira, S.A., Aragão, L.E.O.C., Araujo-Murakami, A., Arets, E.J.M.M., Arroyo, L., Ashton, P., Gerardo Aymard, C., Baccaro, F.B., Banin, L.F., Baraloto, C., Camargo, P.B., Barlow, J., Barroso, J., Bastin, J.F., Batterman, S.A., Beeckman, H., Begne, S.K., Bennett, A.C., Berenguer, E., Berry, N., Blanc, L., Boeckx, P., Bogaert, J., Bonal, D., Bongers, F., Bradford, M., Brearley, F.Q., Brncic, T., Brown, F., Burban, B., Camargo, J.L., Castro, W., Céron, C., Ribeiro, S.C., Moscoso, V.C., Chave, J., Chezeaux, E., Clark, C.J., De Souza, F.C., Collins, M., Comiskey, J.A., Valverde, F.C., Medina, M.C., Da Costa, L., Dančsák, M., Dargie, G.C., Davies, S., Cardozo, N.D., De Haulleville, T., De Medeiros, M.B., Del Aguila Pasquel, J., Derroire, G., Di Fiore, A., Doucet, J.L., Dourdain, A., Droissart, V., Duque, L.F., Ekoungoulou, R., Elias, F., Erwin, T., Esquivel-Muelbert, A., Fauset, S., Ferreira, J., Llampazo, G.F., Foli, E., Ford, A., Gilpin, M., Hall, J.S., Hamer, K.C., Hamilton, A.C., Harris, D.J., Hart, T.B., Hédl, R., Herault, B., Herrera, R., Higuchi, N., Hladik, A., Coronado, E.H., Huamantupa-Chuquimaco, I., Huasco, W.H., Jeffery, K.J., Jimenez-Rojas, E., Kalamandeen, M., Djuikouo, M.N.K., Kearsley, E., Umetsu, R.K., Kho, L.K., Killeen, T., Kitayama, K., Klitgaard, B., Koch, A., Labrière, N., Laurance, W., Laurance, S., Leal, M.E., Levesley, A., Lima, A.J.N., Lisingo, J., Lopes, A.P., Lopez-Gonzalez, G., Lovejoy, T., Lovett, J.C., Lowe, R., Magnusson, W.E., Malumbres-Olarte, J., Manzatto, Â.G., Marimon, B.H., Marshall, A.R., Marthews, T., De Almeida Reis, S.M., Maycock, C., Melgaço, K., Mendoza, C., Metali, F., Mihindou, V., Milliken, W., Mitchard, E.T.A., Morandi, P.S., Mossman, H.L., Nagy, L., Nascimento, H., Neill, D., Nilus, R., Vargas, P.N., Palacios, W., Camacho, N.P., Peacock, J., Pendry, C., Mora, M.C.P., Pickavance, G.C., Pipoly, J., Pitman, N., Playfair, M., Poorter, L., Poulsen, J.R., Poulsen, A.D., Preziosi, R., Prieto, A., Primack, R.B., Ramírez-Angulo, H., Reitsma, J., Réjou-Méchain, M., Correa, Z.R., De Sousa, T.R., Bayona, L.R., Roopsind, A., Rudas, A., Rutishauser, E., Salim, K.A., Salomão, R.P., Schietti, J., Sheil, D., Silva, R.C., Espejo, J.S., Valeria, C.S., Silveira, M., Simo-Droissart, M., Simon, M.F., Singh, J., Shareva, Y.C.S., Stahl, C., Stropp, J., Sukri, R., Sunderland, T., Svátek, M., Swaine, M.D., Swamy, V., Taedoumg, H., Talbot, J., Taplin, J., Taylor, D., Ter Steege, H., Terborgh, J., Thomas, R., Thomas, S.C., Torres-Lezama, A., Umunay, P., Gamarra, L.V., Van Der Heijden, G., Van Der Hout, P., Van Der Meer, P., Van Nieuwstadt, M., Verbeeck, H., Vernimmen, R., Vicentini, A., Vieira, I.C.G., Torre, E.V., Vleminckx, J., Vos, V., Wang, O., White, L.J.T., Willcock, S., Woods, J.T., Wortel, V., Young, K., Zagt, R., Zemagho, L., Zuidema, P.A., Zwerts, J.A., Phillips, O.L., 2020. Long-term thermal sensitivity of earth's tropical forests, Science. https://doi.org/10.1126/science.aaw7578

Tregidgo, D., Barlow, J., Pompeu, P.S., Parry, L., 2020. Tough fishing and severe seasonal food insecurity in Amazonian flooded forests. People and Nature 2, 468–482. https://doi.org/10.1002/pan3.10086

Vatn, A., Pascual, U., Chaplin-Kramer, R., Termansen, M., Arias-Arévalo, P., Balvanera, P., Athayde, S., Hahn, T., Lazos, E., 2024. Incorporating diverse values of nature in decision-making—theory and practice. Philosophical Transactions of the Royal Society B: Biological Sciences 379. https://doi.org/10.1098/rstb.2022.0315

Villamayor-Tomas, S., García-López, G., 2018. Social movements as key actors in governing the commons: Evidence from community-based resource management cases across the world. Global Environmental Change 53, 114–126. https://doi.org/10.1016/j.gloenvcha.2018.09.005

Watson, J.E.M., Dudley, N., Segan, D.B., Hockings, M., 2014. The performance and potential of protected areas. Nature 515, 67–73. https://doi.org/10.1038/nature13947

Wiseman, J., 2006. Local heroes? Learning from recent community strengthening initiatives in Victoria. Australian Journal of Public Administration 65, 95–107. https://doi.org/10.1111/j.1467-8500.2006.00485.x

Yates, G.E., Stein, T. V., Wyman, M.S., 2010. Factors for collaboration in Florida's tourism resources: Shifting gears from participatory planning to community-based management. Landsc Urban Plan 97, 213–220. https://doi.org/10.1016/j.landurbplan.2010.06.003

4. COMMUNITY-BASED FISHERIES MANAGEMENT EXERT A VAST VALUE-ADDED EFFECTIVE PROTECTION FOOTPRINT IN AMAZONIAN FORESTS

Submetido na Nature Sustainability (Em Revisão)

Ana Carla Rodrigues[1,2], Hugo C. M. Costa[2,3], Carlos A. Peres[2,4], Eduardo Sonnewend Brondizio[5,6], Adevaldo Dias[7], José Alves de Moraes[2,8], Pedro Constantino[9], Richard James Ladle[1], Ana Claudia Mendes Malhado[1], João Vitor Campos-Silva[1,2,3,10]

[1] Programa de pós-graduação em Diversidade Biológica e Conservação nos Trópicos, Instituto de Ciências Biológicas e da Saúde, Universidade Federal de Alagoas, Maceió, AL, Brasil

[2] Instituto Juruá, Manaus, AM, Brasil

[3] Programa de Pós-graduação em Ecologia, Instituto Nacional de Pesquisas da Amazonia, Manaus, AM, Brasil

[4] School of Environmental Sciences, University of East Anglia, Norwich, UK

[5] Department of Anthropology, and Center for the Analysis of Social Ecological Landscapes (CASEL), Indiana University, Bloomington, IN, USA

[6] Programa de Pós-graduação em Ambiente e Sociedade (NEPAM), Universidade de Campinas, Campinas, SP, Brasil.

[7] Memorial Chico Mendes, Manaus, AM, Brasil

[8] Associação dos Moradores Agroextrativistas do Baixo Médio Juruá (AMAB), Comunidade Lago Serrado, Carauari, AM, Brasil.

[9] US Forest Service, International Program - Brasil.

[10] Programa de Pós-Graduação em Ciência Animal e Recursos Pesqueiros, Universidade Federal do Amazonas, Manaus, AM, Brasil

4.1 Abstract

Community-based conservation has gained traction in the Brazilian Amazon due to its potential in combining territorial protection, local well-being, and biodiversity conservation. Here, we conducted an innovative assessment of the effective protection footprint of the largest community-based fisheries conservation arrangement in the Amazon. Local communities effectively protected between 1 and 13 lakes, which were on average 47.4 ha in size. However, the effectively protected floodplain area was approximately eight-fold larger than the extent of direct protection, defined as the immediate focal area sustaining financial returns through co-management. The additional protection of a 'functional area' was on average 11,188 ha, or 36-fold larger than the directly protected area. Although the average cost of effective protection was low (US$0.95 ha–1 yr–1), this was entirely incurred by low-income local communities Our study underscores the remarkable effort leveraged by Amazonian rural communities in protecting natural ecosystems and the imperative need to develop compensation mechanisms to financially reward them, which are currently lacking.

Keywords: Communal conservation, co-management, environmental protection, Amazonia, sustainable development, tropical forest

4.2 Introduction

Community-based conservation (CBC), in which local communities lead the management and protection of natural resources, is one of the most promising conservation strategies in developing tropical countries (Berkes, 2007). There are several significant potential co-benefits of CBC initiatives (Brooks et al., 2012). First, CBC ensures biodiversity conservation by promoting sustainable land use practices and critical habitat protection (Campos-Silva et al., 2018). Second, it can generate income and create employment opportunities for local communities through ecotourism, sustainable harvesting of natural resources, and other forms of income generation (Ruiz-Ballesteros and Brondizio, 2013). Third, it can improve social and economic well-being locally by enhancing food security and providing greater access to social services and infrastructure (Campos-Silva et al., 2021; Campos-Silva and Peres, 2016). Fourth, it promotes participatory decision-making, which can enhance the sense of ownership and responsibility among local communities (Ostrom, 2009). Finally, CBC can contribute to the achievement of global conservation goals by effectively conserving biodiversity, building capacity and facilitating knowledge-sharing among stakeholders (Esmail et al., 2023).

CBC is seen as a feasible conservation approach in the Amazon because it combines territorial protection, local welfare, and biodiversity conservation, while also generating income and preventing biodiversity loss (Campos-Silva et al., 2019; Campos-Silva and Peres, 2016). A notable CBC initiative in the Neotropics is the co-management of pirarucu, or giant arapaima (Arapaima gigas) fisheries in Amazonia (Campos-Silva and Peres, 2016; Freitas et al., 2020). Territorial protection is crucial within CBC as it supports source-sink dynamics in harvested Amazonian landscapes, aiding the recovery of historically overexploited species (Arantes et al., 2022; Campos-Silva et al., 2019).

