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par

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Can the concept of ecosystem services facilitate agroecological transition in the Brazilian Amazon? Results from a mixed methods approach in Irituia and Paragominas, Pará state

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Terra !

És o mais bonito dos planetas.

Estão te maltratando por dinheiro.

Tu que és a nave, nossa irmã.

Canta !

Leva tua vida em harmonia.

E nos alimenta com teus frutos.

Tu que és do homem, a maçã.

(Sal da terra, Beto Guedes)

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Résumé long

La région amazonienne est depuis longtemps le lieu d'un débat sur la tension entre la conservation de l'environnement, notamment des ressources forestières, et le développement socio-économique. Proposer un modèle de développement pour la région qui concilie ces différents aspects reste un défi à relever (Costa et Fernandes 2016; Nobre et al. 2016). Comme la majorité de ce biome est située au Brésil, le débat autour de l'Amazonie brésilienne est devenu fondamental, non seulement au niveau national et pan-amazonien, mais aussi au niveau international (Palacio et Wakild 2016). Au Brésil, la délimitation légale de l'Amazonie englobe près des deux tiers du pays. Cette région, qui abrite environ 12 % de la population brésilienne, présente (avec la région nord-est) les indices de développement les plus faibles du pays et, par ailleurs, souffre d'une multitude de problèmes environnementaux (Costa et Fernandes 2016). L'Amazonie abrite une structure complexe d'acteurs caractérisée par de fortes asymétries de pouvoir, constituant un environnement biophysique complexe dans lequel une mosaïque d'activités parfois conflictuelles donne lieu à différentes formes d'interaction entre les personnes et la nature (Montaño 2016). Parmi ces activités, les "agricultures" se distinguent par leur portée générale, leur importance socio-économique et leur grand potentiel pour modifier les écosystèmes et fournir une diversité de services écosystémiques (SE) en lien avec l'eau, les sols et la biodiversité (Fearnside 1997).

Comme le décrivent Castro et Campos (2015), il existe différentes manières de pratiquer l'agriculture en Amazonie, et ces manières ont connu des changements importants au fil du temps. A partir de l'agriculture indigène traditionnelle pratiquée avant la période coloniale (à partir du XVIe siècle), les "agricultures amazoniennes" ont été reconfigurées suivant différents cycles d'exploitation des ressources naturelles (par exemple, "drogas do sertão", hévéa, bois) existant dans la région. Ce processus de transition s'est intensifié dans les années 1960, en réponse à l'intérêt du gouvernement brésilien pour rendre la région plus dynamique et plus intégrée au processus de modernisation économique à l'œuvre dans le pays à cette époque. Dans cette période de grands changements, certaines parties de l'Amazonie ont connu un processus précaire de modernisation de l'agriculture basé sur les principes de la révolution verte, ce qui a bousculé la place de l'agriculture traditionnelle. En conséquence, la structure agraire actuelle en Amazonie est composée d'une combinaison de grands et de petits agriculteurs, avec des modèles de production notoirement différents, qui reflètent aussi différemment les problèmes environnementaux actuels de la région (Pokorny et al. 2013). Parmi ces logiques de production, les exploitations familiales se distinguent par leur rôle stratégique dans la promotion du développement durable régional (Costa 2008; Pokorny et al. 2013).

Au Brésil, le concept d'agriculture familiale englobe, conformément à la loi n° 11.326/2006, un ensemble d'activités rurales à petite échelle pratiquées par différents groupes de personnes (par exemple, agriculteurs, pêcheurs, chasseurs/cueilleurs). L'agriculture familiale est devenue dans le pays une catégorie sociale et politique d'importance nationale dans les années 1990, donnant lieu à un ensemble de politiques qui ont émergé pendant et après cette période dans le but de la renforcer et de promouvoir un développement rural durable (Grisa et Schneider 2014; Schmitt et al. 2017). Ce débat a abouti au déploiement de la *Politique nationale pour l'agroécologie et la production biologique* (PNAPO) en 2012, qui a été précédée par les *Plans nationaux pour l'agroécologie et la production biologique* (PLANAPO), lancés en 2013 et mis à jour en 2016 pour opérationnaliser la PNAPO (Schmitt et al. 2017).

L'efficacité de ces initiatives dans le contexte amazonien est encore incertaine. Le débat sur le modèle agricole à privilégier est loin de faire l'objet d'un consensus (Palacio et Wakild 2016). Le développement du modèle agricole fondé sur les intrants mécaniques et chimiques passe avant le renforcement d'une « agriculture fondée sur la biodiversité » soutenue par la fourniture de SE (Pokorny et al. 2013). Les acteurs locaux qui soutiennent les exploitations familiales (par exemple, dans les services de vulgarisation rurale, le gouvernement local, les institutions de recherche) doivent faire face à de nombreux défis pour promouvoir une transition agroécologique en Amazonie (Sá 2015). Au-delà du manque de ressources financières et d'infrastructures qui empêche une plus grande portée de leurs actions, ces acteurs s'alignent fréquemment sur le paradigme productiviste de la révolution verte (Silva et Martins 2009).

Dans la région Amazonienne plus qu'ailleurs encore, la transition agro-écologique nécessite de créer des espaces de dialogue réunissant différents acteurs, aux visions, intérêts et rapports de force très divers. Ces espaces de dialogue nécessitent des outils opérationnels pour aider à la médiation entre ces différents acteurs, ainsi que la création d'arènes participatives de coordination et de gouvernance. Certains auteurs considèrent que le concept de SE pourrait être pertinent pour caractériser les usages des ressources sur un territoire, préciser les attentes/objectifs des différentes parties prenantes et mettre en débat les modalités de gestion d'un tel territoire (Díaz et al. 2015; Barnaud et al. 2018). Ce sont des éléments clés pour piloter une transition agroécologique sur le terrain (Dendoncker et al. 2018).

Dans ce contexte, cette thèse se propose d'étudier comment le cadre conceptuel des SE peut servir de base cognitive et opérationnelle pour soutenir la transition agroécologique en Amazonie brésilienne.

A cette fin, nous entendons analyser les données empiriques de terrain à la lumière des éléments décrits ci-dessus afin de répondre plus spécifiquement à trois questions :

(Q1) Comment les acteurs locaux appuyant les agriculteurs familiaux perçoivent-ils les SEs et leur processus de co-production ?

(Q2) Comment certains facteurs, internes et externes à l'agroécosystème, influencent-ils la co-production des SE ?

(Q3) Comment formaliser les connaissances liées à la co-production des SE et permettre aux acteurs locaux d'en discuter par des outils méthodologiques appropriés afin d'orienter la transition agroécologique ?

Nous nous concentrons plus spécifiquement sur les exploitations agricoles familiales, en mettant l'accent sur la gestion de l'agrobiodiversité (par exemple, les systèmes de culture annuels et pérennes) qui fait intrinsèquement partie des pratiques utilisées dans ces exploitations. Nous avons choisi comme zone d'étude deux municipalités contrastées situées dans l'est de l'Amazonie brésilienne, Irituia et Paragominas. Dans le premier site d'étude, le secteur agricole est dominé par l'agriculture familiale, qui est souvent biodiversifiée. Par contre, l'agriculture industrielle à grande échelle prédomine dans le second site d'étude et coexiste avec l'agriculture familiale. Par ce choix, nous cherchons à établir une comparaison entre ces deux réalités contrastées. Nous adoptons le niveau de l'exploitation agricole comme échelle principale d'analyse mais considérons également le niveau de la municipalité comme une échelle secondaire, notamment afin de prendre en compte les connexions existantes entre ces deux niveaux, établies à travers les institutions formelles et informelles qui les gouvernent. A cet effet, la notion d'agroécosystème, qui s'inscrit dans le cadre des systèmes socio-écologiques (SES) et décrit les activités agricoles pratiquées sur de petits espaces, apparaît utile pour analyser la gestion mise en œuvre au niveau de l'exploitation, ainsi que ses corrélations sociales et écologiques avec l'environnement (Altieri 1999).

Nous adoptons une perspective multi-acteur pour mener notre recherche. Puisque les concepts de SE et d'agroécologie traitent du SES, il est essentiel de comprendre les perceptions et les attentes des différents acteurs locaux (c'est-à-dire le système social) directement et indirectement impliqués dans la gestion des agroécosystèmes (c'est-à-dire le système écologique) (Reyers et al. 2013). Nous construisons donc notre analyse sur la base des connaissances d'une diversité d'acteurs locaux concernés par les questions rurales en général et par nos questions de recherche en particulier. Nous choisissons également une perspective de recherche « transdisciplinaire », couvrant des éléments de différentes disciplines scientifiques (principalement l'agronomie et les sciences sociales), ainsi que des connaissances provenant d'acteurs extérieurs à la sphère académique, notamment les agriculteurs (Brandt et al. 2013).

Pour soutenir cette perspective, nous avons mis en œuvre une « approche de méthodes mixtes » combinant des méthodologies qualitatives classiques et des méthodologies semi-quantitatives (Sattler et al. 2018), avec, en arrière-plan, la modélisation d'accompagnement (COMMOD) (Barreteau et al. 2010), à savoir :

- **Entretiens semi-directifs** - Des entretiens semi-directifs avec des personnels des institutions impliquées dans les questions rurales liées à l'appui aux agriculteurs ont été réalisés entre octobre 2017 et février 2018. Ainsi, nous avons approché 24 institutions, en interrogeant au moins un répondant clé pour chacune d'entre elles, pour un total de 30 personnes interrogées, 15 à Paragominas et 15 à Irituia.
- **Questionnaires auprès des agriculteurs (visites sur le terrain)** – Les visites de terrain ont été réalisées entre janvier et octobre 2018. Nous avons visité soixante agriculteurs familiaux (30 à Paragominas et 30 à Irituia) afin d'observer l'agrobiodiversité (fréquence et diversité des systèmes de culture), les pratiques agricoles, le rôle de l'intervention externe des différents acteurs, et les perceptions concernant les motivations et les défis pour adopter des systèmes biodiversifiés.
- **Jeu de rôles** – Un modèle de simulation a été co-construit avec les acteurs locaux (principalement d'Irituia) et a servi de support à différents ateliers menés sous la forme de session de jeu de rôles pour observer et discuter de la perception des SE par

les acteurs. Le jeu a été développé principalement au cours du premier semestre 2018, à travers un processus de co-construction incluant des chercheurs, des conseillers, des agriculteurs.

- **Observation participante** - Afin d'obtenir un aperçu plus clair de la mesure dans laquelle le concept de services écosystémiques est utilisé et discuté au niveau local, des informations qualitatives supplémentaires ont été collectées en observant régulièrement l'implication des différentes acteurs locaux (dont les agriculteurs) dans leurs activités et en participant à des événements et des activités de terrain concernant des questions liées à l'agenda rural.

Cette étude a été menée dans le cadre de deux projets de recherche qui ont été entrepris en parallèle dans notre zone d'étude. Le projet STRADIV, qui a financé cette thèse, a abordé le thème de la biodiversification des agroécosystèmes, en rassemblant un large panorama de systèmes biodiversifiés d'Amérique Centrale, des Antilles françaises, du Burkina Faso, du Cameroun, de Madagascar et du Brésil. En Amazonie, ce projet s'est concentré sur la municipalité de Paragominas et s'est plus particulièrement intéressé à la biodiversification des cultures annuelles cultivées par les petits exploitants. Le travail sur le terrain a été progressivement intégré à la mise en œuvre d'un autre projet, REFLORAMAZ, dont le thème central était la restauration des forêts, avec un accent particulier sur les systèmes agroforestiers. Il était centré sur le nord-est de l'État du Pará et comparait cinq municipalités, en particulier Irituia. Cette thèse a intégré la dynamique d'exécution de ces deux projets, de sorte qu'une diversité de chercheurs, d'étudiants de master et de doctorat, d'agriculteurs ont contribué activement aux réflexions et aux activités de terrain.

Les réponses à nos questions de recherche sont fournies dans trois articles, chacun se concentrant sur une question. Certains aspects transversaux sont ensuite approfondis dans une discussion générale.

Le **premier article**[1] étudie comment une diversité de parties prenantes soutenant les petits exploitants dans les municipalités de Paragominas et Irituia au Brésil perçoivent les SE et les pratiques agricoles. Cette étude vise à identifier les services mis en avant, les

[1] Cette étude a abouti à l'article : Antonio Gabriel L. Resque, Marie-Gabrielle Piketty, Emilie Coudel, Samir Messad, Christophe Le Page. Co-production of ecosystem services through agricultural practices: perception of stakeholders supporting smallholders in the Brazilian Amazon. Article accepté pour publication le 17 mars 2021 dans un numéro spécial de la revue Cahiers Agricultures, dont le thème était agriculture et SE.

facteurs influençant la différenciation de ces perceptions et la manière dont elles lient les SE aux pratiques agricoles (co-production). Nous abordons avec cet article plus spécifiquement notre première question de recherche (**Q1**).