CBC-mediated territorial protection is ensured by 24/7 environmental surveillance, deterring poaching by local and external resource users (Franco et al., 2021). Community surveillance restricts outsider access and enforces protection rules through punitive measures, such as confiscating products, removing trespassers, and notifying government agencies (Queiroz, 2015). Surveillance, initiated in 1995, was key in developing ‘fishing agreements’—formal commitments among communities to comply with management rules—and led to the 2002 consolidation of a community-based environmental protection system (Franco et al., 2021).

The CBC approach has been remarkably successful. For example, wild arapaima populations increased by 425% along the Juruá River (Campos-Silva et al., 2019), mirroring trends in other basins adopting this approach (Castello et al., 2009; Petersen et al., 2016). Additionally, this approach positively impacted fish communities' structure and composition, increasing species richness, body mass, abundance, and biomass (Medeiros-Leal et al., 2021).

A major motivation for arapaima fisheries co-management is to generate demographic benefits for resource populations, resulting in both subsistence and direct income (Campos-Silva et al., 2020). However, the economic burden of territorial surveillance falls heavily on disenfranchised local communities, potentially threatening the long-term viability of this conservation program (Robalino et al., 2021). Arapaima CBC presents a common-pool resource dilemma: enhanced fish populations allow fishers to secure predictable quotas, but this requires costly monitoring and enforcement to ensure sustainable floodplain management. Besides monitoring costs, fishing communities face significant logistical expenses in marketing their fish quotas (Instituto Juruá, unpubl. data). Research suggests that conservation policies need to offer sufficient incentives to stimulate local economic interests and mobilize commitments to formalize conservation actions (Londres et al., 2023). Therefore, the disparity between positive large-scale conservation outcomes and low socioeconomic benefits poses a significant challenge to the sustainability of CBC efforts (Campos-Silva et al., 2019).

One way to offset these costs is through Payment for Environmental Services (PES) programs co-designed with communities, providing compensation for the use and stewardship of resources to ensure environmental services. PES participants can be individuals, enterprises, NGOs, private institutions, or the public as direct or indirect beneficiaries of territorial protection (Wunder, 2015). PES often involves carbon sequestration, water quality, ecotourism, and biodiversity protection (Ezzine-De-Blas et al., 2016). Implementing PES for biodiversity is challenging due to indirect, delayed benefits, often requiring legal support (Hein et al., 2013). In Latin America, PES uptake has increased, targeting forest carbon, hydrological catchments, and biodiversity conservation. Balancing payments is complex due to socio-ecological intricacies and history; PES can reduce deforestation, especially under long-term contracts (Charoud et al., 2023), and bolster ecosystem resilience (Ocampo-Melgar et al., 2024). Even in areas with limited governance, PES can yield significant benefits (Salzman et al., 2018).

Successful PES programs should adapt to diverse conditions and be integrated into flexible, existing governance structures. Long-term effectiveness requires continuous monitoring of costs, production, and impacts, with a focus on enhancing natural resources rather than merely maintaining the status quo (Börner et al., 2017). Effective implementation also hinges on creating schemes that enhance social equity and foster intrinsic motivation, which are justified on both normative and instrumental grounds (Akers and Yasué, 2019). These schemes should be managed autonomously, fairly, and efficiently to maximize socio-environmental benefits and ensure resource conservation (Lliso et al., 2021).

Here, we quantitatively assess the impact of the largest community-based conservation program in Brazilian Amazonia by examining the full extent of community-led environmental surveillance and their associated costs considering 96 protected lakes located along the Juruá River, a major tributary of the Amazon. Specifically, we estimate the full spatial extent of floodplain and upland forests that local communities can effectively guard as a consequence of CBC, and the economic cost incurred by this surveillance, which are currently borne out by the communities. We use these estimates to highlight the enormous effort invested by Amazonian rural communities to ensure the protection of natural ecosystems, arguing for the development of new governance and financial tools to reward strong local conservation measures by legitimate resource users as a cost-effective and socially just approach to ensure forest protection. Finally, we discuss the potential viability of PES approaches to support community-based conservation and reduce the asymmetry between the costs of conservation efforts incurred locally and environmental benefits accrued at much larger spatial scales.

4.3. Results

4.3.1 Operational structure of community-led protection

Local guards covering a floodplain area are community members who participate in arapaima management, and may be organized in pairs or small teams of up to eight people. The rotation among teams is determined by the community and is established depending on the physical environment, such as lake location, lake accessibility, distance to the community support base, and number of guards available in the community (Figure 1A). In general, surveillance forays could range from six hours to seven consecutive days, but in a few communities the guard lived in a floating house on the lake all year-round. Surveillance costs are mostly paid for by community members themselves, in which household food and fuel supplies are made available to enable travel to the vicinity of each surveillance site. However, a few communities included surveillance activities as part of the total cost of arapaima management. The most critical surveillance season was when the level of floodwaters was receding. Illegal fishers at this time could rapidly move into a lake and harvest protected stocks of commercially desirable fish species, resulting in the remaining stock to relocate from any given lake in search of safer sites elsewhere (Figure S1).

4.3.2 Community-based protection footprint

A total of 96 protected oxbow lakes under the direct jurisdiction and stewardship of 14 rural communities and hosting a population count of approximately 109,000 adult arapaima, were mapped along the Juruá River (Figure 1B). These communities were on average spaced by 82.8 km from the nearest town (range = 51.78 - 110.9 km). Each of these communities on average contained 12.6 families (range = 2 - 32), with a total of 177 families participating in community-led lake surveillance. On average, 6.4 lakes (range = 1 - 13) were protected per community, with individual lakes accounting for a mean dry-season area of 47.39 (± 82.26) ha. The spatial extent of direct protection was on average 305 ha per community, but the wider territorial protection resulting from effective protection was on average 2,346 ha (Table S1, Figure 2A). In other words, the extent of effectively protected areas was almost eight-fold larger than the aggregate size of all protected lakes within the jurisdiction of any given community, which corresponds to the actual focal area that derived financial returns through co-management. The functional floodplain area supporting co-management was even larger: on average this amounted to 11,189 ha per community, an area ~36-fold larger than the directly protected area (ANOVA, df = 3, F = 93.41, $p < 0.001$; Figure S2; Table S2). Finally, each local community included in this study incidentally protected an overall additional average upland area of 12,383 ha of terra firme (nonflooded) forests by simply closing off those areas by severing physical access through the floodplain area protected by

CBC. This area was on average nearly 40-fold larger than the directly protected area. Combining all four zones of either direct or incidental protection, each community in fact protected a mean total area of floodplain and upland forest nearly 86 times larger than the total dry-season area of lakes sustaining local arapaima populations.

4.3.3 Financial cost of CBC protection

The current community-scale monetary costs of environmental surveillance were calculated based on real-world expenditure information reported by each community. The mean annual cost of territorial surveillance was estimated at ~US$31,271 to ensure the overall effective protection of 32,844 ha of floodplain environments. In other words, on average ~US$0.95 was spent on each hectare of effectively protected area. Surveillance expenditure was conservatively estimated at zero labour costs and based on only fuel and food supplies consumed by lake guards who volunteered to contribute unpaid labour time. These costs are low compared to the estimated community-led costs based on our three potential hypothetical PES scenarios. We found that if two lake guards were to be rewarded by local daily wages, these costs would increase to US$5.30/ha. Assuming that labour costs for two guards could be met considering the Brazilian minimum wage, these costs would slightly increase to US$5.40/ha. Finally, considering standard payment rates recently awarded by the official environmental protection agency (ICMBio), these costs would further increase to US$9.60/ha (Figure 2B).

On average, surveillance costs represented 32% of the overall costs of community-based fisheries management and exerted a negative impact of 21% of the net community income. Our model selection identified three most parsimonious models (Table S3). The model averaging approach revealed that travel distance to the farthest lake, which was typically isolated from the river channel, was the most important predictor across all plausible models in explaining protection costs ($\omega AICc = 1$). Additionally, the authorized arapaima harvest quota ($\omega AICc = 0.33$) and number of protected lakes ($\omega AICc = 0.32$) emerged as other important variables, each appearing in one of the selected models (Figure S2).

To ensure a fair reward system to local fishers who protect wide-ranging fisheries resources that transcend local jurisdictions, we identified three potential scenarios according to the payment system complying with Brazilian labour regulations. The cost of any PES program was calculated considering the fishing quota allowed by the regulatory agency, so that PES costs could be equated to a standard unit of fish offtake (kg of harvested fish). This facilitates the payment rationale to local fishers, in addition to the fact that large quotas translate into more intensive efforts to protect supporting habitats. In these terms, local payments would range from US$0.94/kg of fish considering local wages to US$1.70/kg of fish considering ICMBio hiring practices (Table S4). Considering labour costs in terms of the current minimum salary according to Brazilian labour law, cost estimates would be comparable to those based on local daily wages (US$0.95/kg). These cost estimates mean that ensuring the viability of a PES program covering the entire Central Juruá River basin would require funding in the order of between ~US$1,770,000 and ~US$3,170,000 each year. If we were to project those values to support CB fisheries management across the entire state of Amazonas, this would require between ~US$50.3 million and ~US$90.1 million in annual payments, which would benefit over 400 rural communities and ensure the socially just protection of approximately 15 million hectares of floodplain forests.

4.4 Discussion

The territorial protection and resource surveillance carried out by Amazonian local communities involved in arapaima co-management has ensured the protection of vast areas of tropical forest, safeguarding the flow of multiple ecosystem services at different scales (Campos-Silva and Peres, 2016). Beyond the ecological benefits reported to date, our results show that community-led protection of aquatic environments within community-based fisheries arrangements also ensure the added-value protection of much larger aquatic and terrestrial areas compared to only the aggregate lake area where dry-season fishing activities are conducted. Quantifying this enormous effort allocated by Indigenous Peoples and Local Communities to protect their own territories reinforce the positive role of traditional people on conservation of Amazonian environments (Brondízio et al., 2021).

Local communities are always present, thereby protecting their aquatic environments all year-round and 24 hours each day. Yet commercially valuable fish stocks become more vulnerable during the receding floodwaters, which renders community protection efforts even more diffuse, more complex, and more demanding. Therefore, surveillance requires enormous dedication of time and effort, in addition to incurring a high cost to already low-income families, by limiting their capacity to engage in other profitable activities and subsistence food production (Campos-Silva et al., 2020). In this context, community-led territorial governance and protection represents a substantial opportunity cost for local households. It is therefore critical to recognize, and ideally enhance, communal surveillance activities through financial support of local communities if the long-term success of these CBC outcomes are to be maintained (Charoud et al., 2023).

Spatial footprint of community-led protection

We show that the scale of effective environmental protection by Juruá communities, considering their routine surveillance routes on foot, is almost eight-fold larger than the actual aggregate lake area. This extended protection footprint in fact becomes much larger, considering that guarding floodplain environments during the critical time of the year incidentally precludes access to adjacent upland forests that would otherwise be reached. Therefore, by precluding illegal incursions by outside users into the floodplain and its anastomosing channels, local communities also ensure the added-value protection of vast areas of unflooded upland forests. In this context, beyond the strong positive impact on fisheries resources and aquatic biodiversity shown elsewhere (Campos-Silva et al., 2019; Campos-Silva and Peres, 2016), the effective protection of both várzea and terra firme forests during the low-water season clearly delivers strong additional benefits to terrestrial biodiversity conservation by preventing illegal exploitation by fishers, hunters, loggers and, more recently, miners.

Another key finding reported here is the spatial extent of functional protection, which is an important hidden positive impact of community-based conservation. The Juruá River experiences a flood pulse that can reach depths of up to 11 m for up to 230 days a year (Campos-Silva et al., 2021). Arapaima fish exhibit lateral migration patterns during this prolonged flood pulse, including habitual movements into flooded forests between tributary lakes and perennial streams, and the main river channel (Campos-Silva et al., 2019). Population recovery of this apex predator is closely associated with lateral migration and replenishing of depleted environments (Campos-Silva et al., 2019), which can impact the top-down trophic dynamics across an area ~255-fold larger than the neighbouring lake area, thereby controlling the abundance of other important prey species (Campos-Silva et al., 2021). In addition, the spatial contagion of enforcing protection ensures recolonization of previously depleted areas far away from the target lake, reinforcing the importance of co-management activities in promoting food security for Amazonian rural communities (Tregidgo et al., 2020).

Cost of community-based protection in a seasonal environment

Arapaima population viability is closely linked to the hydrological cycle, including the supra-annually variable seasonal flood pulse, which markedly alters the seasonal fluvial connectivity of the floodplains along major meandering rivers of the Amazon (Junk et al., 1989). During the flood season, arapaima moves between lakes, the main river channel, and the flooded forest, where they have access to high-quality food sources (Campos-Silva et al., 2019). When floodwaters begin to recede, arapaima shows a high degree of site fidelity, returning to their breeding lakes, particularly when conditions are quiet including low ambient noise (Campos-Silva et al., 2019). Our results show a much greater community effort during this period in protecting stocks against human disruptions induced by fishing gear and poaching (Figure 2B). This leads to a marked peak of labour-intensive surveillance activity that requires substantial resources, including food supplies, fuel, boats and canoes, and a larger number of volunteers because schools of arapaima can flee the lakes prematurely if they perceive a threat from outside fishers.

Comparing the costs of community-led efforts against alternative scenarios that rely on proactive participation of government agencies or NGOs, we easily reach the conclusion that local community inclusion in conservation arrangements is the cheapest and most cost-effective mechanism to ensure the protection of natural ecosystems, such as the Juruá floodplains. However, we emphasise the glaring lack of social justice behind this strategy given the heavy burden and local opportunity costs considering that the time and effort spent in territorial protection could be allocated to alternative income generation activities. In fact, the substantial asymmetry between large conservation benefits accrued at multiple scales and the local socioeconomic costs incurred locally represents one of the main bottlenecks in implementing community-based arrangements. This distortion thus needs to be addressed to strengthen the CBC model in Amazonia and beyond.

Although the costs of community-led protection can be seen as exceedingly low compared to the typical investments in conservation interventions by most external agencies (Silva et al., 2019), those values are extremely high for disenfranchised local communities, which accept to soldier on because this heavy burden yields many other benefits beyond a simple monetary trade-off (Campos-Silva et al., 2021). Our study communities have legitimized their interests through co-management actions, increasingly engaging in conservation practices with intrinsic motivations that are often above economic payoffs. In addition to collective decision-making, there is a collective sense of autonomy and belonging that ensures access to natural resources for both present and future generations (Gamarra et al., 2019; Ostrom, 2009). Given little or no action enacted by toothless environmental agencies throughout the Amazon, this local community empowerment has filled the vacuum by successfully protecting their own territories against major threats by external enterprises waging predatory overexploitation (Levis et al., 2020; Lopes et al., 2021).

Strengthening recognition of hidden environmental services

Community-led biodiversity protection thorough local empowerment can ensure socio-environmental governance and maintenance of ecosystem services and opportunities for self-development both inside and outside protected areas (Campos-Silva et al., 2021), especially when confronting hostile policies dismantling environmental regulations (Vale et al., 2021). However, local communities cannot continue to shoulder the heavy burden of 24-by-7 environmental protection without external support. This is vital for the maintenance of community-based conservation, given that biodiversity-based value chains are not sufficiently fair to cover the intrinsic costs of environmental protection. In addition, above and beyond the financial costs associated with surveillance efforts, there are other secondary opportunity costs incurred by neglecting horticultural investments, which also provide subsistence and income (Alves-Pinto et al., 2018; Newton et al., 2012). Furthermore, a relentless state of surveillance and readiness imposes a substantial physical and psychological toll, given the ever-present possibility of violent hostilities from potential intruders, which in extreme cases can be life-threatening (Campos-Silva et al., 2020).

Payments for Ecosystem (or environmental) services (PES) has the potential to contribute highly positive conditional incentives for the provision of ecosystem services (Wunder, 2015). Although this approach is more common in terrestrial conservation, it has recently grown in fisheries management (Bladon et al., 2016). In sum, PES is more likely to succeed within fisheries arrangements that show (i) demand for one or a set of ecosystem services or bottlenecks in the value-chain; (ii) evidence-based approach with a clear baseline; (iii) clear boundaries and property rights; (iv) strong local governance; (v) robust monitoring, control and surveillance; and (vi) financial sustainability (Bladon et al., 2016). Arapaima co-management in the Brazilian Amazon shows a high level of community organization, in addition to the balanced participation of local institutions, NGOs, academic institutions, and government agencies. These conditions provide a solid foundation for the implementation, organization, and development of PES programs involving established CBC arrangements. This is critical because the lack of socio-political organization often makes these schemes unworkable (Salzman et al., 2018).

Our study clearly underscores an imperative moral challenge of directly compensating local communities providing a wider public good generated by their environmental protection efforts (Arantes et al., 2022). A fairer return on their conservation efforts is vital to compensate for their tangible contributions and roles as protagonists of these arrangements, aligning biodiversity protection with local wellbeing. As such, strengthening and ensuring better surveillance conditions and greater economic returns to local communities can capture the long-term goals of local environmental and socioeconomic sustainability.

A co-designed PES model should be transparent in terms of who pays (the buyers), who benefits (the beneficiaries), and who sells (the providers) (Mohammed, 2013). We advocate that a PES mechanism within the arapaima CBM program in Brazil should be supported multilaterally between inter-governmental funds, non-governmental initiatives, and international cooperation, considering that the ecosystem services indirectly provided by local communities operate at a global scale (Levis et al., 2020). The Brazilian government has the means to implement a PES program, which could become a key financial mechanism, strengthening the economic benefits of environmental protection, promoting an increased sense of ownership, and engaging new communities into arapaima management, similarly to other PES programs like the Bolsa Floresta (Cisneros et al., 2022). However, we highlight the importance of securing enough decision-making power for local leaders and community representatives to ensure procedural and representative justice throughout the entire process of implementing and maintaining programs (Lopes et al., 2021).

Community participation is a crucial element in the processes of designing, implementing, and monitoring the effectiveness and success of PES activities (Kaiser et al., 2021). In addition, this must be based on transparency among investors, beneficiaries, and providers (Shapiro-Garza et al., 2020; Upton, 2020). Thus, the active participation of community members, together with inter-institutional partnerships, can render bureaucratic and legal processes enforceable in a participatory manner (Shapiro-Garza et al., 2020).

PES programs have raised significant ethical and social concerns. Treating natural resources as commodities, subject to transactions, can exacerbate unequal benefit distribution, potentially disadvantaging involved communities (Kaiser et al., 2021). For initiatives to be effective, equity in PES benefit distribution must be integrated throughout the workflow. Ignoring the interconnected aspects of socio-biodiversity can undermine conservation efforts. Focusing solely on measurable environmental services and oversimplifying ecological processes can undervalue natural resources (Kaiser et al., 2021; Shapiro-Garza et al., 2020). A comprehensive resource assessment is necessary to avoid excluding critical operational factors in PES development and maintenance (Kaiser et al., 2021).

While benefiting from PES, communities can paradoxically become dependent and vulnerable without strategies to mitigate financial and structural risks ensuring program continuity (Upton, 2020). Diversifying funding sources reduces risks associated with interruptions or delays in payments and benefits (Kaiser et al., 2021). This approach ensures long-term viability for community-based surveillance systems, making them fair activities (Shapiro-Garza et al., 2020). Our findings show that CBM is a highly viable and cost-effective method for implementing PES, allowing for territorial protection across vast Amazonian Forest areas with relatively modest investments, significantly enhancing frontline conservation efforts.