Les résultats de cet article sont basés sur les 30 entretiens semi-structurés avec les principales parties prenantes des deux municipalités étudiées (Paragominas et Irituia). 17 différents SE et 15 pratiques agricoles ont été identifiés. Une analyse statistique par positionnement multidimensionnel (MDS) permet de différencier les perceptions des parties prenantes quant à la coproduction des SE. Les SE les plus cités sont l'approvisionnement en nourriture, la régulation des cycles de l'eau, ainsi que la fertilité et l'érosion des sols. Dans l'ensemble, il y a une perception positive sur le fait que les pratiques agricoles fournissent des SE. Les pratiques fondées sur la biodiversité sont associées à la fourniture d'un large spectre de SE, tandis que les pratiques mécano-chimiques sont principalement liées à l'approvisionnement en nourriture. L'utilisation du feu, la déforestation et l'utilisation d'herbicides/pesticides chimiques sont perçus comme ayant les effets les plus négatifs sur la fourniture de SE. Le type d'activité exercée par les acteurs et leur municipalité sont les principaux facteurs influençant leur perception de la coproduction des SE. En conclusion, le concept de coproduction des SE liés aux agroécosystèmes est jugé pertinent car il structure la façon dont les acteurs locaux reconnaissent, même si ce n'est pas de manière exhaustive, une diversité d'effets des pratiques agricoles sur la fourniture de services.

Dans le **deuxième article**, nous avons cherché à identifier certains facteurs externes à l'agro-écosystème, notamment le marché, qui peuvent influencer l'agrobiodiversité dans une situation réelle[2]. En nous appuyant sur l'expérience de deux programmes institutionnels d'achat de produits alimentaires (à savoir le PAA et le PNAE), nous démontrons dans cet article comment ces deux programmes valorisent actuellement l'agrobiodiversité en fonction du contexte local à Paragominas et Irituia. Dans ce travail nous analysons : (a) comment ces programmes d'achats institutionnels intègrent actuellement l'agrobiodiversité (cultures et systèmes de culture) en fonction du contexte local ; (b) les principaux défis que les parties

[2] Cette étude a été publiée dans l'article suivant : Antonio Gabriel L. Resque, Emilie Coudel, Marie-Gabrielle Piketty, Nathalie Cialdella, Tatiana Sá, William Assis, Marc Piraux and Christophe Le Page. Agrobiodiversity and public food procurement programs in Brazil: influence of local stakeholders in configuring green mediated markets. Article publié le 7 mars 2019 dans la revue Sustainability.

prenantes perçoivent pour l'adoption de systèmes biodiversifiés ; et (c) dans quelle mesure les principales parties prenantes impliquées dans ces programmes associent l'agrobiodiversité à la fourniture de services écosystémiques. Nous répondons partiellement dans ce chapitre à notre deuxième question de recherche (**Q2**).

Nous avons mené cette recherche en 2017, simultanément dans les municipalités de Paragominas et d'Irituia. Pour ce faire, nous nous sommes appuyés sur : (a) 30 entretiens avec une diversité d'acteurs locaux directement et indirectement liés à la mise en œuvre des programmes dans les deux communes de l'étude ; (b) l'observation de leur participation à des événements et des activités de terrain ; (c) des entretiens avec des agriculteurs qui ont un degré de contact différent avec les institutions considérées ; (d) la documentation fournie par les acteurs locaux sur le fonctionnement des programmes.

Notre recherche montre que ces programmes ont inclus jusqu'à 42 espèces à Irituia et 32 espèces à Paragominas. Les espèces de cultures pérennes sont le type de culture le plus courant à Irituia (jusqu'à 50%), tandis que les légumes sont les plus courants à Paragominas (jusqu'à 47%). Bien que dans les deux municipalités les parties prenantes identifient un grand nombre de services écosystémiques (jusqu'à 17), les services mentionnés à Irituia sont plus étroitement liés à l'agrobiodiversité. Les parties prenantes indirectement associées aux programmes ont une vision plus large des services écosystémiques. À Paragominas, les principaux défis pour la promotion de la biodiversité étaient plus étroitement liés à des questions paradigmatiques, telles que la mentalité et la culture, alors qu'à Irituia, ils étaient liés à des questions de production, telles que la connaissance et la vulgarisation rurale. Nous concluons que ces programmes d’achats institutionnels peuvent être des outils utiles pour promouvoir la biodiversification des systèmes de production locaux, mais que leur potentiel dépendra de l'implication d'institutions qui ne sont pas directement associées à leur administration. De plus, malgré les différences observées dans le contexte de production, la fourniture de plus de services écosystémiques semble être une motivation convaincante pour promouvoir les changements dans les agroécosystèmes.

Dans le **troisième article**[3], nous avons examiné comment les services écosystémiques sont pris en compte (parmi d'autres facteurs) dans le processus de prise de décision des acteurs locaux impliqués dans la gestion des agroécosystèmes. À cette fin, nous présentons un jeu de rôles co-construit utilisé pour explorer, dans un environnement de simulation, comment certains facteurs internes (par exemple, la main-d'œuvre, les ressources financières, les connaissances) des agroécosystèmes influencent ce processus de prise de décision concernant la transition agroécologique dans ces unités. Nous abordons dans ce chapitre plus directement notre troisième question de recherche (**Q3**). Nous contribuons également partiellement dans ce chapitre à répondre à nos première (**Q1**) et deuxième (**Q2**) questions.

Le jeu a été développé en 2018 à partir d'un processus de co-construction mené sur notre site d'étude qui incluait principalement des agriculteurs, des étudiants et des chercheurs. Les informations utilisées sur cet article sont basées sur deux sessions du jeu organisées en 2019 à Paragominas et Irituia, impliquant des participants hétérogènes issus de différentes institutions locales. Nos résultats indiquent que les sessions de jeu ont montré comment la fourniture de services écosystémiques, ainsi que d'autres facteurs (par exemple, les valeurs, la disponibilité des facteurs), est prise en compte dans la planification de la configuration spatio-temporelle de l'agroécosystème et des pratiques agricoles associées. Ils ont également révélé certains compromis dans ce processus de décision. Nous concluons que le jeu de rôles a permis aux parties prenantes de synthétiser et de discuter de différents types de connaissances sur ce processus. Le fait de porter ces éléments à discussion peut contribuer à une meilleure compréhension commune des défis et des possibilités de la gestion écologique des agroécosystèmes et peut faire émerger des solutions qui sont conformes aux attentes locales.

En rassemblant et synthétisant tous les éléments présentés dans les trois articles publiés dans des revues scientifiques, qui constituent le cœur du manuscrit de thèse, il est possible

[3] Cette étude a abouti à l'article : Antonio Gabriel L. Resque, Eva Perrier, Emilie Coudel, Layse Galvão, João Vitor Fontes, Renan Carneiro, Livia Navegantes, Christophe Le Page. Discussing ecosystem services of management of agroecosystems: a role-playing game in the eastern Brazilian Amazon. Cet article a été soumis, en février 2020 , à un numéro spécial de la revue Agroforestry Systems consacré à la publication de certains des résumés présentés au quatrième congrès mondial d'agroforesterie (ce qui était le cas de cet article), qui s'est tenu à Montpellier, en France, en mai 2019. Il est actuellement en cours de révision.

de discuter des contributions de notre travail en se référant aux trois questions abordées dans cette thèse.

Comment les acteurs locaux appuyant les agriculteurs familiaux perçoivent-ils les SE et leur processus de co-production ?

Identification des SE et des pratiques de gestion associées : Qu'attendent les acteurs locaux par rapport à la gestion des agroécosystèmes ?

Le concept de services écosystémiques, qui a été proposé comme objet frontière pour discuter des aspects de la relation entre la nature et les êtres humains, est encore rarement intériorisé par la plupart des acteurs locaux qui ont participé à la recherche et le sujet est rarement discuté dans leurs cercles. Malgré ce manque général de connaissance du cadre conceptuel des SE, plusieurs services ont été fréquemment mentionnés par les acteurs locaux. La fourniture de biens (principalement de la nourriture) a été le plus souvent mentionnée, mais un certain nombre de services de régulation et de support ont également été mis en avant. Nos résultats ont également mis en évidence que dans les agroécosystèmes déboisés d'Amazonie, le maintien ou la restauration des services écosystémiques (y compris les biens) dépend des types d'interventions humaines (par exemple, la plantation ou la gestion de systèmes agroforestiers ; les pratiques agricoles sur brûlis). Cela souligne l'importance du concept de coproduction des SE pour mieux comprendre comment l'agriculture est pratiquée dans ces zones, en particulier les différents types de capital utilisés par les agriculteurs. Enfin, les résultats des articles 1 et 3 soulignent la logique de la compréhension des exploitations agricoles familiales en tant qu'espace de fourniture et d'utilisation de multiples SE (et aussi de disservices) qui sont interconnectés. Cette discussion renforce donc la pertinence du débat sur la multifonctionnalité dans l'agriculture familiale.

Comment les perceptions des SE et des pratiques de gestion associées diffèrent-elles entre les parties prenantes ?

Les résultats des entretiens semi-directifs et des sessions de jeu ont démontré que la perception des différents éléments mentionnés ci-dessus liés à la coproduction des SE varie considérablement parmi les acteurs locaux. Les résultats de l'article 1 ont démontré la pertinence du **contexte local** dans l'identification des services perçus par les acteurs locaux et ont suggéré que, en plus d'autres aspects (par exemple le type d'activité, le positionnement idéologique), le contexte différencie également les perceptions des acteurs sur la façon dont les pratiques agricoles et les SE sont liés. Les résultats de l'article 1 ont aussi démontré que les perceptions des SE et des pratiques agricoles associées varient en fonction du **type d'activité** entrepris par chaque partie prenante. Enfin, ces résultats démontrent également que les différences dans la perception des SE par les parties prenantes ne sont pas directement liées au **type de connaissances** qu'elles possèdent. En d'autres termes, les agriculteurs et les scientifiques, par exemple, peuvent avoir le même profil de perception des services écosystémiques (par exemple, l'importance de la fertilité des sols) dans un contexte donné. Cependant, des études antérieures suggèrent que des aspects plus qualitatifs de la perception des services (c'est-à-dire la mention d'une observation hautement scientifique ou empirique des services) sont effectivement influencés par le type de connaissance (Altieri 2004; Martín-López et al. 2012). Ceci est cohérent avec les résultats des sessions de jeu décrites dans l'article 3, où nous avons observé différentes manières de jouer le jeu par les représentants des agriculteurs (décisions plus basées sur des observations empiriques) et par d'autres acteurs scientifiques techniques (décisions plus basées sur des indicateurs) visant à fournir un SE ou non.

Comment certains facteurs, internes et externes à l'agroécosystème, influencent-ils la co-production des SE ?

Facteurs internes à l'agroécosystème liés à la coproduction des SE.

Les résultats des sessions de jeu indiquent que l'équilibre de la disponibilité et de l'utilisation des "**ressources physiques**" (par exemple, l'argent et la main-d'œuvre) est un facteur important dans la mise en œuvre des pratiques de gestion, mais d'autres facteurs sont également pris en considération par les décideurs. Notamment, les **valeurs des acteurs** : une décision de ne pas adopter une pratique particulière (par exemple l'utilisation d'un herbicide), même dans une situation où elle est nécessaire, est généralement justifiée dans le jeu par un sens de la valeur. La **fourniture de SE** est également reconnue comme l'un de ces moteurs.

Les **connaissances concernant les SE** eux-mêmes et la manière dont les stratégies de gestion peuvent avoir un impact sur la fourniture de ces services jouent également un rôle important. Par exemple, dans le jeu, certaines équipes mentionnaient la fourniture de certains services comme un objectif de leur stratégie (par exemple l'approvisionnement en eau), mais mettaient en œuvre des formes de gestion qui compromettaient la fourniture de ces services (par exemple le défrichement des ripisylves pour cultiver les cultures annuelles). Ces attitudes résultaient en partie de la méconnaissance de l'effet de certaines pratiques sur la fourniture des services.

Marchés institutionnels et co-production de SE (facteurs externes)

Les programmes d'achats institutionnels décrits dans l'article 2 sont des facteurs contextuels socio-économiques externes à l'agroécosystème qui ont augmenté ou créé un marché pour un large spectre de cultures. Ils ont donc modifié l'importance (c'est-à-dire l'attribution de la valeur d'usage) accordée à ces cultures et ont amélioré le bien-être des agriculteurs, principalement grâce aux revenus tirés de la vente des produits, mais aussi indirectement grâce au bien-être de ceux qui consomment ces produits. Nous avons donc observé, conformément à Spangenberg et al. (2014), que les changements de la demande des populations pour un SE (et par conséquent dans son « attribution de valeur d'usage ») conduisent à une altération du niveau de gestion des agroécosystèmes afin d'augmenter l'offre de ce service, si cela est permis par d'autres facteurs contextuels (par exemple, les restrictions légales, le manque de ressources matérielles, les valeurs, les normes), avec de possibles impacts en cascade sur un ensemble de SE corrélés.