4.5 Conclusion

Arapaima management in Brazilian Amazonia has emerged as a strong window of opportunity to align biodiversity protection with sustainable and equitable prosperity. However, any socioeconomic gains accrued from sustainable offtakes are still very modest considering the huge positive conservation impact (Campos-Silva et al., 2021, 2020, 2019; Campos-Silva and Peres, 2016). We here uncover the hidden added-value of community-based territorial surveillance, which ensures both biodiversity protection and the provision of a wide range of ecosystem services that, in turn, enhances the quality of life of local people. We reinforce the need to both recognize and reward the enormous effort allocated by local communities to protect Amazonian natural ecosystems. It is thus imperative to consolidate this new pathway towards a brighter future for Amazonia, in which local livelihoods and the protection of Earth's largest tropical forest are inextricably linked.

4.6 Methods

4.6.1 Study Area

This study was conducted along the Juruá River, a major tributary of the Solimões (=Amazon) River, and primarily within the ~2.58-million-hectare municipal county of Carauari (4° 52′ 58″ S, 66° 53′ 45″ W) in the State of Amazonas, Brazil. This region is strongly influenced by commercial and subsistence activities involving fishing, agriculture, and Euterpe (açaí) fruit and oilseed extraction (Newton et al., 2012). This region contains two contiguous sustainable-use protected areas: the 632,949-ha Uacari Sustainable Development Reserve (RDS Uacari, 5º43'58"S, 67º46'53"W; Decree No. 25,039 of Jun. 1, 2005), and the 253,227 ha Extractive Reserve Médio Juruá (ResEx Médio Juruá, 5º33'54"S, 67º42'47"W; Decree No. n/a of Mar. 4, 1997). These reserves were decreed in 1997 and 2005, respectively, and currently contain ~4,000 inhabitants distributed across 74 communities, most of which near the river channel, along a fluvial distance of 800 km, in addition to communities located along the banks of oxbow lakes and perennial streams (Figure 1B).

4.6.2 Resource governance resulting from arapaima co-management

To ensure both economic and food security for rural communities, Fishing Accords (i.e. formal agreements) were widely negotiated in the mid-Juruá region during the 2010s. These accords involved local communities, including those outside protected areas, as well as the Fishers Cooperative of Carauari, the nearest urban centre. The agreements created three different categories of access to lake resources during the dry season, when lakes become clearly discrete geographic features where fish concentrate: (1) Subsistence-use lakes, which are intended to supply local subsistence needs, and which are restricted to artisanal fishers from the resident community who are responsible for guarding that lake; (2) Protected lakes, which are managed by local communities primarily as arapaima stock recovery sites, and exclude both commercial and subsistence fishing boats, except for a brief community-led offtake season based on a strict harvest quota predetermined by IBAMA, the Brazilian Natural Resources Agency (Campos-Silva and Peres, 2016); and (3) Production lakes, which are open-access to both commercial and subsistence fishers.

A floating wooden watchtower is typically erected at the main strategic entrance of the lake. Equipped with makeshift hunting gear and subsistence supplies, these stationary posts, which are occupied by a small patrol unit and managed by the resident community, conduct round-the-clock armed surveillance. During the arapaima management season, some of the protected lakes are harvested by the resident community for a brief period of up to 5 days per year, according to a previously determined proportional harvest quota based on a stock assessment defined as the number of adult and juvenile arapaima counted at that lake in the previous year (see Campos-Silva and Peres, 2016).

Annual arapaima counts began at several lakes along the mid-Juruá in 2005, and lake management was implemented in 2010 by a partnership between local communities, local associations, and federal and state agencies. Arapaima counts take place during the low-water season at each monitored lake each year, and the census data are forwarded to IBAMA. IBAMA then authorizes a lake-specific harvest quota of up to 30% of all adults (>1.5m in length) counted, depending on the fish processing requirements of the resident community and other extenuating factors.

4.6.3 Data analysis

4.6.3.1 Quantifying territorial protection

We conducted participatory community mapping through semi-structured interviews (CAAE research ethics permit 52148721.6.0000.5013) with lake guards, community leaders, and community residents. First, we asked general questions to describe the surveillance dynamics, including the main actors, surveillance alternation dynamics, impact of seasonality on surveillance dynamics, surveillance pathways, conflict resolution strategies, and associated costs. Participatory community mapping occurred interactively using A3-sized hardcopy cartographic maps showing LANDSAT-8 satellite images in RGB (5,4,3) colour composition, with a scale of 1:100,000 for location and identification of each lake where territorial surveillance had been deployed by each community. Each lake management category was identified by outlining locations on the map using colour markers (Wartmann and Purves, 2017). Participatory community mapping was carried out with community residents who had extensive previous experience with both spatial landmarks across the waterscape, which is the main form of transport in this region, the overall landscape, and in-depth knowledge of arapaima co-management activities (Patton, 2015; Silvano et al., 2023). Floodplain mapping was carried out within the scope of either community meetings or visits to resident households (Saija et al., 2017). Experienced individuals were identified by community leaders.

Arapaima co-management activities exert varying impacts at different spatial scales of influence (Figure 2A). First, there is a (1) direct scale of protection, represented by the immediate lake area where actual surveillance takes place. Second, there is an (2) effective scale of protection, which is represented by the total area within the community surveillance boundaries. Third, there is a (3) functional scale of protection, represented by the functional impact zone exerted by spatial exclusion, particularly related to the vagrancy and movement capacity of the target species protected at each lake. Finally, there is an (4) incidental scale of protection at which local communities indirectly protect large portions of upland (terra firme) forests farther inland by simply restricting entry to strategic access points within the more accessible adjacent floodplains.

Direct scale of protection

During the mapping sessions, all lakes protected through surveillance that are managed by any given community were identified and further classed as direct surveillance areas, as they are the focus of management activities, and their total area was measured using the MapBiomas Água Project collection 1 dataset (MapBiomas 2021), which mapped all open water bodies across Brazil.

Effective scale of protection

Territorial surveillance for lake protection is a set of actions and adaptive strategies that occur on a full-time basis, but intensified in the dry season, to protect areas of management interest. These areas include subsistence-use, protected, and production lakes that are harvested for local subsistence. Surveillance aims to protect lakes from illegal harvesting by either local or external fishers, and any other exploitation activities that can disturb the lake and the surrounding forest, such as hunting and timber extraction. Surveillance strategies are continuously adapted according to the needs of each community and depend on the number of managed lakes, number of people available for surveillance, landscape context, and geographic accessibility of each lake.

Surveillance is conducted by travelling around the perimeter of each lake by canoe or on foot, depending on the season, searching for any presence or signs of intruders. In several communities, floating wooden houses are placed at strategic entry points of access to lakes to optimize surveillance. During surveillance, lake guards cover a floodplain area much larger than the size of individual lakes, which we refer to as “effective scale of protection”, where illegal activities, including poaching, fishing, and logging, are excluded. To estimate the effective protection of each lake, we combined GPS tracks and spatial data recovered from interviews to map the daily paths that community guards frequently travelled to protect each lake. The area effectively protected, including seasonally-flooded várzea forest and open-water bodies, was estimated, including all reported paths on foot and/or canoes between lakes, and all strategic surveillance points that were frequently accessed by outside users attempting illegal fishing. Polygons drawn during participatory mapping were reproduced in QGIS 3.14 (QGIS, 2023) at the same scale using the corresponding satellite image to fine-tune estimates of the effective scale of protection.

Functional scale of protection

We also estimated the functional protection area of each lake based on the ranging ecology of giant arapaima (Arapaima gigas), the conservation target species in this arrangement. We therefore considered arapaima movement patterns, which had been quantified during a previous telemetry study (Campos-Silva et al., 2019), to estimate the capacity of each lake to function as a source area of individuals moving into depleted lakes and the spatial configuration of landscape-scale population gene flow, both of which can sustain ecological interactions and top-down control of food webs mediated by an apex predator (Campos-Silva et al., 2021).

This was estimated using a 1,730-m buffer area around the dry-season perimeter of each lake (i.e. the direct scale of protection). This threshold value corresponds to the radius of an average circular Arapaima home range area, defined by the Minimum Convex Polygon formed by positional fixes obtained for 12 juveniles and adults. Six of these individuals were tracked in our study area in 2014 and seven in 2015 using conventional VHF telemetry, amounting to 309 locations, 125 and 184 of which during the dry and wet seasons, respectively (see Campos-Silva et al., 2019). Individual estimates are available within Table S.5.

Incidental scale protection

In addition to these three scales of protection, oxbow lake surveillance also incidentally protects all the rear areas of upland forests by closing off the physical accessibility to unauthorized users of the várzea floodplain. This strategy prevents non-resident loggers, hunters, and fishers from accessing upland areas, typically to stealthily exploit natural resources without the explicit consent of the local community. This scale of protection was estimated by multiplying the total width of várzea floodplains protected at the effective scale by a conservative 10-km length of upland forests that could be potentially affected by illegal extractive activities (Benítez-López et al., 2019; Peres et al., 2016). To assess differences in spatial extent between different scales of protection, an Analysis of Variance (ANOVA) was performed with the response variable on a logarithmic scale. Assumptions of normality of residuals and homogeneity of variances were evaluated using the Shapiro-Wilk and Levene tests, respectively.

4.6.3.2 Assessing protection dynamics and costs

To better understand local surveillance priorities according to the flood pulse dynamics, we organized focal group interviews at each community with 45 experienced fishers who had conducted local lake surveillance for at least 15 years. These focal groups were adept at mapping the seasonality of surveillance because of previous experience and fluctuations in water level change the accessibility to water-bodies and their vulnerability. Surveillance costs were acquired during interviews and encompassed general operational expenditure including fuel, food, and butane gas used as fuel to power outboard motors during surveillance routes, according to the unique ways in which each community carried them out. This excludes labour input and expenditure related to purchase and maintenance of wooden or aluminium boats, outboard motors, paddles, and infrastructure such as strategically positioned floating houses, which served to accommodate lake guards during surveillance shifts. To supplement our field data, we assessed the annual reports of arapaima management fisheries provided by the Association of Rural Producers from Carauari (ASPROC) produced in 2022. ASPROC is a grassroots smallholder and fisher-led organization leading the arapaima management along the Juruá River. We computed the surveillance expenses associated with all four scales of surveillance and subsequently compared costs under three different scenarios: 1) current expenditure covered by local communities or guards who were community members lacking any labour wage payments, 2) general expenditure and costs considering local daily wages of US$14.30 for two people working all year-round; 3) costs incurred by hiring two individuals receiving a minimum wage of US$442.24 (US$247.30 in wages plus US$194.90 in labour taxes) to conduct surveillance in compliance with Brazilian labour regulations, and 4) potential expenditure of US$852 (US$510.20 in wages plus US$341.80 in taxes) covered by the Brazilian

Environmental Agency for two additional environmental agents, according to the hiring notice SEI/ICMBio 15343964 and law 7.957/1989.

We also performed Generalized Linear Models (GLM) using a Gaussian distribution for continuous data to investigate the community-scale variation in protection costs (response variable) as a function of distance to the nearest town, number of lakes requiring protection, distance to the farthest lake, and the locally authorized harvest quota. We mitigated for collinearity between predictors using the Variance Inflation Factor (VIF < 3), excluding variables above this threshold (Zuur et al., 2010). We further combined all possible models, from the constant to the full model, using the dredge function of the MuMIn package. Models were selected based on the lowest Akaike information criterion (AIC) corrected for small sample sizes (AICc). The ΔAICc value represents the difference between the AICc of a given model and the lowest AICc, whereas ΔAICc < 2 represent the most likely set of parsimonious models (Burnham and Anderson, 2002). Finally, we applied a model-averaging approach, which represented the beta average of all predictors included in the set of most parsimonious models, and determined the relative importance of each explanatory variable given their model frequency and cumulative Akaike weight. All analyses were conducted in R 4.3.1. All monetary costs were standardized and corrected for inflation from October 2021 to July 2023 and converted into USD using a 4.91 BRL exchange rate.

Lastly, we estimated the financial imperative of meeting the overall costs of territorial protection through a PES mechanism. In an attempt to estimate a value that could cover the costs of territorial protection, we built three alternative scenarios i) considering all operational costs, including fuel and food requirements and, at least two people hired through daily wages, ii) operational costs and minimum wages following Brazilian labour regulations, and iii) operational costs and human resources hired through the standard practices followed by the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), Brazil’s environmental agency responsible for Protected Areas and environmental management. These compensation mechanisms provide valuable insights into ways of rewarding local dwellers for their role in territorial protection. However, it is essential to recognize that community protection of their environments is a collective effort. Therefore, involving local leaders in program design is crucial from the outset to identify the most effective ways of rewarding those engaged in territorial protection. Finally, we divided these values by the potential fish catch of each community to calculate monetary expenditure per unit of fish biomass harvested, which can facilitate the rational implementation of a PES program based on territorial protection and official catch statistics.

Referências

Akers, J.F., Yasué, M., 2019. Motivational Crowding in Payments for Ecosystem Service Schemes: A Global Systematic Review. Conservation and Society 17, 377–389. https://doi.org/10.4103/cs.cs_18_90

Alves-Pinto, H.N., Hawes, J.E., Newton, P., Feltran-Barbieri, R., Peres, C.A., 2018. Economic Impacts of Payments for Environmental Services on Livelihoods of Agro-extractivist Communities in the Brazilian Amazon. Ecological Economics 152, 378–388. https://doi.org/10.1016/j.ecolecon.2018.05.016

Arantes, C.C., Castello, L., Basurto, X., Angeli, N., Sene-Haper, A., McGrath, D.G., 2022. Institutional effects on ecological outcomes of community-based management of fisheries in the Amazon. Ambio 51, 678–690. https://doi.org/10.1007/s13280-021-01575-1

Benítez-López, A., Santini, L., Schipper, A.M., Busana, M., Huijbregts, M.A.J., 2019. Intact but empty forests? Patterns of hunting-induced mammal defaunation in the tropics. PLoS Biol 17, e3000247. https://doi.org/10.1371/journal.pbio.3000247

Berkes, F., 2007. Community-based conservation in a globalized world, Proceedings of the National Academy of Sciences of the United States of America. https://doi.org/10.1073/pnas.0702098104

Bladon, A.J., Short, K.M., Mohammed, E.Y., Milner-Gulland, E.J., 2016. Payments for ecosystem services in developing world fisheries. Fish and Fisheries 17, 839–859. https://doi.org/10.1111/faf.12095

Börner, J., Baylis, K., Corbera, E., Ezzine-de-Blas, D., Honey-Rosés, J., Persson, U.M., Wunder, S., 2017. The Effectiveness of Payments for Environmental Services. World Dev. https://doi.org/10.1016/j.worlddev.2017.03.020

Brondízio, E.S., Aumeeruddy-Thomas, Y., Bates, P., Carino, J., Fernández-Llamazares, Á., Ferrari, M.F., Galvin, K., Reyes-García, V., McElwee, P., Molnár, Z., Samakov, A., Shrestha, U.B., 2021. Locally Based, Regionally Manifested, and Globally Relevant:

Indigenous and Local Knowledge, Values, and Practices for Nature. Annu Rev Environ Resour 46, 481–509. https://doi.org/10.1146/annurev-environ-012220-012127

Brooks, J.S., Waylen, K.A., Mulder, M.B., 2012. How national context, project design, and local community characteristics influence success in community-based conservation projects. Proc Natl Acad Sci U S A 109, 21265–21270. https://doi.org/10.1073/pnas.1207141110

Burnham, K.P., Anderson, D.R., 2002. Model Selection and Inference: A Practical Information-Theoretic Approach, 2nd ed. Springer New York LLC, New York.

Campos-Silva, J.V., Hawes, J.E., Freitas, C.T., Andrade, P.C.M., Peres, C.A., 2020. Community-Based Management of Amazonian Biodiversity Assets, in: Baldauf, C. (Ed.), Participatory Biodiversity Conservation: Concepts, Experiences, and Perspectives. Springer International Publishing, Cham, pp. 99–111. https://doi.org/10.1007/978-3-030-41686-7_7

Campos-Silva, J.V., Hawes, J.E., Peres, C.A., 2019. Population recovery, seasonal site fidelity, and daily activity of pirarucu (Arapaima spp.) in an Amazonian floodplain mosaic. Freshw Biol 64, 1255–1264. https://doi.org/10.1111/fwb.13301

Campos-Silva, J.V., Peres, C.A., 2016. Community-based management induces rapid recovery of a high-value tropical freshwater fishery. Sci Rep 6, 1–13. https://doi.org/10.1038/srep34745

Campos-Silva, J.V., Peres, C.A., Amaral, J.H.F., Sarmento, H., Forsberg, B., Fonseca, C.R., 2021. Fisheries management influences phytoplankton biomass of Amazonian floodplain lakes. Journal of Applied Ecology 58, 731–743. https://doi.org/10.1111/1365-2664.13763

Campos-Silva, J. V., Hawes, J.E., Andrade, P.C.M., Peres, C.A., 2018. Unintended multispecies co-benefits of an Amazonian community-based conservation programme. Nat Sustain 1, 650–656. https://doi.org/10.1038/s41893-018-0170-5

Castello, L., Viana, J.P., Watkins, G., Pinedo-Vasquez, M., Luzadis, V.A., 2009. Lessons from integrating fishers of arapaima in small-scale fisheries management at the mamirauá reserve, amazon. Environ Manage 43, 197–209. https://doi.org/10.1007/s00267-008-9220-5

Charoud, H., Costedoat, S., Izquierdo-Tort, S., Moros, L., Villamayor-Tomás, S., Castillo-Santiago, M.Á., Wunder, S., Corbera, E., 2023. Sustained participation in a Payments for Ecosystem Services program reduces deforestation in a Mexican agricultural frontier. Sci Rep 13, 1–14. https://doi.org/10.1038/s41598-023-49725-7

Cisneros, E., Börner, J., Pagiola, S., Wunder, S., 2022. Impacts of conservation incentives in protected areas: The case of Bolsa Floresta, Brazil. J Environ Econ Manage 111, 102572. https://doi.org/10.1016/j.jeem.2021.102572

Esmail, N., McPherson, J.M., Abulu, L., Amend, T., Amit, R., Bhatia, S., Bikaba, D., Brichieri-Colombi, T.A., Brown, J., Buschman, V., Fabinyi, M., Farhadinia, M., Ghayoumi, R., Hay-Edie, T., Horigue, V., Jungblut, V., Jupiter, S., Keane, A., Macdonald, D.W., Mahajan, S.L., McVey, A., Moehrenschlager, A., Nelson, F., Noshirwani, M.M., Ntiamoa-Baidu, Y., Postigo, J.L., Rakotondrazafy, V., Rao, M., Roe, D., Sierra Huelsz, J.A., Stolton, S., Tawake, A., Wintle, B., 2023. What's on the horizon for community-based conservation? Emerging threats and opportunities. Trends Ecol Evol 38, 666–680. https://doi.org/10.1016/j.tree.2023.02.008

Ezzine-De-Blas, D., Wunder, S., Ruiz-Pérez, M., Del Pilar Moreno-Sanchez, R., 2016. Global patterns in the implementation of payments for environmental services. PLoS One 11, 1–16. https://doi.org/10.1371/journal.pone.0149847

Franco, C.L.B., El Bizri, H.R., Souza, P.R. e., Fa, J.E., Valsecchi, J., Sousa, I.S. de, Queiroz, H.L. de, 2021. Community-based environmental protection in the Brazilian Amazon: Recent history, legal landmarks and expansion across protected areas. J Environ Manage 287. https://doi.org/10.1016/j.jenvman.2021.112314

Freitas, C.T., Espírito-Santo, H.M.V., Campos-Silva, J.V., Peres, C.A., Lopes, P.F.M., 2020. Resource co-management as a step towards gender equity in fisheries. Ecological Economics 176. https://doi.org/10.1016/j.ecolecon.2020.106709

Gamarra, N.C., Correia, R.A., Bragagnolo, C., Campos-Silva, J.V., Jepson, P.R., Ladle, R.J., Mendes Malhado, A.C., 2019. Are Protected Areas undervalued? An asset-based analysis of Brazilian Protected Area Management Plans. J Environ Manage 249, 109347. https://doi.org/10.1016/j.jenvman.2019.109347

Hein, L., Miller, D.C., de Groot, R., 2013. Payments for ecosystem services and the financing of global biodiversity conservation. Curr Opin Environ Sustain 5, 87–93. https://doi.org/10.1016/j.cosust.2012.12.004

Junk, W.J., Bayley, P.B., Sparks, R.E., 1989. The flood pulse concept in river-floodplain systems. Canadian special publication of fisheries and aquatic sciences 106, 110–127.