Nous suggérons donc, en termes de coproduction des SE, qu'un contexte externe « positif » en faveur de l'approvisionnement en SE (par exemple, des politiques favorables, des incitations commerciales) peut favoriser leur fourniture, mais que même dans un scénario défavorable, certains agriculteurs disposant de plus de connaissances et reconnaissant l'importance des SE peuvent continuer sur la voie de la biodiversité.

Comment formaliser les connaissances liées à la co-production des SE et permettre aux acteurs locaux d'en discuter par des outils méthodologiques appropriés afin d'orienter la transition agroécologique ?

Importance du cadre conceptuel de SE pour orienter la transition agro-écologique dans nos deux zones d'étude.

Le cadre des SE permet de regrouper différents aspects sociaux, économiques et environnementaux de l'utilisation du sol qui sont pertinents pour la mise en œuvre de la transition agroécologique dans des situations réelles. Cependant, des études récentes (par exemple, Duru et al. 2015; Geertsema et al. 2016) ont démontré que l'opérationnalisation du cadre conceptuel des SE est encore fragilisée par des lacunes dans les connaissances et par le manque d'outils méthodologiques adéquats pour explorer la complexité des questions liées à ce concept dans différents contextes et à différentes échelles d'analyse.

Ainsi, dans une perspective constructiviste, en analysant quels services sont perçus (et valorisés) par les acteurs locaux comme étant coproduits à l'échelle des agroécosystèmes, notre contribution à l'opérationnalisation du concept de SE consiste à (a) générer des connaissances opérationnelles sur le système social (c'est-à-dire la connaissance des *drivers* et des préférences des parties prenantes) et les systèmes écologiques (c'est-à-dire la connaissance des processus écosystémiques) qui sont complémentaires pour soutenir une gestion de l'utilisation du sol capable de fournir des SE multiples, et (b) essayer de formaliser ces connaissances à l'aide d'outils méthodologiques appropriés (par exemple, un modèle, des indicateurs).

Co-production de connaissances opérationnelles sur les SE.

En termes de co-production des SE, nos résultats **améliorent la compréhension des connaissances et préférences des parties prenantes en matière de SE**, en particulier :

- Les résultats de l'article 1 révèlent quels services sont perçus par les différentes parties prenantes et comment elles perçoivent la co-production de ces services ;
- Les résultats de l'article 2 mettent en lumière les défis que les participants perçoivent dans la coproduction de ces SE ;
- Les résultats de l'article 3 améliorent notre compréhension de la manière dont les parties prenantes prennent des décisions lorsqu'elles sont confrontées aux différents compromis et facteurs associés à la fourniture de SE.

Ce type de connaissances est utile pour comprendre les attentes des différentes parties prenantes concernant la coproduction des SE, leurs raisons de valoriser ces SE, ainsi que leurs attentes en matière de mobilisation de ces SE. Ces connaissances peuvent être utilisées pour rechercher des solutions de gestion actionnables.

En s'appuyant sur les connaissances des acteurs locaux, nos résultats aident également à **comprendre différents aspects des SE et à coproduire de nouvelles connaissances "scientifiques" locales.** Ces nouvelles connaissances comprennent:

- La corrélation entre les pratiques agricoles et les SE, à partir des résultats des entretiens décrits dans l'article 1. Dans ce cas, même si différents SE et pratiques agricoles ont été perçus, peu de contradictions ont été observées dans les déclarations faites par les différentes parties prenantes sur la manière dont une pratique agricole particulière affecte la fourniture d'un service donné. Comme mentionné par Faugère et al. (2010), « la même relation exprimée par différents informateurs peut être considérée comme une nouvelle connaissance scientifique potentielle ». Ainsi, dans l'état actuel des connaissances scientifiques, l'étude de ces déclarations peut permettre de mieux faire connaître l'effet local des pratiques agricoles sur les services écosystémiques ;
- La manière dont les éléments du contexte social et les facteurs externes aux agroécosystèmes affectent le processus de co-production de services (principalement l'accès aux marchés), à partir de l'étude de la mise en œuvre des programmes d'achats institutionnels décrits dans l'article 2 ;
- La co-construction du jeu a permis l'hybridation des connaissances par la définition d'indicateurs de certains facteurs internes liés à la gestion des agroécosystèmes. Dans ce cas, les informations intégrées au jeu s'appuyaient principalement sur les connaissances des acteurs locaux, considérés comme des experts des agroécosystèmes locaux, qui étaient ensuite articulées avec les connaissances techniques et scientifiques, comme détaillé dans Perrier (2018). Les connaissances hybrides générées ont abouti à un formalisme commun contenant les informations jugées pertinentes par le groupe d'acteurs impliqués dans le processus de co-construction, comme le préconise l'approche de modélisation d'accompagnement (Barreteau et al. 2010).

Ces résultats aident à formaliser les connaissances des parties prenantes sur la gestion de l'utilisation du sol (et les attentes et facteurs qui motivent ces actions) à travers le cadre conceptuel de SE. Ils représentent les connaissances opérationnelles sur les questions de SE dans nos deux zones d'étude, qui ont été obtenues à partir de et peuvent être utilisées pour alimenter les outils méthodologiques pour soutenir la transition agroécologique comme discuté ci-dessous.

Implications méthodologiques : Génération d'un cadre opérationnel à partir de connaissances actionnables

Une « approche de méthodes mixtes », combinant des éléments qualitatifs et semi-quantitatifs (voir Anguera et al. 2018 pour une revue), a été construite et utilisée dans cette thèse pour recueillir les différents types d'informations sur les SE discutés ci-dessus.

Principalement dans les premières étapes de cette recherche, nous avons utilisé certaines méthodes qualitatives courantes utilisées en sciences sociales, telles que les entretiens semi-directifs et l'observation participante. Ces méthodes ont ensuite été combinées de manière interactive avec des méthodes semi-quantitatives, telles que l'utilisation de questionnaires et l'utilisation d'un jeu de rôles co-construit. Les méthodes qualitatives ont été importantes pour la recherche exploratoire, ainsi que pour recueillir des informations sur les systèmes socio-écologiques locaux et sur les différentes perceptions et valeurs des acteurs locaux concernant les sujets de recherche. Les méthodes quantitatives ont principalement servi à traduire des informations abstraites en indicateurs plus facilement observables et mesurables, susceptibles de soutenir le processus décisionnel, notamment en matière de stratégies de gestion.

Les résultats scientifiques de la thèse (c'est-à-dire les aspects sociaux et écologiques de la coproduction des SE) et les outils méthodologiques produits (et qui restent à produire) sont donc, respectivement, des « connaissances *actionnables* » et un « cadre *opérationnel* ». Ils devraient faciliter le processus de prise de décision pour la mise en œuvre d'une agriculture fondée sur la biodiversité, en informant les différents aspects de la chaîne de coproduction des SE, du processus écosystémique à la génération du bien-être humain, et en permettant aux parties prenantes d'accéder à ces informations et d'en discuter.

En bref, nous avons vu que le cadre conceptuel de la coproduction des SE va au-delà de l'exploration des éléments directement corrélés à la gestion des agroécosystèmes : il constitue également un outil viable pour stimuler la communication entre les différents acteurs sur le sujet. Une meilleure compréhension des nombreux mécanismes qui sous-tendent la coproduction des SE et le partage de différentes connaissances et perceptions peuvent contribuer à une prise de conscience plus collective de la transition agroécologique.

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Introduction

The Amazon region has long been the stage for a debate on the dichotomy between environmental conservation, especially of forest resources, and socio-economic development. Coming up with a model of development for the region that reconciles these different aspects remains an unmet challenge (Costa and Fernandes 2016; Nobre et al. 2016)[4]. Since the majority of this biome is located in Brazil, the debate around the Brazilian Amazon has become fundamental, not only at the national and pan-Amazon levels, but also internationally (Palacio and Wakild 2016). In Brazil, the legal delimitation of the Amazon encompasses almost two-thirds of the country. It is home to about 12% of the Brazilian population, and has (along with the north-east region) the country's lowest development indexes, and, in addition, suffers from a host of environmental problems (Costa and Fernandes 2016). In this region, there is a complex structure of actors characterized by stark power asymmetries playing out in an also complex biophysical environment in which a mosaic of sometimes conflicting activities result in different forms of interaction between people and nature (Montaño 2016). Among these activities, the "agricultures" stand out due to their overarching scope, socio-economic significance and great potential to alter ecosystems and the provision of a diversity of ecosystem services (ES) such as water, soils and biodiversity (Fearnside 1997).

As described in Castro and Campos (2015), there are different ways of practicing agriculture in the Amazon, and these ways have undergone significant changes over time. From the traditional indigenous agriculture practiced before the colonial period (starting in the 16th century), the "Amazonian agricultures" were reconfigured following different cycles of exploitation of agricultural goods (e.g., "drogas do sertão," rubber, timber) in the region. This transition process intensified in the 1960s, in response to the interest of the Brazilian government in making the region more dynamic and more integrated into the process of economic modernization that was driving the country at that time. In this period of great change, some parts of the Amazon experienced a precarious process of "agricultural modernization" based on the principles of the Green Revolution, which started to coexist,

[4] The references of the citations made in this Introduction will be included in Chapter 1 of this manuscript.

not always harmoniously, with the traditional agriculture already existing there. As a consequence, the agrarian structure today in the Amazon is composed of a combination of large and small farmers, with production patterns that are notoriously different, and that also reflect differently on the region's current environmental problems (Pokorny et al. 2013).

According to Costa (2008), three types of productive rationales make up the productive mosaic currently observed in Amazonian agricultural areas. A **large-scale business agriculture** characterized by professional management, sometimes linked to multinationals or a business group external to the region, whose decisions on land use (or non-use) depend directly on an economic analysis of potential profits to be made. **Large farms** (i.e. "fazendas"), which also practice large-scale agriculture, but based on family management and employed labor, and whose local importance derives from power relations based on political or economic influence or even tradition. **Family farms**, for their part, represent units of production and consumption practiced on a small scale, based on family management and labor. Among these production rationales, family farms stand out for their strategic role in promoting regional sustainable development (Costa 2008; Pokorny et al. 2013).

In Brazil, the concept of family farming encompasses, in accordance with the Law No. 11.326/2006, a set of small-scale rural activities practiced by different groups of people (e.g. farmers, fishermen, extractivists). Family farming gained prominence in the country in the 1990s as a social and political category of national relevance, giving rise to a set of policies that emerged during and after this period with the aim of strengthening these farms and promoting sustainable rural development (Grisa and Schneider 2014; Schmitt et al. 2017). This debate resulted in the rolling out of the "National Policy for Agroecology and Organic Production" (PNAPO) in 2012, which was preceded by the "National Plans for Agroecology and Organic Production" (PLANAPO), launched in 2013 and updated in 2016 to operationalize the PNAPO (Schmitt et al. 2017).

The effectiveness of these initiatives in the Amazonian context is still uncertain. The discussion on which agricultural model to prioritize is far from reaching a consensus (Palacio and Wakild 2016). The mechanical-chemical input-based agricultural model, with its core objective of producing agricultural commodities such as soy and meat, is accorded priority over the strengthening of a "biodiversity-based agriculture" sustained by the provision of ES

(Pokorny et al. 2013). Local actors supporting family farms (e.g. rural extension, public policies, research institutions) have to contend with numerous challenges in promoting an agroecological transition in the Amazon (Sá 2015). In addition to the lack of financial resources and infrastructure that prevents a broader reach of their actions, these actors frequently align with the Green Revolution's productionist paradigm (Silva and Martins 2009).

In this context, the agroecological transition in the region has to bring together different actors, with very diverse visions, interests and power relations in a dialogue. Such dialogues need operational tools that can help mediation between these different actors, as well as the creation of participatory arenas of coordination and governance. Some authors believe that the concept of ES could be relevant for characterizing uses of resources in a territory, specifying the expectations/objectives of different stakeholders and putting the modalities of management of such a territory into debate (Díaz et al. 2015; Barnaud et al. 2018). These are key elements for steering an on-ground **agroecological transition** (Dendoncker et al. 2018).

Given this background, we intend in this thesis to investigate how the conceptual framework of ES can serve as a cognitive and operational basis to support the agroecological transition in the Brazilian Amazon. We focus more specifically on family farms, emphasizing the management of the agrobiodiversity (e.g., annual and perennial cropping systems) that is intrinsically part of these farms' practices. We chose two contrasting municipalities located in the eastern Brazilian Amazon, Irituia and Paragominas, as our study area. The farming sector in the first study site is dominated by family farming, which is often biodiversified. In contrast, large-scale industrial agriculture predominates in the second study site, although it coexists with family farming. Through this choice, we seek to draw a comparison between these two contrasting realities. We adopt the farm level as the main scale of analysis but also consider the municipality level as a secondary scale, in particular in order to take into account the existing connections between these two levels, established through the formal and informal institutions governing them. For this purpose, the notion of the **agroecosystem**, which describes agricultural activities practiced in small spaces, seems to be a framework based on social-ecological systems (SES), useful both for analyzing the management implemented at the farm level, as well as its social and ecological correlations with the environment (Altieri et al. 1999).

We adopt a multi-actor perspective as a fundamental premise of our research. Since the concepts of ES and agroecology deal with SES, it is essential to understand the perceptions and expectations of the different local actors (i.e. social system) directly and indirectly involved in the management of agroecosystems (i.e. ecological system) (Reyers et al. 2013). We therefore construct our analysis on the knowledge of a diversity of local actors concerned with rural issues and about the topics under investigation. We also choose a "transdisciplinary" research perspective, covering elements from different scientific disciplines (mainly agronomy and the social sciences), as well as knowledge from actors outside the academic sphere, especially farmers (Brandt et al. 2013). To support this perspective, we implement a "mixed-methods approach" combining well-tested qualitative methodologies with semi-quantitative ones such as role-playing games (Sattler et al. 2018), with, as background, companion modeling (COMMOD) (Barreteau et al. 2010).

This study was conducted within the context of two research projects that were undertaken in parallel in our study area. The STRADIV[5] project, which financed this thesis, addressed the topic of biodiversification of agroecosystems, bringing together a wide range of biodiversified systems from Central America, the French West Indies, Burkina Faso, Cameroon, Madagascar and Brazil. In the Amazon, this project focused on the municipality of Paragominas and was more specifically interested in the biodiversification of annual crops cultivated by smallholders. The field work was progressively integrated with the implementation of another project, REFLORAMAZ,[6] which had forest restoration as its central theme, with a strong emphasis on agroforestry systems. It had a local focus in north-east Pará State, comparing 5 of its municipalities, in particular Irituia. This thesis integrated the dynamics of execution of these two projects, so that a diversity of researchers, master's

[5] "STRADIV – System approach for the TRAnsition to bio-DIVersified agroecosystems," financed by Agropolis Fondation under reference ID 1504-003.

[6] "Refloramaz – Forest restoration by family farmers in the Eastern Amazon," financed by Agropolis Fondation under reference ID 1503-011 through the *"Investissements d'avenir"* program (Labex Agro:ANR-10-LABX-0001-01), and by Embrapa (SEG 03.15.12.004.00.00).

and doctoral students, farmers, among other participants, actively contributed to the construction of the reflections and field activities that underpinned this research.

This manuscript is organized in six chapters. In the first chapter, we carry out a literature survey to construct the conceptual framework of the thesis. We begin by exposing the reasons that form the basis of the quest for sustainable agriculture. We then present the potential of the ES conceptual framework, more precisely the co-production of ES, to promote the agroecological transition. We conclude this chapter by presenting the research questions that guided this thesis, and the results we mobilized to answer each of them.

In the second chapter, we present the context of the research, highlighting in detail the area of study, the local actors involved in the research, and the methodological tools selected to explore our questions in that context. We focus in this chapter on essential information so that the reader can have an overall understanding of the research carried out. Some information is repeated in the articles that compose this document, since each of them is meant to be read independently.

In chapters 3, 4 and 5, we present the results of this thesis, with each chapter referring to a scientific paper. The first paper deals with the perceptions of local actors about ES and the co-production of these services. The second paper focuses on the importance of two food procurement programs that promote agrobiodiversity in agroecosystems. The third paper presents a role-playing game co-built to encourage discussion with local actors on factors pertaining to agroecosystem management.

Finally, in chapter 6, we conduct a transversal discussion of the results presented in each of these papers, highlighting how these results served to answer our research questions, and thus contribute to knowledge about co-production of ecosystem services and the agroecological transition. We conclude by summarizing the contributions of the thesis to the challenges of the agroecological transition in the Amazon, its limitations and further perspectives.

Chapter 1: Research problem and conceptual framework

We present in this first chapter the conceptual framework, objectives and the structure of the thesis. In a first moment, we discuss socio-economic and environmental elements that support the need to implement an agroecological transition. Next, we present the conceptual framework of ecosystem services (ES), more precisely the co-production of ES. We then discuss the multi-level and multi-actors aspects of rural areas. Regarding the issue of scale, we present the relevance of the agroecosystem as a scale of analysis to meet our objectives and how this scale integrates with the agroecological transition process. We then highlight the methodological challenges for research on ES. Finally, we will detail our research questions and the structure of the results.

1. The crisis in the global agricultural production paradigm and the search for sustainable agriculture

We are at a time of unprecedented threats to ecosystems around the world. Human activity now affects the entire planet and is the dominant cause of most contemporary environmental changes (e.g. land surface and atmospheric composition) (Lewis and Maslin 2015). It is also the main factor behind changes in ecosystems in recent decades (Bennett et al. 2015). In this context, farmers are a major group of natural resource managers since they are responsible for agriculture, which, in order to meet our requirement for *goods* (e.g. food, fiber and other raw materials), represents the largest use of land worldwide (Foley et al. 2005; Zhang et al. 2007), covering over one-third of terrestrial ecosystems (Díaz et al. 2020). Agriculture depends however on important *ecosystem processes* that are dependent on the proper functioning of ecosystems (Altieri and Nicholls 2005; Zhang et al. 2007). Both goods and processes can be thought of as ecosystem services (ES), understood as the “outputs of ecosystems from which humans derive (direct or indirect) benefits” (Lamarque et al. 2014). Agricultural ecosystems are therefore often at the center of the complex set of questions involving ecosystem issues, contributing to and suffering from many of its consequences (Wood et al. 2000; FAO 2007).

Land-use practices were altered fundamentally in the second half of the last century as a result of a process of industrialization of agriculture, called the Green Revolution (Foley et al. 2005). In order to maximize crop productivity, a variety of mechanical and chemical management practices were disseminated at that time to increase labor efficiency and yields (Therond et al. 2017). Although some production units were directly affected by this process, others (mainly poor farms in developing countries) remained untouched (Altieri 2002; Mazoyer and Roudart 2017). More recently, this process of modernization of agriculture has been exacerbated by globalization, which has increased the flows of materials and information throughout the world (Tilman et al. 2001).

As a result, there exist today a diversity of agricultural models around the world, ranging from smallholder subsistence farms on marginal lands to high-technology agricultural units deeply connected to global markets (Altieri et al. 2012), with each model being distinguished by factors such as scale, biotechnological functioning (e.g. chemical-input or biodiversity-based) and associated socio-economic contexts (van der Ploeg 2009; Therond et al. 2017). The relationship of these different forms of agriculture with ecosystems (and consequently with the provision, degradation and use of ES) also varies (Foley et al. 2005). For example, industrial agriculture is usually highly dependent on inputs and mechanical factors, so that distancing from nature is an inexorable process. Smallholders remain, for their part, usually totally or partially spared from modern agricultural technologies, especially if they are located in developing countries (Silva and Martins 2009; Altieri et al. 2012). Their farms are therefore usually perceived as having a reduced impact on the ecosystem (especially when compared to industrial farms) and being more dependent on ES (van der Ploeg 2009; Pokorny et al. 2013; Duru and Therond 2015).

In recent decades, even while there is an acknowledgement of the unprecedented increase in crop productivity resulting from the process of modernization of agriculture (Foley et al. 2005), more attention has been paid to the negative socio-economic and environmental impacts of this process (Duru and Therond 2015). In **socio-economic terms**, this model has contributed to widening the disparities between farmers, as those who were able to adopt the new technologies largely improved their harvests, as compared to other farmers with fewer resources (Altieri et al. 2012). By replacing human labor by machinery, this process has also contributed to an increase in unemployment in rural areas (Mazoyer and Roudart 2017).

Furthermore, the dramatic reduction and high volatility in agricultural prices as a result of increased productivity and the globalization of markets has made it economically impossible for a diversity of farmers to continue farming, leading to the collapse of their farms (von der Weid 2009). Farmers who have been able to access these technologies are also experiencing their various negative effects, such as indebtedness, health problems and loss of autonomy, sometimes even driving them to suicide (Kim et al. 2017; Martins 2018). There are also numerous **environmental negative impacts** resulting from the dissemination of this model of agriculture. The contamination of waters cycles, salinization of soils and mortality of pollinating insects are closely linked to the use of agrochemicals on farms (von der Weid 2009). The decline in biodiversity through the loss, modification and fragmentation of habitats is also notable (Foley et al. 2005; Duru and Therond 2015). The emission of 13% of global anthropogenic greenhouse gases that contributed to global warming between 2007 and 2016 has been mainly attributed to this model of agriculture through deforestation, emissions from livestock, and soil and nutrient management (IPPC 2019).

There is also controversy surrounding this model's sustainability, given that its functioning is based on the depletion of non-renewable resources (Tilman et al. 2002). For example, its energetic base relies on the use of fossil fuels (e.g. use of tractors, harvesters for production; storage and processing; transport of inputs and products), which are highly susceptible to market volatility (von der Weid 2009). Chemical fertilizers are also at threat, as their sources are progressively depleted (e.g. potassium), and their extraction becoming increasingly expensive (Therond et al. 2017).

As a consequence, this agro-industrial model of production has been increasingly called into question (Tilman et al. 2001), which has led to the necessity of finding forms of agriculture that are more socially equitable and environmentally friendly, capable of ensuring productivity and of fulfilling its objective of promoting human welfare (Altieri and Nicholls 2005; Therond et al. 2017). In response, a diversity of "sustainable farming practices" have been proposed in recent decades (e.g. permaculture, organic farming, conservation agriculture, biodynamic agriculture), most of them forming the basis for "agricultural systems with a wide diversity of environmental and socio-economic performances" (Therond et al. 2017).

In an effort to make a coherent classification system of the different “agricultures” that claim to be conscious of environmental issues, Duru and Therond (2015) describe two main pathways for the “ecological modernization of agriculture” based on agronomic aspects. The **first** is concerned with reducing environmental impacts, improving the efficiency of the use of inputs (e.g. fertilizers, pesticides, water) or replacing chemical inputs with organic ones, without changing the status of a production-oriented agriculture. The **second** is supported by the implementation of management practices that increase the supply of ES and reduce dependence on external inputs, and which are concerned with social, cultural, spatial and political aspects (Horlings and Marsden 2011).

In this sense, agroecology stands out for its versatility in being conceived as a scientific discipline, agricultural practice, and political or social movement (Wezel et al. 2009; Hainzelin 2015), more in line with the **second pathway** of the ecological modernization of agriculture (Gliessman 2001; Horlings and Marsden 2011). In the productive sphere, agroecology not only proposes a progressive transition from systems with a high use of chemical inputs to agricultural systems based on biodiversity management (FAO 2015), but also proposes improvements in land and labor productivity for those farms that have not yet started on any intensification process (Altieri 2002; Hainzelin 2015). To make this happen effectively, recent studies advocate that it is also necessary to go beyond the scale of the farm and establish a (re)connection between those who produce food (i.e. farmers) and those who consume it. This would require a reorganization of the global food system, including of a diversified set of actors concerned with this process (FAO 2015; Therond et al. 2017).

Although the concepts of agroecology and of ES have emerged from different backgrounds (e.g., authors; disciplines; political and institutional contexts)[7], these two concepts have becoming increasingly interconnected in recent times. **Agroecology** has started to be recognized as embodying the set of principles necessary for sustainable land management in consonance with the provision and use of ES (Duru et al. 2015; FAO 2015). Indeed, different recent studies demonstrate how agroecological agricultural systems can provide different ES (Palomo-Campesino et al. 2018; Boeraeve et al. 2020). In a symmetrical manner, other studies (e.g. Duru and Therond 2015; Therond et al. 2017; Dendoncker et al.

[7] See Wezel et al. (2009) and Nahlik et al. (2012), respectively, for a historical background of the emergence of the concepts of agroecology and of ecosystem services.

2018) stress the usefulness of the **ES framework** in steering the implementation of these agroecological principles in real world situations, in particular **(a)** by improving the understanding of the ecological and social drivers of the agroecological transition and **(b)** by allowing this understanding to be shared with stakeholders directly and indirectly concerned with ecosystem management. In this document, we will deepen the discussion on how the concepts of ES and agroecology can be linked in order to understand the expectations and constraints about the process of the agroecological transition perceived by local actors concerned with rural issues.