Kaiser, J., Haase, D., Krueger, T., 2021. Payments for ecosystem services: A review of definitions, the role of spatial scales, and critique. Ecology and Society 26. https://doi.org/10.5751/ES-12307-260212

Levis, C., Flores, B.M., Mazzochini, G.G., Manhães, A.P., Campos-Silva, J.V., Borges de Amorim, P., Peroni, N., Hirota, M., Clement, C.R., 2020. Help restore Brazil's governance of globally important ecosystem services. Nat Ecol Evol. https://doi.org/10.1038/s41559-019-1093-x

Lliso, B., Pascual, U., Engel, S., 2021. On the role of social equity in payments for ecosystem services in Latin America: A practitioner perspective. Ecological Economics 182, 106928. https://doi.org/10.1016/j.ecolecon.2020.106928

Londres, M., Salk, C., Andersson, K.P., Tengö, M., Brondizio, E.S., Russo Lopes, G., Siani, S.M.O., Molina-Garzón, A., Gonzales, T., Montoya, D.R., Futemma, C., de Castro, F., Tourne, D.C.M., 2023. Place-based solutions for global social-ecological dilemmas: An analysis of locally grounded, diversified, and cross-scalar initiatives in the Amazon. Global Environmental Change 82. https://doi.org/10.1016/j.gloenvcha.2023.102718

Lopes, P.F.M., de Freitas, C.T., Hallwass, G., Silvano, R.A.M., Begossi, A., Campos-Silva, J.V., 2021. Just Aquatic Governance: The Amazon basin as fertile ground for aligning participatory conservation with social justice. Aquat Conserv 31, 1190–1205. https://doi.org/10.1002/aqc.3586

MapBiomas Project. (2021). Mapping of water surfaces in Brazil (Collection 1). Accessed January 2022 from [https://plataforma.brasil.mapbiomas.org/agua].

Medeiros-Leal, W.M., Castello, L., Freitas, C.E.C., Siqueira-Souza, F.K., 2021. Single-Species Co-management Improves Fish Assemblage Structure and Composition in a Tropical River. Front Ecol Evol 9. https://doi.org/10.3389/fevo.2021.604170

Mohammed, E.Y., 2013. Economic incentives for marine and coastal conservation: Prospects, challenges and policy implications, in: Economic Incentives for Marine and Coastal Conservation: Prospects, Challenges and Policy Implications. Routledge, pp. 1–270. https://doi.org/10.4324/9780203728345

Newton, P., Nichols, E.S., Endo, W., Peres, C.A., 2012. Consequences of actor level livelihood heterogeneity for additionality in a tropical forest payment for environmental services programme with an undifferentiated reward structure. Global Environmental Change 22, 127–136. https://doi.org/10.1016/j.gloenvcha.2011.10.006

Ocampo-Melgar, A., Barría, P., Cerda, C., Venegas-González, A., Fernández, J., Díaz-Vasconcellos, R., Zamora, J., 2024. Payment for Ecosystem Services: institutional arrangements for a changing climate in the Chilean Mediterranean Region. NPJ Climate Action 3. https://doi.org/10.1038/s44168-024-00132-2

Ostrom, E., 2009. Understanding institutional diversity, Understanding Institutional Diversity. Princeton, NJ. https://doi.org/10.1093/oso/9780190672492.003.0008

Patton, M.Q., 2015. Qualitative research & evaluation methods: Integrating theory and practice, 4th ed. Sage Publications.

Peres, C.A., Emilio, T., Schietti, J., Desmoulière, S.J.M., Levi, T., 2016. Dispersal limitation induces long-term biomass collapse in overhunted Amazonian forests. Proc Natl Acad Sci U S A 113, 892–897. https://doi.org/10.1073/PNAS.1516525113/SUPPL_FILE/PNAS.201516525SI.PDF

Petersen, T.A., Brum, S.M., Rossoni, F., Silveira, G.F.V., Castello, L., 2016. Recovery of Arapaima sp. populations by community-based management in floodplains of the Purus River, Amazon. J Fish Biol 89, 241–248. https://doi.org/10.1111/jfb.12968

QGIS.org. 2023. QGIS Geographic Information System. Open-Source Geospatial Foundation Project. http://qgis.org

Queiroz, R.C., 2015. Vigilância e proteção de terras indígenas: Programa de Capacitação em Proteção Territorial. FUNAI/GIZ, Brasília.

R Core Team. 2023. R: A language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna, Austria. www.R-project.org.

Robalino, J., Pfaff, A., Sandoval, C., Sanchez-Azofeifa, G.A., 2021. Can we increase the impacts from payments for ecosystem services? Impact rose over time in Costa Rica, yet spatial variation indicates more potential. For Policy Econ 132, 102577. https://doi.org/10.1016/J.FORPOL.2021.102577

Ruiz-Ballesteros, E., Brondizio, E.S., 2013. Construção de Acordo Negociado : A Emergência do Turismo de Base Comunitária em Floreana (Ilhas Galápagos) 72, 323–335.

Saija, L., De Leo, D., Forester, J., Pappalardo, G., Rocha, I., Sletto, B., Corburn, J., Mwau, B., Magnaghi, A., 2017. Learning from practice: environmental and community mapping as participatory action research in planning. Planning Theory and Practice 18, 127–153. https://doi.org/10.1080/14649357.2016.1262982

Salzman, J., Bennett, G., Carroll, N., Goldstein, A., Jenkins, M., 2018. The global status and trends of Payments for Ecosystem Services. Nat Sustain 1, 136–144. https://doi.org/10.1038/s41893-018-0033-0

Shapiro-Garza, E., McElwee, P., Van Hecken, G., Corbera, E., 2020. Beyond Market Logics: Payments for Ecosystem Services as Alternative Development Practices in the Global South. Dev Change 51, 3–25. https://doi.org/10.1111/dech.12546

Silva, J.M.C. da, Castro Dias, T.C.A. de, Cunha, A.C. da, Cunha, H.F.A., 2019. Public spending in federal protected areas in Brazil. Land use policy 86, 158–164. https://doi.org/10.1016/j.landusepol.2019.04.035

Silvano, R.A.M., Baird, I.G., Begossi, A., Hallwass, G., Huntington, H.P., Lopes, P.F.M., Parlee, B., Berkes, F., 2023. Fishers' multidimensional knowledge advances fisheries and aquatic science. Trends Ecol Evol 38, 8–12. https://doi.org/10.1016/j.tree.2022.10.002

Tregidgo, D., Barlow, J., Pompeu, P.S., Parry, L., 2020. Tough fishing and severe seasonal food insecurity in Amazonian flooded forests. People and Nature 2, 468–482. https://doi.org/10.1002/pan3.10086

Upton, C., 2020. Conserving Natures? Co-producing Payments for Ecosystem Services in Mongolian Rangelands. Dev Change 51, 224–252. https://doi.org/10.1111/dech.12549

Vale, M.M., Berenguer, E., Argollo de Menezes, M., Viveiros de Castro, E.B., Pugliese de Siqueira, L., Portela, R. de C.Q., 2021. The COVID-19 pandemic as an opportunity to weaken environmental protection in Brazil. Biol Conserv 255, 108994. https://doi.org/10.1016/j.biocon.2021.108994

Wartmann, F.M., Purves, R.S., 2017. What's (not) on the map: Landscape features from participatory sketch mapping differ from local categories used in language. Land (Basel) 6. https://doi.org/10.3390/land6040079

Wunder, S., 2015. Revisiting the concept of payments for environmental services. Ecological Economics 117, 234–243. https://doi.org/10.1016/j.ecolecon.2014.08.016

Zuur, A.F., Ieno, E.N., Elphick, C.S., 2010. A protocol for data exploration to avoid common statistical problems. Methods Ecol Evol 1, 3–14. https://doi.org/10.1111/j.2041-210X.2009.00001.x.

Figures

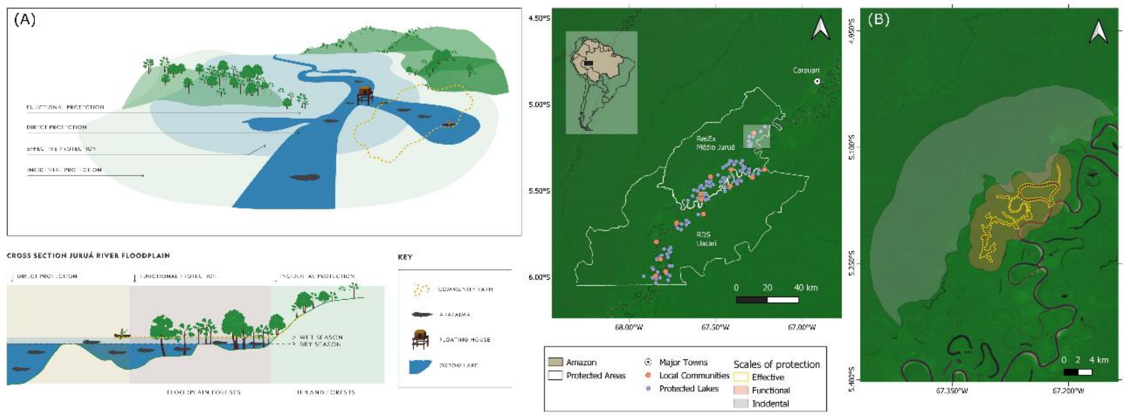

Figure 1. (A) Illustration elucidating the landscape where territorial protection and surveillance are implemented. Protection extends far beyond oxbow lakes, covering substantially larger areas. Arapaima co-management activities have varying impacts at different spatial scales (1) Direct scale of protection: immediate lake areas under surveillance; (2) Effective scale of protection: full-time territorial surveillance, intensified during the dry season, protecting areas of management interest; (3) Functional scale of protection: estimated based on the movement ecology of arapaima , considering their ability to sustain ecological interactions; and (4) Incidental scale of protection: indirect surveillance of adjacent upland forest areas that are incidentally protected by restricting access to the floodplain by outside users. (B). Mid-section of the Juruá River, western Brazilian Amazonia. Orange circles represent 14 communities located within two contiguous sustainable-use forest reserves, with a combined area of 886,176 ha. These communities perform territorial surveillance for co-management of arapaima (Arapaima gigas) fisheries within 96 lakes (indicated by blue dots). Inset map shows (i) the effective scale of protection (in yellow), which included to the routes that community rangers patrol to protect lakes, and (ii) the scale of functional protection (shaded in orange), in which arapaima stocks are fully protected to move into floodplains during the high-water season. Finally, the wider (iii) scale of incidental protection (shaded in grey) represents

the adjacent upland (terra firme) forests that are also closed off by restricting access by outsiders into floodplain forests.