2. Ecosystem services: a metaphor for understanding the relationship between man and nature

2.1. Conceptual framework of ES

Since the term ecosystem service was used for the first time, several **definitions** and **classification systems** have been proposed (Table 1). These varied definitions can be complementary or contrasting in terms of the ideas, norms and values that underpin them (Nahlik et al. 2012; Barnaud and Antona 2014). The existence of different classification systems, in turn, is necessary for taking into account the different decision contexts (e.g., understanding and education; landscape management; cost-benefit analysis) in which the ES concept can be used (i.e. fit for purpose) (Fisher et al. 2009; Lamarque et al. 2011a), as observed by Costanza (2008):

> *"In the messy world we do inhabit, we need multiple classification systems for different purposes, and this is an opportunity to enrich our thinking about ecosystem services rather than a problem to be defined away" (Costanza 2008, p. 1).*

Since research on ES often tries to address multiple objectives associated with these contexts, a combination of different classification systems is usually necessary (Fisher et al. 2009).

Table 1. Definitions of and classification systems for ES.

<table>
<tr><td rowspan="7">Definition</td><td colspan="2">Definition</td><td>Citation</td></tr>
<tr><td colspan="2">"…the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life."</td><td>(Daily 1997)</td></tr>
<tr><td colspan="2">"…the benefits human populations derive, directly or indirectly, from ecosystem functions."</td><td>(Costanza et al. 1997)</td></tr>
<tr><td colspan="2">"…the benefits people obtain from ecosystems."</td><td>(MEA 2005)</td></tr>
<tr><td colspan="2">"…components of nature, directly enjoyed, consumed, or used to yield human well-being."</td><td>(Boyd and Banzhaf 2007)</td></tr>
<tr><td colspan="2">"…the aspects of ecosystems utilized (actively or passively) to produce human well-being."</td><td>(Fisher et al. 2009)</td></tr>
<tr><td colspan="2">"...the direct and indirect contributions of ecosystems to human wellbeing."</td><td>(Sukhdev et al. 2010)</td></tr>
<tr><td rowspan="6">Classification system</td><td>Characteristic</td><td>Classes</td><td>Citation</td></tr>
<tr><td>Functional aspects (what purposes do they serve?)</td><td>Provisioning, regulating, cultural and supporting services</td><td>(MEA 2005)</td></tr>
<tr><td>Aspects enjoyed</td><td>Final and intermediate services</td><td>(Boyd and Banzhaf 2007)</td></tr>
<tr><td>Spatial characteristics (location of provision and use)</td><td>Global, local, in situ, directional flow or user movement-related services</td><td>(Costanza 2008)</td></tr>
<tr><td>Rivality or excludability</td><td>Market, club, public goods or open access service</td><td>(Costanza 2008; Barnaud and Antona 2014)</td></tr>
<tr><td>Role for agriculture</td><td>Input services, disservices</td><td>(Zhang et al. 2007; Le Roux et al. 2008; Tibi and Therond 2018)</td></tr>
</table>

Through this diversity of definitions and classification systems, the idea of ES was widely disseminated by the report published by the "Millennium Ecosystem Assessment" (MEA 2005), an initiative of the United Nations that was intended to assess the consequences of ecosystem changes for human well-being. This report also proposed a classification system, which has since become the most widely adopted one. This document drew attention to humankind's dependence on the proper functioning of ecosystems and to the fact that many of these services have been degraded by human activity or used unsustainably (15 out of the 24 services analyzed by this initiative were in the process of being depleted), which could bring negative impacts to society as a whole. The concept of ES has thus become an important *metaphor* for relating ecosystem functioning to human welfare and for guiding environmental policies (Bennett et al. 2015; Spangenberg et al. 2015; Berbés-Blázquez et al. 2016). The ES concept is now widely discussed in **different disciplines**, such as economy, ecology and agronomy (Fisher et al. 2009; Barnaud and Antona 2014), through **different initiatives**, such as "The Economics of Ecosystems and Biodiversity (TEEB)" (Sukhdev et al. 2010) and the "Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES)" (Díaz et al. 2015). In this regard, a recent IPBES report notes that ecosystem goods and services (called “Nature’s contributions to people” in the report) across the world continue to degrade, calling for more “urgent and concerted efforts fostering transformative change” (Díaz et al. 2020).

Despite some criticism directed at the concept of ES, e.g. the absence of a meaningful and consistent definition (Nahlik et al. 2012); its anthropocentric and utilitarian character (Maris 2014; Acosta 2016); and little consideration of the human and social sciences (Díaz et al. 2018)[8], this concept has proven important in demonstrating the different contributions of nature and humans to the provision (and degradation) of important ecosystem functions (i.e. co-production of ES) (Spangenberg et al. 2014a; Palomo et al. 2016), thus enabling the inclusion of societal aspects in nature-related issues (Berbés-Blázquez et al. 2016). Nevertheless, despite some efforts in translating this concept into a language easily understandable by a diversity of stakeholders (i.e. scientists from different disciplines, policymakers, farmers, NGOs) (Lamarque et al. 2014), it still seems to be a challenge to get the non-scientific world to accord it any consideration (Díaz et al. 2015, 2018).

In addition to finding a clear definition of the concept, it is imperative to understand the mechanisms from which ecosystem structures and processes are mobilized and used to generate well-being in order to make this concept more operational for governance and decision-making regarding human and nature issues (Haines-Young and Potschin 2010; Spangenberg et al. 2014b, 2015). Among the various efforts to define and operationalize the concept of ES, we consider the conceptual framework of co-production especially useful to understand the relations between humans and nature, especially in agricultural systems, which we aim to investigate in this thesis. We will delve deeper into this conceptual framework in the next section.

[8] Such criticisms are at the root of recent propositions of alternative concepts to ecosystem services, such as Nature's Contributions to People (Díaz et al. 2018).

2.2. *What is the role of humans and nature on the supply of ES? The concept of co-production of ES*

"Co-production" is an important notion to support the interface between knowledge generation and governance in sustainability sciences (Miller and Wyborn 2018) and can be applied to the concept of ES. On managed land, most ES are not just nature-produced, but are "anthropogenically defined and produced," resulting from "socio-technical systems activating the potentials offered by nature's functions" (Spangenberg et al. 2014a). For their part, Bennett et al. (2015) state that "ecosystem services are themselves the manifestation of complex interactions between the biophysical context, ecological processes and human interventions." Thus, these services are in fact "co-produced" by humans and nature, a process that intensifies with the increase of human intervention in ecosystems (Ellis and Ramankutty 2008).

Two phases can be distinguished in this co-production process (Palomo et al. 2016). A **cognitive phase** of identifying and taking advantage of ecosystem functions as possible service generators (i.e. a phase of attributing use value) (Russell et al. 2013; Fischer and Eastwood 2016). A **physical phase**, during which humans will invest resources (e.g. time, energy, labor, material, money) in order to intervene in the biodiversity or the ecosystem to mobilize and appropriate the functions of the ecosystems previously identified (and thus generate benefits) (Spangenberg et al. 2014a; Palomo et al. 2016; Fischer and Eastwood 2016). Physical co-production of ES occurs from different "paths" (Palomo et al. 2016). We can use here as an example the case of soil fertility (intermediate service) in the floodplains of the Amazon (Figure 1) to better explain this process.

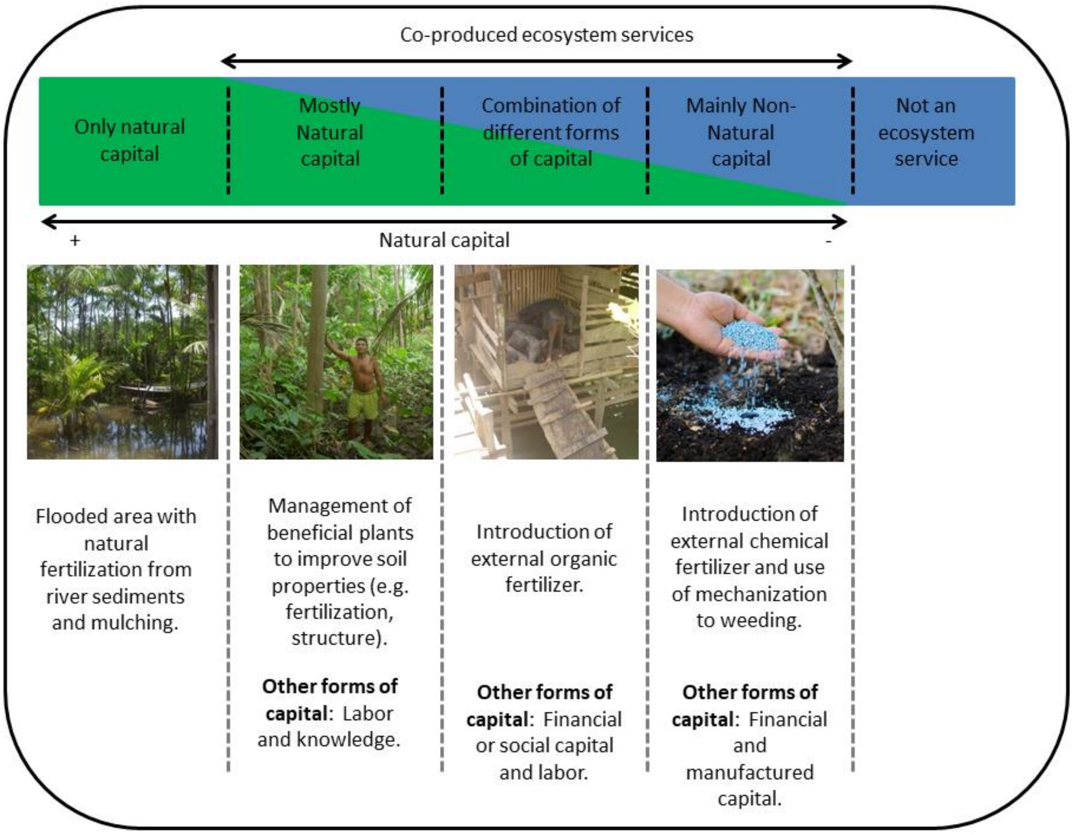

Figure 1**.** Conceptual gradient of natural capital content in the co-production of ES (figure top) and as applied to the soil fertility service (figure bottom). Adapted from Palomo et al (2016) and contextualized by the author for Amazonia.

In this example, there is a progressive increase in human intervention through investment in different resources (i.e. knowledge, work, exchange network, money, chemical inputs, machinery) in order to improve the expression of soil fertility. Even though the management practices initially adopted (i.e. introduction of plants and organic inputs) did improve the expression of ecosystem processes linked to soil fertility (a positive feedback process, as described in Van der Ploeg (2008)), farmer intervention has culminated in the substitution (and possible damage) of these processes by use of anthropogenic inputs. As a consequence, it is expected that the introduction of these anthropogenic inputs will lead to a short-term increase in the supply of goods (e.g. açai) and a reduction in workload, but also increase the risk for the provision of other ES (e.g. water quality) and thus for soil fertility itself over the long term.[9] As Bennett et al. (2015) state:

> *"Differences in the role and balance of ecological and social components in the supply of services are likely to lead to contrasting emergent system properties or unexpected effects on long-term sustainability of service supply" (Bennett et al. 2015, p. 1).*

Even in highly artificialized systems (fully blue box in Figure 1), such as in vitro meat production, it is inconceivable to envision the production of human well-being without the contribution of natural capital (Costanza et al. 1997). Indeed, it is also difficult nowadays to generate such well-being based only on natural capital, such as a few hunter-gatherer indigenous tribes still do, as humans are increasingly intervening in ecosystems (Ellis and Ramankutty 2008). This observation refers to an inconclusive debate (such as the one presented by Méral and Pesche 2016, p. 60) on whether ES refer exclusively to the benefits originating from ecosystem processes (only the contribution of natural capital) or are the co-product of the interaction between natural capital and other forms of capital.

In line with Palomo et al. (2016), we assume that ES are "jointly produced by social-ecological processes", but that it is essential to distinguish between the different forms of capital involved in the provision of a given ES and to evaluate the impact of their use on the quality of ecosystems. Making this distinction is not simple because often the uses of different types of capital are intrinsically intertwined, which tends to obscure the specific contribution of each type to the provision of a certain service (Berbés-Blázquez et al. 2016).

Hence, some key issues arise from the elements exposed while trying to elucidate this debate. The first is the **extent and type of human interventions coupled with natural processes for the co-production of different services**. Non-natural capital can be integrated into the stages of co-production of ES in different ways (Van Oudenhoven et al. 2012). Different combinations of these types of capital will result in different biotechnical models (e.g. more intensive in labor and knowledge and closely tied to natural capital; more intensive in financial and manufactured capital as substitutes for natural capital). They can

[9] The process described here is the opposite of the agroecological transition process that will be discussed later in this document.

also affect the quantity and quality of services delivered in different ways (Palomo et al. 2016).

It is important to recognize this fact in order to investigate to what extent a given service (e.g. soil fertility for crops) originates from ecosystem processes or other forms of non-natural capital (Boyd and Banzhaf 2007; Palomo et al. 2016). The emphasis on outputs (benefits) tends to obscure the different types of capital that are mobilized to generate such benefits (Berbés-Blázquez et al. 2016). It is therefore important to assess the social, economic and ecological costs associated with each combination of types of capital (Berbés-Blázquez et al. 2016; Palomo et al. 2016).

A second issue is the **availability to ecosystems managers (e.g. farmers) of these different forms of capital in order to co-produce services**. The availability of different forms of capital can vary widely depending on different contexts (between different places and also between different actors in a same place) (van der Ploeg 2009). It is well-known that poor farmers in developing countries have limited access to financial and manufactured capital (Altieri 2002). Consequently, they will usually depend on labor and traditional knowledge to manage their agroecosystems (Altieri and Nicholls 2005; Toledo and Barrera-Bassols 2008; Jankowski 2013). In contrast, farmers in developed countries have, in general, greater possibilities of accessing the overall package of modern agriculture (e.g. inputs, machinery, technical assistance) (Duru and Therond 2015). Therefore, in order to be effective, ecosystem management plans must consider these different socio-economic contexts (Spangenberg et al. 2014a).

It is therefore necessary to investigate the **other contextual factors that influence the decision-making process to mobilize different forms of capital in the co-production of services**. While it is well established that the availability of capital represents a key factor in the adoption of biotechnology models (Altieri 2002; van der Ploeg 2009; Therond et al. 2017), it is also known that other elements (e.g. climate conditions, socio-political contexts, knowledge, ideological positioning) may influence this decision-making process (Lamarque et al. 2014; Teixeira et al. 2018). Seen this way, a decision represents a preferential action taken by a person or entity based on knowledge, values and influenced by contextual socio-economic and ecological factors (Lamarque et al. 2014). In a favorable situation, in which resources are available and there are few restrictions, the decision taken can be translated into action (Stern 2000).

Investigating these issues is therefore of the utmost importance for designing realistic land use management strategies in order to promote ES delivery (Bennett et al. 2015). As noted by Palomo et al. (2016), different biotechnical models result in **trade-offs** (and synergies) and affect **resilience** and **equity** in the co-production and use of services. We define these three concepts, which are fundamental to a better understanding of the conceptual framework of co-production of ES:

Trade-offs (and synergies): Management interventions and interactions among services (e.g. pollination may increase fruit production) can drive positive or negative changes in the supply of one or more ES (Bennett et al. 2009). In this sense, trade-offs in the co-production of ES are situations in which an intervention affects provisioning of different services in opposite directions (i.e. “one service increases while another decreases”) (Rodríguez et al. 2006; Bennett et al. 2009; Berbés-Blázquez et al. 2016). These trade-offs can occur at different scales (e.g. local, regional or global), concurrently or across time (i.e. when interactions at a given time may trigger the provision of a service in the future) (Bennett et al. 2015). In the latter case, a trade-off can also be observed within a same service (i.e. exploitation of a service today may impair its provision in the future) (Spangenberg et al. 2014b; Palomo et al. 2016). Synergies in the co-production of ES refer to situations in which a given intervention can increase the provision of different services (i.e. provision of bundles of services) (Bennett et al. 2009; Reyers et al. 2013).

Resilience: Resilience of social-ecological systems (SES) in the context of ES co-production is understood as the capacity of these systems to “continue providing a desired set of ecosystem service flows in the face of unexpected shocks and ongoing changes” (Biggs et al. 2012). Resilience is closely tied to the maintenance of biodiversity and ecosystem functions (Oliver et al. 2015) and also to the capacity of reversibility (i.e. “likelihood that the perturbed ES may return to its original state if the perturbation ceases”) of the provision of a service (Rodríguez et al. 2006). In this reading, resilience is more than just “ecological resilience;” it also depends on social aspects (i.e. strong institutions, norms, laws, policies) (Altieri and Nicholls 2012). Thus, “understanding how altering the mix of ecological and social contributions to services affects long-term sustainability is a key step in improving the management of ecosystems and their services" (Bennett et al. 2015).

Equity: Understanding the mechanisms of co-production of ES can improve awareness about the distribution of co-production costs and benefits of the resulting services and, therefore, about how these factors shape the equity of well-being in society (Reyers et al. 2013; Palomo et al. 2016). In this sense, the capacity of co-production (and use) of ES will "depend on the access and control over the different types of capital" (Palomo et al. 2016). Trade-offs in the provision of different services entails "social trade-offs and compromises among people" (Barnaud and Antona 2014) since they usually result in winners and losers (Reyers et al. 2013; Berbés-Blázquez et al. 2016). Indeed, Bennett et al. (2015) note:

> *"Understanding how individuals' consumption of a particular ecosystem service in one place can limit the use and enjoyment of this or other services by other people elsewhere, is therefore a major research priority"(Bennett et al. 2015, p. 5).*

It is thus crucial to consider the social interactions among local actors (i.e. between providers and beneficiaries, among beneficiaries, and among providers of services) and the possible asymmetries of these interactions, which are important to determine which services will be prioritized (Hein et al. 2006). The way to deal with these interactions depends on the scale of provision and use of services (i.e. local, regional or global), and also on the type of service (i.e. according to rivality and excludability) (Costanza 2008; Barnaud and Antona 2014; Spangenberg et al. 2014b). Uncertainties are also observed in these situations as decision-makers "rarely have full knowledge of the wider ramifications of their decisions on ecosystems" (Berbés-Blázquez et al. 2016).

2.3. How do ES originate from the ecosystem to benefit human beings? Operationalization of the conceptual framework of ES

The framework proposed in Spangenberg et al. (2014b) is of interest since it bases a possible operationalization of the conceptual framework of ES on the concept of co-production of these services. These authors developed the "cascade model" of ES generation and valuation (Haines-Young and Potschin 2010) in order to improve its applicability to socio-economic processes through a scheme that can explore social elements and the agents potentially involved in the process of generation and allocation of ES (Spangenberg et al. 2014b, a). This model therefore provides relevant keys to frame our field research, especially to investigate how contextual factors (especially the market) can modify the provision of certain services.

This scheme's core principle is that the recognition and use of ES depends on complex social processes. It differs from the cascade model (and frameworks advanced by other authors, such as Daily 1997), which envisions ES as "free gifts of nature." The proposed framework (Figure 2) introduces the concept of **ecosystem service potentials** as an intermediate element between ecosystem functions and services (Spangenberg et al. 2014b).

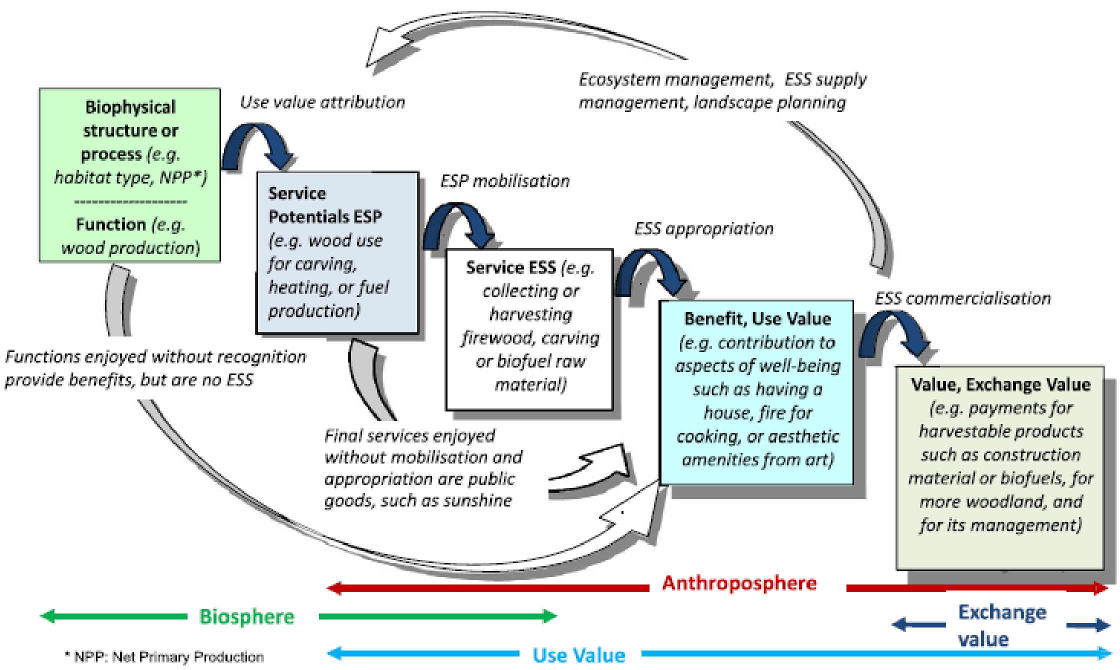

Figure 2. Scheme of generation and use of ES (from Spangenberg et al. 2014b).

As described above, **ecosystem functions** exist independently of human existence (e.g. air purification, soil biogeochemical processes, biomass production). To avoid confusion in the use of this term, "ecosystem function" is used in this scheme to refer to the "functioning of the ecosystem" (i.e. biophysical traits of ecosystems, including structures and processes).[10] The first step in the process of co-production of ES according to this model is human recognition (a cognitive act) of the potential usability of these ecosystem functions (i.e. use value attribution), constituting an **ecosystem service potential**. ES are therefore socially constructed since their recognition depends on societal choices, resulting from human perceptions and interests (Barnaud and Antona 2014). This process of recognition is context-dependent (Díaz et al. 2006), varying in space and time according to elements such as culture, preferences, needs, biophysical aspects (Haines-Young and Potschin 2010; Barnaud and Antona 2014; Lamarque et al. 2014; Fischer and Eastwood 2016).

These functions of ecosystems that are socially recognized as useful (i.e. potential ES) can then be **mobilized** by using certain resources such as technology, inputs, labor and knowledge (Lele et al. 2013) and by respecting formal and/or informal rules (e.g. laws, restrictions of access to spaces, community land-use agreements) (Lamarque et al. 2014; Spangenberg et al. 2014a). Once **mobilized**, they can be **appropriated** (individually or collectively) by users, being consumed directly (e.g. household consumption by farmers) or sold to generate benefits, a process that also requires investment of capital (Spangenberg et al. 2014a). There are a few ecosystem functions (e.g. climate regulation, oxygen production by a forest), however, that can be enjoyed without the need for human intervention (Spangenberg et al. 2014b). To be considered as ES, these functions must be recognized and valued by the potential "users" as useful.

Hence, the steps of **mobilization** and **appropriation** of ES (in response to the use value attribution) usually require management of the structures and processes of ecosystems (Spangenberg et al. 2014b; Bennett et al. 2015). It is not uncommon for this management process to be conducted in an unsustainable form:

> *"Ecosystem management would then try to enhance the supply [of a given service] hoping for continued demand, but may not be able to succeed as overstressing the resilience of ecosystems by managing too narrowly for one specific ecosystem service potential or by mobilizing it beyond the regeneration rate will lead to collapse" (Meadows et al. 1992 in Spangenberg et al. 2014b, p. 7).*

[10] The term "ecosystem functions" is also used to describe some functionality attributed by humans to ecosystem processes. Here, these functionalities are called "ecosystem services potential."

This scheme is also useful in highlighting the feedback mechanism arising from the management induced by the demand for a service and the ecosystem's ability to provide this (or another associated) service (Lamarque et al. 2014; Spangenberg et al. 2014a). Indeed, the actors involved in the process of generating and using ES are not always aware of this relationship (Bennett et al. 2015). In this sense, this scheme can be used as a management planning tool (Spangenberg et al. 2014b). Implementing these elements in rural spaces, however, requires the consideration and understanding of elements at different scales and of the different actors who interact in these spaces (Foley et al. 2005), as we discuss in more detail in the next section.

3. Understanding the provision and use of ES in rural areas: a multi-actor and multi-level perspective

Rural areas are social-ecological systems (SES) based on the complex relationship between ecological and social structures and processes (Wilson et al. 2013; Reyers et al. 2013). They co-evolve from the interactions between a diversity of cultural, economic, institutional and technological aspects that comprise the **social system**, being still influenced by (and in some aspects influencing) the dynamics of the **ecological system** (e.g. biodiversity, soils, climate) (Lamarque et al. 2014; Bennett et al. 2015; Darnhofer 2015). These areas are composed of different organizational levels, with specific actors and human agency associated with each of these levels (Preston et al. 2015), as well as different ecological aspects (Duru and Therond 2015). It is therefore fundamental to understand the different levels and the actors operating at each level to comprehend their interactions with ecological aspects in order to co-produce and use ES (Preston et al. 2015).