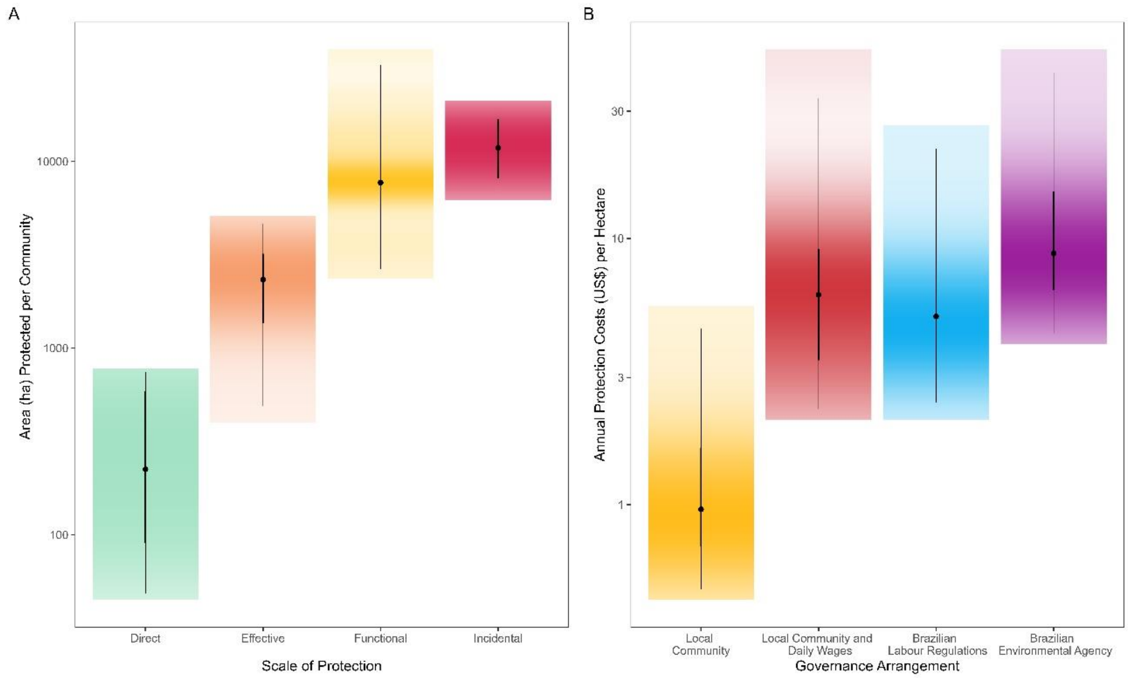

Figure 2. Boxplots depicting (A) the area (in hectares, log10 scale) and spatial scales of protection implemented by Amazonian rural communities in Arapaima co-management along the Juruá River, and (B) the protection costs (US$/per hectare/year) borne by these communities, including estimated costs under three alternative scenarios: (i) employing two lake guards per community at local daily wages, (ii) hiring two guards under Brazilian labour regulations, and (iii) hiring two environmental agents deployed by a government agency.

Acknowledgments:

This work was made possible through a myriad of partners. We thank the financial support Fundo Brasileiro para a Biodiversidade (FUNBIO) and Instituto Humanize (Project No. 021/2021), which played a crucial role in facilitating and advancing this study. This research is also part of the National Geographic and Rolex Perpetual Planet Amazon Expedition. We are also grateful for the support from FAPEAM within the Amazônia + 10 initiative (grant number 01.02.016301.04664/2022-03). Instituto Juruá also acknowledges the support from Mulago Foundation, The Pilot House, Synchronicity Earth, International Conservation Fund and International Conservation Fund of Canada, ACR would like to acknowledge the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for providing her doctoral scholarship (Grant No. 88887.505812/2020-00). Additionally, Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) awarded an exchange scholarship (Grant No. 200625/2022-5) to ACR at Indiana University. JVC-S gratefully acknowledges financial support for this publication by the Fulbright Amazonia program, which is sponsored by the U.S. Department of State and the Fulbright Commission in Brazil. Its contents are solely the responsibility of the author and do not necessarily represent the official views of the Fulbright Program, the Government of the United States, or Fulbright Brasil). CAP and Instituto Juruá are supported by a Frontiers Planet Prize. We thank the Secretaria do Estado do Meio Ambiente e Desenvolvimento Sustentável do Amazonas (SEMA, DEMUC), and Instituto Brasileiro do Meio Ambiente e Recursos Naturais Renováveis (ICMBio) for granting research permits. We are grateful to the Associação dos Produtores Rurais de Carauari, Associação dos Moradores da Reserva de Desenvolvimento Sustentável Uacari, Departamento de Mudanças Climáticas e Gestão de Areas Protegidas da Secretaria de Meio Ambiente do Amazonas and all local communities along the Médio Juruá region. Their collaboration, insights, and support were instrumental in the successful execution of this project.

7 Conclusões gerais

A pesca manejada do pirarucu promove benefícios multidimensionais para comunidades rurais na Amazonia brasileira que muitas vezes carecem de acesso a serviços públicos, mas demonstram uma governança de recursos comuns eficaz. A inclusão de múltiplos atores nos ambientes de tomada de decisão aumenta a resiliência desse modelo de governança que é baseado em décadas de conhecimento e organização social, demonstrando o potencial da sociobioeconomia para alinhar a proteção da biodiversidade com o bem-estar na Amazônia, indo além das dimensões meramente monetárias. As comunidades manejadoras de pirarucu percebem as contribuições da natureza de forma diferente, principalmente valores não-materiais como união, oportunidades recreativas, novas experiências de aprendizado e o reforço do conhecimento tradicional. Embora os ganhos socioeconômicos atual com a venda da quota autorizada tem transformado a vida ribeirinha, os valores ainda são modestos em comparação ao valor agregado não reconhecido da vigilância territorial comunitária. Esta vigilância não só garante a proteção da biodiversidade, mas também fornece uma ampla gama de serviços ecossistêmicos, como a provisão de materiais, manutenção e criação de habitats, regulação climática e segurança alimentar melhorando a qualidade de vida das populações locais. Portanto, reconhecer e recompensar os esforços substanciais dessas comunidades na proteção dos ecossistemas amazônicos é imperativo para um futuro mais brilhante para a Amazônia, onde os meios de subsistência dos moradores das várzeas e a proteção da floresta continuem profundamente conectados.

8 APÊNDICE A – MATERIAL SUPLEMENTAR

Community-based fisheries management exert a vast value-added effective protection footprint in Amazonian forests

Ana Carla Rodrigues[1,2], Hugo C. M. Costa[2,3], Carlos A. Peres[2,4], Eduardo Sonnewend Brondizio[5,6], Adevaldo Dias[7], José Alves de Moraes[2,8], Pedro Constantino[9], Richard James Ladle[1], Ana Claudia Mendes Malhado[1], João Vitor Campos-Silva[1,2,3,10]

[1] Programa de pós-graduação em Diversidade Biológica e Conservação nos Trópicos, Instituto de Ciências Biológicas e da Saúde, Universidade Federal de Alagoas, Maceió, AL, Brasil

[2] Instituto Juruá, Manaus,AM, Brasil

[3] Programa de Pós-graduação em Ecologia, Instituto Nacional de Pesquisas da Amazonia, Manaus, AM, Brasil

[4] School of Environmental Sciences, University of East Anglia, Norwich, UK

[5] Department of Anthropology, and Center for the Analysis of Social Ecological Landscapes (CASEL), Indiana University, Bloomington, IN, USA

[6] Programa de Pós-graduação em Ambiente e Sociedade (NEPAM), Universidade de Campinas, Campinas, SP, Brasil.

[7] Memorial Chico Mendes, Manaus, AM, Brasil

[8] Associação dos Moradores Agroextrativistas do Baixo Médio Juruá (AMAB), Comunidade Lago Serrado, Carauari, AM, Brasil.

[9] US Forest Service, International Program - Brasil.

[10] Programa de Pós-Graduação em Ciência Animal e Recursos Pesqueiros, Universidade Federal do Amazonas, Manaus, AM, Brasil

This PDF file includes:

Figure S.1., Figure S.2., Table S.1., Table S.2., Table S.3. and Table S.4.