3.1. A multi-actor perspective

The structure and composition of the set of stakeholders (individuals and organizations) at the different levels in rural areas are generally complex (Darnhofer 2015). There exist a set of actors (e.g. policymakers, farmers, scientists, representatives of NGOs) each with a given activity (e.g. promoting public policies, disseminating knowledge, supplying inputs for agriculture, producing and consuming goods) (Barreteau et al. 2010; Lamarque et al. 2011b; Spangenberg et al. 2015) that contributes to the functioning of these spaces. In this sense, Spangenberg et al. (2015) note that participation of these different actors is important to the whole process (i.e. cognitive and physical phases) of co-production of ES:

> *"It is important to realize that stakeholders and governance issues (like formal and informal institutions) are not only relevant in lower parts of the cascade where benefits or values are addressed but also in the upper section where use values are defined and service potentials are mobilized"(Spangenberg et al. 2015, p. 2).*

The formal and informal conventions of the social system in rural areas, broadly defined as "institutions," constitute the "arrangements that people design to regulate their interactions with ecosystems" (Berbés-Blázquez et al. 2016). They facilitate or hinder the "governance" of these spaces, understood as the "process of decision-making and the process by which these decisions are being implemented" (Spangenberg et al. 2015), providing unique characteristics for each of these SES (Bennett et al. 2015). Cognitive aspects, such as preferences, values and knowledge, underpin the formation of the formal and in particular informal conventions that constitute the institutions "governing" ecosystem management in rural areas (Bennett et al. 2015; Spangenberg et al. 2015). As shown in Figure 2, such cognitive aspects are also behind the process of social construction of ES, which will steer decision-making about which services are likely to be mobilized for generating well-being (Spangenberg et al. 2014b).

Despite the existence of some studies that have tried to investigate cognitive aspects pertaining to ES, mainly concerning farmers (e.g. Lamarque et al. 2014; Bernués et al. 2016; Teixeira et al. 2018), little knowledge exists about the diversity of stakeholders concerned by the process of co-production of ES and their perceptions, value systems and expectations from these services (Díaz et al. 2015; Spangenberg et al. 2015). Without this knowledge, the understanding of how "institutions" (i.e. the social system) can interact with ecological systems for the governance of ES is limited, as we will be unaware of what variations in the provision of these services will affect the users' expectations and, consequently, their well-being (Haines-Young and Potschin 2010; Bennett et al. 2015). It is thus imperative to consider such aspects for a better understanding of ES governance in rural areas.

Furthermore, it is necessary to investigate potential social conflicts and inequalities at the different levels at which each actor will act (Bennett et al. 2015) since the interactions between the actors and their capacity to act are highly variable in different contexts of ES management. As Berbés-Blázquez et al. (2016) note:

> *"Decisions pertaining to the use of ecosystem services do not happen in a vacuum but are influenced by relationships between social groups that are positioned differently with respect to their ability to influence the behavior of other social groups, and consequently the outcomes of ecosystem management, for their own benefit" (Berbés-Blázquez et al. 2016, p. 1).*

The knowledge and preferences of local actors about ES are not static and can change behaviors and social arrangements (Miller and Wyborn 2018). Hence, to minimize social asymmetries, Miler and Wilbor (2018), citing Berkes (2009), emphasize the importance of "learning and adaptive governance," described as an "iterative, interactive processes of knowledge production and sharing, planning, and action." According to these authors, this process may "produce new patterns of governance and redistributions of power."

3.2. A multi-level perspective

The constitution of the institutions and governance of ES in rural areas previously discussed has to be necessarily contextualized with respect to their different levels of organization (Locatelli et al. 2017). Thus, it is imperative to have a multi-level perspective when dealing with these SES. The choice of the most appropriate levels for intervention will be a result of the context of the intended intervention.

Large scales, such as the municipality or rural community, can be approached with concepts such as territory and landscape, which are often used interchangeably but can be distinguished by some fundamental elements. The concept of **territory**, "socially constructed space where actors interact" (Brunet et al. 1993), is most often appropriated to understand aspects of governance, which may include governance of ES, and of the structure and composition of the set of local actors (Caron 2017). **Landscape**, a concept more used by ecologists mainly when investigating the "interactions between species and ecosystems," is important, in principle, to study the ecological composition and structure of large areas (i.e. landscape matrix) that determine provision of certain ES (e.g. pest and disease control)

(Tscharntke et al. 2005; Landis 2017). That said, a diversity of ecological interactions is considered in the territorial approach, while in the landscape approach, the role of human interventions is also considered. The term used will finally depend on the discipline or on the objective of the research[11] (Caron 2017).

Smaller scales are also fundamentally important and need to be considered. The **farm**, as the management level at which farmers directly intervene, represents the main level of decision-making as far as the technological standards to be implemented are concerned, based on the different possible resources to be mobilized (Laurent et al. 2003). The **plot**, which represents the main production unit, is the level at which agricultural practices are implemented, and at which technical and agronomic interventions take place (Papy 2001). Even though farmers represent the main actors operating at the farm and plot levels, the farming activity is spatially embedded and thus affected by the expression of the socio-ecological conditions at the large scales (Bourgeois 1983; Darnhofer 2015) that usually support the dominant forms of agricultural production in rural areas (Duru and Therond 2015). However, the precise mechanism through which interaction occurs at these levels in order to determine agricultural activity on these spaces remains inadequately addressed (Lamarque et al. 2011b; Ruckelshaus et al. 2015), especially with regards to land-use management in order to provide ES (Bennett et al. 2015).

Given these multi-actor and multi-level aspects of rural areas, as well as the complexity of the relationships that exist between human agency and nature at each level, we assume that an SES-based approach is imperative for an improved comprehension of these spaces (Reyers et al. 2013). The notion of **agroecosystem**, broadly used to describe agricultural activities practiced by groups of people in small areas, is a promising SES framework to investigate aspects of co-production of ES and to incorporate and link elements at different levels in rural areas (Altieri 2002; Tibi and Therond 2018; Preston et al 2015). The agroecosystem can be conceptualized in different ways but, in line with some authors such as Altieri et al. (1999) and Gliessman (2001), we consider it to be an agricultural ecosystem whose boundaries normally coincide with those at the farm level. These authors assume for this statement that, in a same space (a rural community, for example), each farm will

[11] As described in Caron (2017), this discussion is weaker in the English language, where the term "landscape" is accorded priority and encompasses several elements of the territorial approach.

differentiate itself from the others in socio-economic and ecological aspects, thus resulting in "specific agricultural systems," which are also linked in different degrees to aspects of the environment that surrounds it. In the following section, we further discuss the relationship between the concept of co-production of ES and of the agroecosystem, and how these concepts correlate with the different levels in rural area.

3.3. Bridging the gap between different concepts of ES to understand agroecosystem management

Agricultural ecosystems, or agroecosystems, are a result of human intervention on ecosystems to produce food, fibers, and other raw materials that, when done in conventional ways, normally generate a detrimental change in the expression of basic functions (structures and processes) necessary for their proper functioning (Altieri et al. 1999). These changes undermine desirable ecological characteristics of these spaces, such as nutrient cycling and natural pest and disease control (Table 2).

Table 2. Main characteristics of agroecosystems and natural ecosystems. From Altieri et al. (1999), p. 108.

Structural and functional differences between agroecosystems and natural ecosystems.		
Characteristics	**Agroecosystems**	**Natural ecosystems**
Net productivity	High	Medium
Trophic chains	Simple, Linear	Complex
Species diversity	Low	High
Genetic diversity	Low	High
Mineral cycles	Open	Closed
Stability (resilience)	Low	High
Entropy	High	Low
Human control	Definite	Not needed
Temporal permanence	Short	Long
Habitat heterogeneity	Simple	Complex
Phenology	Synchronized	Seasonal
Maturity	Immature, early successional	Mature, climax

Agroecosystems are composed of two intertwined subsystems. The ***biophysical part*** comprises the interactions of biotic components (e.g. crops, weeds, pests and natural enemies) and abiotic components (e.g. temperature, soil nutrients, water levels) existing in the environment. The ***socio-economic part*** consists of the people (farmers) who manage and intervene in the biophysical subsystem and the means (e.g. knowledge, workforce, machines, inputs) they mobilize to support the production process (Figure 3) (Altieri 2002; Van der Ploeg, 2008; Tibi and Therond 2018).

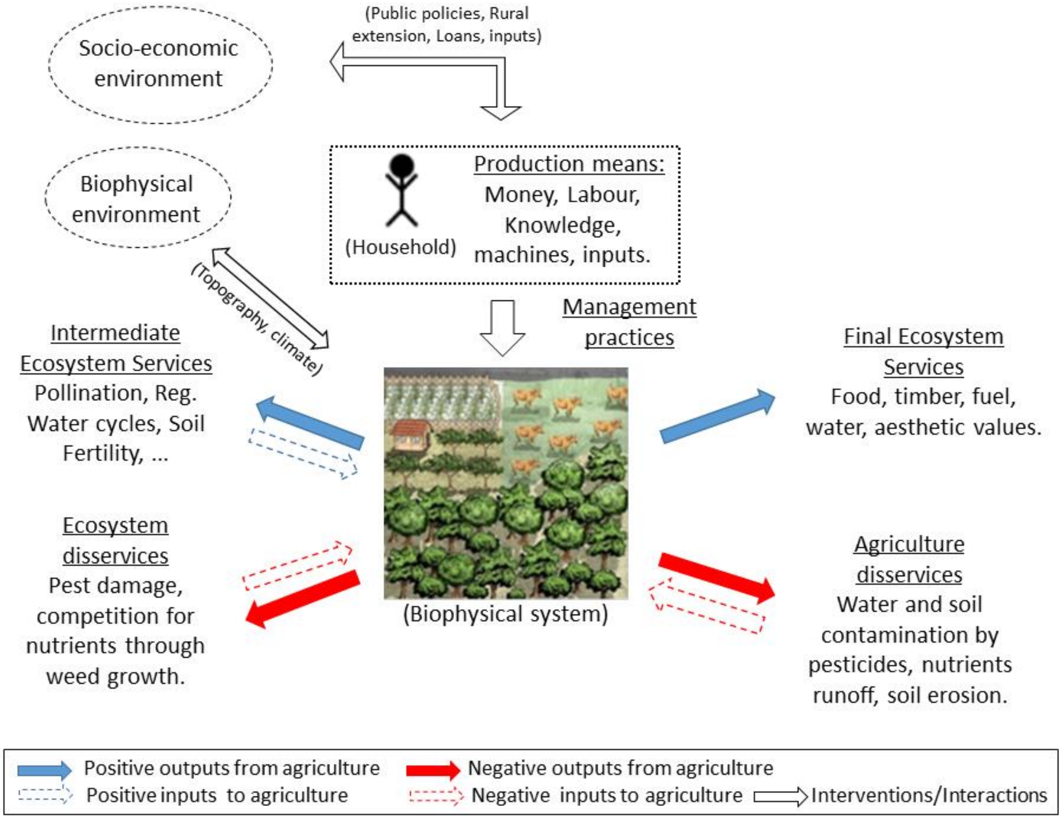

Figure 3. Simplified representation of an agroecosystem. By the author, based on Tibi and Therond, 2017 and Zhang et al. 2007.

Many of the public policies, projects and actions implemented in rural areas focus on the agroecosystem (Silva and Martins 2009), linking farmers (i.e. socio-economic subsystem) with the socio-economic aspects of the environment. Access to these elements, however, will vary between farmers for various reasons such as networking, interest in participation or information about these initiatives (Altieri 2002; Toledo and Barrera-Bassols 2008; Van der Ploeg 2008). The availability of biophysical factors (e.g. water, fertile soils, topography) will also differ between agroecosystems due, in particular, to the location of units, which will depend on the possibilities the farmer has to access better lands (Altieri 2002; Zhang et al. 2007).

- *ES (and disservices) in agroecosystems*

As shown in Figure 3, a diversity of ES is co-produced in agroecosystems (Zhang et al. 2007; Power 2010) as a result of land use management and the influence of the biophysical environment (Zhang et al. 2007; Duru and Therond 2015). ES directly enjoyed (such as provisioning and some cultural services) are called final services and those that have a mediating function in generating final services (e.g. soil fertility, pollination) are called intermediate services (Boyd and Banzhaf 2007). The sub-group of intermediate services that support crop yield in agroecosystems is called "input services" (Le Roux et al. 2008).

A number of disservices are also associated with the functioning of agroecosystems (Zhang et al. 2007). These can be understood as: (a) **the negative effects of biodiversity or of certain ecosystem processes for humans**, usually a reduction in productivity or an increase in production costs (e.g. pest damage, competition for nutrients through weed growth); (b) **the negative impacts of human activities on the environment**, normally arising from an implementation of harmful management practices (e.g. environmental contamination through the use of chemical inputs), called "agriculture disservices" (Tibi and Therond 2018). Although the latter are more intrinsically linked to the type of management practices implemented by farmers, management practices can also result in the expression of the first type of disservices (Duru and Therond 2015).