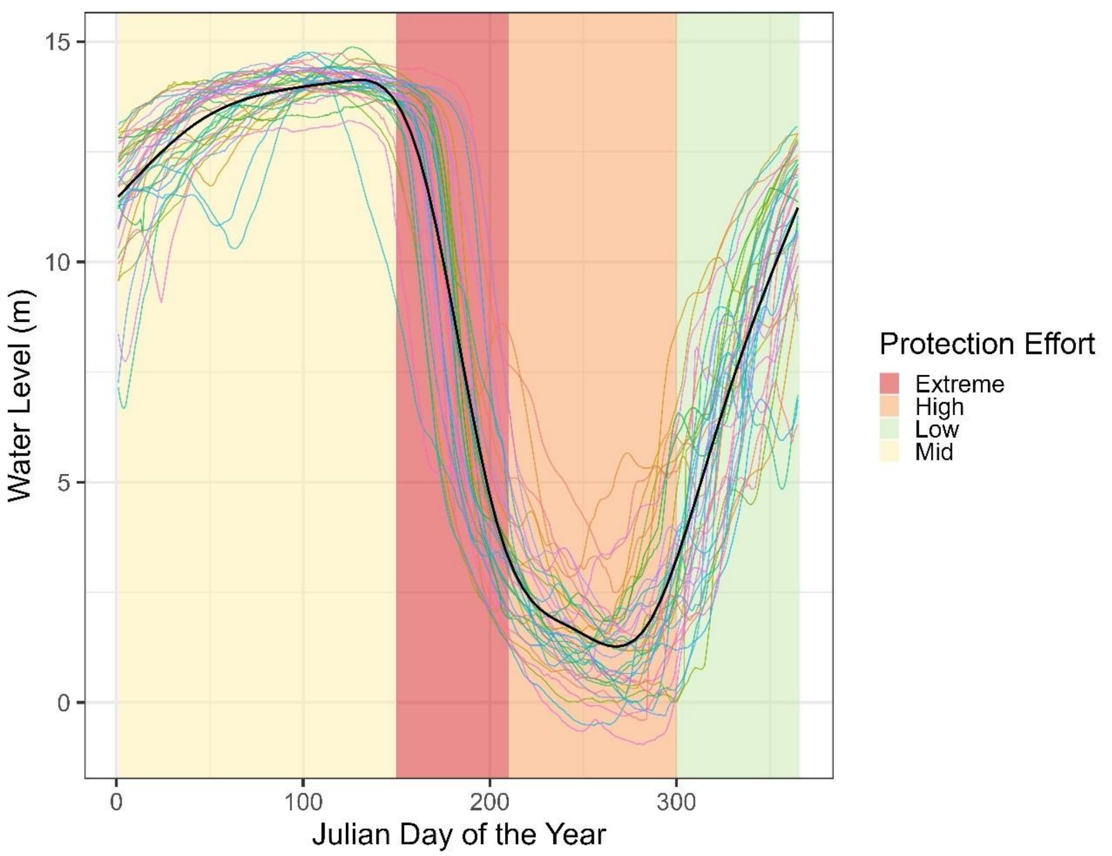

Figure S.1. The Juruá River flood pulse in meters over the last 38 years and community-based surveillance efforts. Community surveillance efforts intensify during the period of receding floodwaters in which fish stocks become more concentrated and more vulnerable.

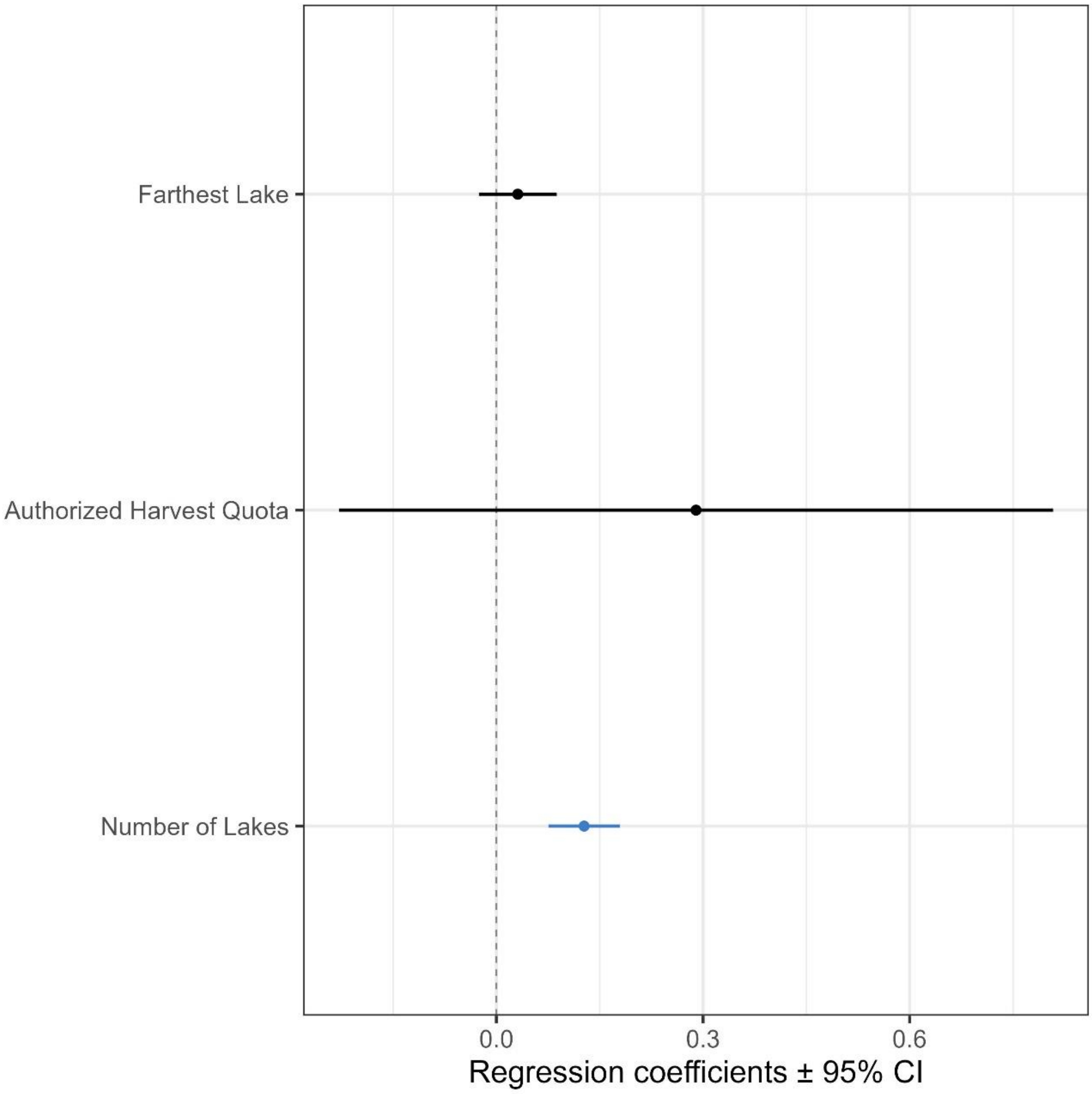

Figure S.2. Coefficient estimates ± 95% confidence intervals, showing the magnitude and direction of different explanatory variables for community-based territorial protection obtained by a generalised linear model-averaging approach.

Table S.2. Spatial scales, total areas (ha), and total costs (US$ ha–1 yr–1) of territorial protection carried out by local communities engaged in arapaima (*Arapaima gigas*) co-management fisheries along the Juruá River, western Brazilian Amazon.

Spatial scale of protection	Total area (ha)	Protection ratio[1]	Mean area (ha) per community	Total cost (US$ ha^{-1} yr^{-1})
Direct area	**4,263**	**1.0**	**305**	**0.95**[2]
Effective area	**32,844**	**7.7**	**2,346**	**0.95**
Functional area	**156,645**	**36.7**	**11,189**	**0.19**
Incidental area	**173,359**	**40.7**	**12,383**	**0.18**
All scales of protection	**367,111**	**85.1**	**26,223**	**-**

[1] Protected area ratio between any given spatial scale and the scale of direct protection of oxbow lakes under the jurisdiction of any given community, where *Arapaima* management activities take place.

[2] The cost of either direct or effective protection are the same, given that local communities conduct broader surveillance protecting areas beyond the immediate scale of direct protection of oxbow lakes.

Table S.2. Tukey's Honest Significant Difference (HSD) *post hoc* test performed between different spatial scales of protection carried out by Amazonian rural communities engaged in Arapaima (*Arapaima gigas*) co-management along the Juruá River, western Brazilian Amazonia

Pairwise comparison		Estimate	Conf.low	Conf.high	p value
Incidental	Direct	-1.736	-2.044	-1.428	0
Incidental	Effective	-0.767	-1.075	-0.459	< 0.0001
Incidental	Functional	-0.128	-0.437	0.179	0.684
Direct	Effective	0.968	0.660	1.276	< 0.0001
Direct	Functional	1.607	1.299	1.915	0
Effective	Functional	0.638	0.330	0.946	< 0.0001

Table S.3. Top-ranked candidate models (ΔAICc < 2) explaining costs of territorial protection performed by rural Amazonian communities engaged in sustainable arapaima (*Arapaima gigas*) fisheries along the Juruá River, western Brazilian Amazonia, including their respective Akaike information criterion with small sample size correction (AICc), the difference between a given model and the best model (ΔAICc), and the model Akaike weights (ωAICc); d.f. = degrees of freedom, logLik = log-likelihood

Model Formula	df	logLik	AICc	ΔAICc	ωAICc
Farthest Lake distance	3	-14.293	36.586	0	0.351
Farthest Lake Distance + Harvest Quota	4	-12.539	36.715	0.129	0.329
Farthest Lake Distance + Number of Lakes	4	-12.566	36.768	0.182	0.320

Table S.4. Comparative estimates of community-based protection costs of local *Arapaima* stocks under different governance scenarios. These cost estimates are expressed in terms of both (i) US dollars per hectare per year and (ii) the value of a Payment for Ecosystem Services (PES) program, expressed in US dollars per kilogram of sustainably harvested fish.

Governance arrangement	Protection costs US$ $^{-ha\ -yr}$	PES US$ per kg ofharvested fish
Local Community	0.95	0[1]
Local Community and Daily wages	5.3	0.94
Brazilian Labour regulations	5.4	0.95
Brazilian Environmental Agency	9.6	1.70

[1] The costs of protection incurred by local communities are currently not covered within any PES arrangement.