- *Who benefits from co-production of ES in agroecosystems?*

Farmers and society as a whole are beneficiaries of ES (Tibi and Therond 2018). Farmers can benefit directly through the consumption or marketing of products (in the case of final services) or, as noted above, indirectly from a range of regulation and supporting services. Final services, whose benefits are more evident, are in general the services that are primarily expected from these units (Tibi and Therond 2018). Despite their importance, intermediate services are often overlooked due to a variety of factors such as trade-offs, workload, and lack of knowledge (Lewan and Söderqvist 2002; Spangenberg et al. 2014b). Society as a whole can also benefit from ES through the quantity of products purchased (in the case of goods) or indirectly through a better environment (e.g. climate regulation, forest conservation, clean water supply) resulting from the adoption of beneficial practices by farmers, which also contribute to product quality. Ecosystem disservices are, in turn, mainly harmful to farmers and, in the case of "agricultural disservices," they are also harmful to society as a whole.

The focus on the outcomes (i.e. benefits) that ES provide to people means the inputs required to deliver these services are often overlooked, especially the human labor employed in the ES co-production (Berbés-Blázquez et al. 2016; Palomo et al. 2016). This is a significant observation, especially as concerns agricultural areas where most (if not all) services are in fact co-produced by farmers and nature (Méral and Pesche 2016). In these cases, even though ES benefit farmers and society (in different ways), the cost of co-producing them is normally borne by farmers. This aspect mirrors the discussion about **equity** in the co-production of ES (see section 1.2.2). The scheme described in Figure 2 is useful in this respect, as it proposes a complete framework for a sustainable management of the agroecosystem, starting from the identification of the desired benefits (i.e. demand side driven approach), the management measures necessary to co-produce ES to generate such benefits, and the environmental and socio-economic costs (Spangenberg et al. 2014b).

Fostering and enhancing the provision of ES in agroecosystems is indeed challenging (Griffon 2009). Consequently, farmers in many cases engage in the use of chemical inputs rather than biodiversity management as a way of obtaining bigger harvests quickly, even if this may lead to a reduction in long-term productivity or a loss in the quality of the goods produced:

> *"Modern agricultural land-use practices may be trading short-term increases in food production for long-term losses in ecosystem services, including many that are important to agriculture" (Fisher 2005 in Therond 2017, p. 1).*

Any effort to develop realistic alternatives for the transition to forms of agriculture based on ES, or the maintenance of farmers who still practice these forms of agriculture, must necessarily contend with this set of factors at the local level (FAO 2015; Therond et al. 2017). Building on the conceptual frameworks proposed by Gliessman (2014) and Therond et al. (2017), we now propose a description of the different stages of an agroecological transition analyzed at the level of the agroecosystem.

- *Classification of agroecosystems and transition between agricultural models*

The classification of farming systems (Figure 4) proposed by Therond et al. (2017) is useful in relating the agroecological transition to the changes in the production of ES in agroecosystems. These authors describe three types of farming systems according to the type of management practices adopted: chemical input-based, organic input-based, and biodiversity-based, differentiated by the role accorded to ES and external inputs. This classification is consistent with the first three levels of the agroecological transition proposed by Gliessman (2014). This latter author also describes the steps farmers actually take in moving from chemical input-based to biodiversity-based farming systems (i.e. the agroecological transition), aiming to achieve an agroecosystem design that maintains productivity but incorporating as far as possible the characteristics of natural ecosystems.

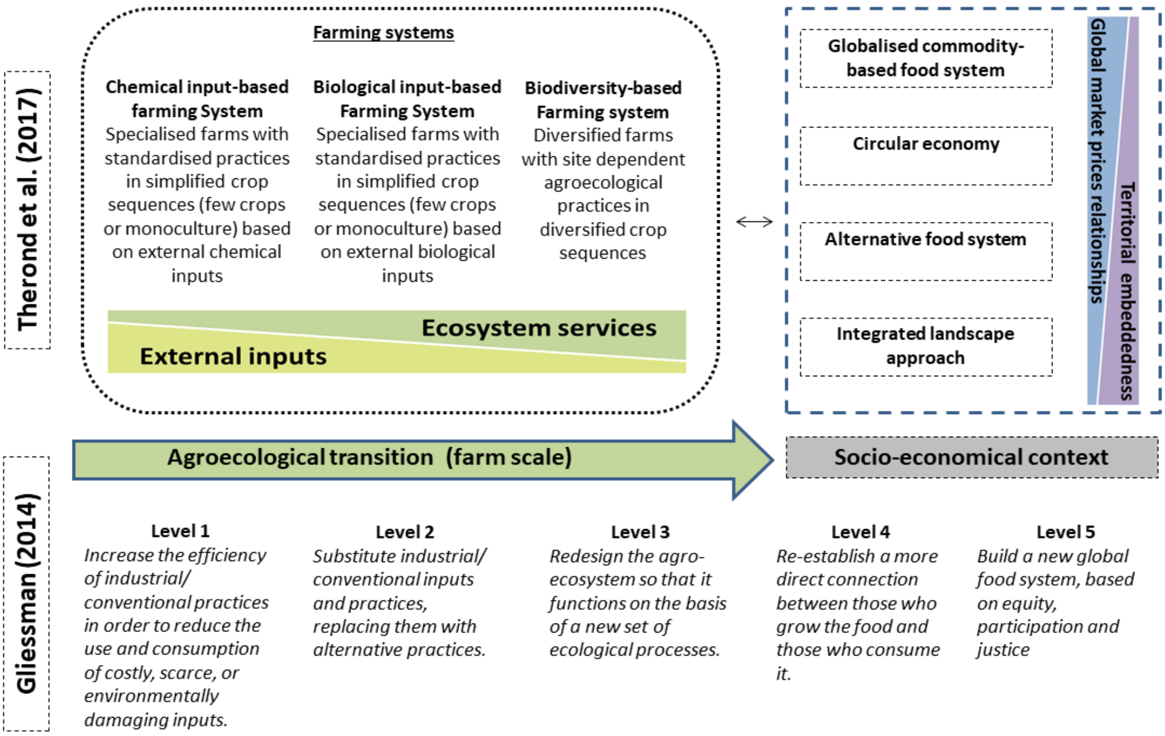

Figure 4. Classification of agroecosystems and the transition between models. By the author, based on Therond et al. (2017) and Gliessman (2014).

The classification scheme and the transition process described in Figure 4 brings to the agroecosystem level the discussion inspired from Figure 1, which describes the different levels of contribution of ecosystem processes and other forms of capital in the co-production of ES. In summary, the scheme presented in Figure 4 also proposes a progressive contribution of natural capital from the lowest to the highest level of transition, replacing the use of chemical and external biological inputs. This could be accompanied, however, by an increase in other forms of social capital, such as knowledge or labor.

The schemes of both Gliessman (2014) and Therond et al. (2017) agree on the importance of the socio-economic context for defining the characteristics of agroecosystems. In this respect, the former author stresses the need for a process of ethical and economic evolutionary change for the entire global food system, intrinsically rooted in local interactions (between farmers and consumers) to achieve the agroecological transition. The latter authors, for their part, describe different socio-economic contexts into which farming systems may be integrated, from relationships based on global market prices to territorial embeddedness. Unlike the process of gradual transition suggested by Gliessman (2014), these authors consider that each type of farming system may be associated with the different socio-economic contexts, resulting in different "agriculture models."[12]

Therond et al. (2017) also recognize that these different agriculture models can coexist at the landscape level (e.g. agroecosystems with different standards in a same municipality) or at the agroecosystem level (i.e. a same agroecosystem associating plots with different standards). Therefore, the conditions (i.e. biophysical and socio-economic **trade-offs, synergies** or **neutral relations**) under which they co-exist should also be investigated:

> *"It is necessary to clarify to what extent and under what conditions co-existence of input-based and biodiversity-based farming systems in the landscape is compatible with the objectives of developing ecosystem services at this level" (Therond et al, 2017, p. 17)*

As far as research on the agroecological transition is concerned, there exist several studies supporting the shift from chemical-based to organic input-based systems (FAO 2015). However, research on developing biodiversity-based agriculture is still scarce (DeLonge et al. 2016; Therond et al. 2017). In this regard, different features of the conceptual framework of the co-production of ES (such as the key issues presented in section 1.2.2) are

[12] In this research, Therond et al. (2017) identify 6 types of agriculture models based on observations of models existing in different parts of the world. However, the authors emphasized that this is a conceptual framework that allows the identification and description of additional models.

singled out by some authors (e.g. Dendoncker et al. 2018) as being promising to clarify some of the key points of the agroecological transition in order to promote biodiversity-based agriculture in different local contexts. However, as Duru and Therond (2015) note, there is a lack of knowledge for this purpose in different disciplines and of adequate methodological tools to better investigate such points. In the following section, we will address different methodological challenges confronting research on ES, correlating with co-production of ES in agricultural areas.

4. Methodological challenges for research on ES

The metaphor of ES brings together a set of human and nature issues, thus research on ES is necessarily a "transdisciplinary" endeavor (Costanza et al. 2014). **Transdisciplinarity**, according to Brandt et al. (2013), is a "research approach that includes multiple scientific disciplines (i.e. interdisciplinarity) focusing on shared problems and the active input of practitioners from outside academia." Hence, in order to give an account of these different issues that form the basis of the debate around ES and to consider the points of view and expectations of the various actors who are involved, from researchers to agroecosystem managers, transdisciplinarity becomes fundamentally necessary (Brandt et al. 2013; Barnaud and Antona 2014; Spangenberg et al. 2015).

Even if different disciplines and methods may stand out depending on the scientific and policy questions at stake and the type of data available, a coherent framework to explore ES issues should be capable of dealing with this complexity (De Groot et al. 2010; Brandt et al. 2013; Mouchet et al. 2014) through:

- The comprehension of the ecological processes that underpin these services (e.g. spatiotemporal dynamics, interaction among services) (Kremen 2005; Zhang et al. 2007; Fisher et al. 2009).
- The understanding of knowledge types, capabilities, rights, value systems, and preferences of societies directly and indirectly related to the management and use of different services (Reyers et al. 2013; Spangenberg et al. 2015).
- The identification of the opportunities and limitations of management interventions in agroecosystems to provide one or more ES and their implications for the provision of targeted (and non-targeted) services today and through time (Bennett et al. 2009).

- The assessment of the relative contribution of nature and other forms of capital (i.e. technology, inputs, labor and knowledge) to the co-production of ES (Costanza et al. 2014; Bennett et al. 2015).

A more specific focus on ES research aimed at implementing biodiversity-based agriculture leads to an emphasis on different disciplines. The contributions of **ecology**, in the form of basic or applied ecology sub-disciplines, are important to characterize links between biodiversity and ecosystem functions and its connection to environmental disturbances (such as those resulting from agriculture) and ES (Cardinale et al. 2012; Duru et al. 2015). **Agronomic studies** are important for the design of diversified systems based on the understanding of the relationship between planned and associated biodiversity in interaction with agricultural practices and of its effects on ES, at the scales of the plot and of the agroecosystem (Zhang et al. 2007; Tibi and Therond 2018). **Social sciences** can contribute with a suitable approach to investigate the farmers' knowledge, both to generate site-specific knowledge of agroecosystem management and to understand their perceptions and expectations about ES and the related socio-economic variables (Faugère et al. 2010). **Geographical studies**, based on territorial or landscape approaches, are necessary to investigate the formal and informal institutions that mediate ES governance, the relationship between local actors in rural spaces and the multifunctional aspects of the diversity of ES to be produced in these spaces (Tscharntke et al. 2005; Caron 2017; Landis 2017). Some recent scientific fields, such as **socio-ecological research** (Collins et al. 2011) and **landscape sustainability science** (Wu 2013), that have emerged specifically aimed at analyzing aspects of human-nature relationships are also important and deserve consideration.

Various challenges exist, however, in conducting research along these lines on biodiversity-based agriculture (Brandt et al. 2013; Duru and Therond 2015), ranging from the difficulty in understanding and predicting the dynamics of agroecosystems (Kremen 2005; Duru et al. 2015) to the lack of understanding of the complexity of human-related issues pertaining to ES (Bennett et al. 2015). Integrating elements originating from these different disciplines represents an additional challenge to overcome (Spangenberg et al. 2015). Since these elements are highly context-dependent (Díaz et al. 2006), the research community has to investigate them in different local contexts, which makes it harder to infer universal rules. According to Duru et al. (2015) and Spangenberg et al. (2015), one of the biggest challenges is to develop an innovative framework capable of: **(a)** initially generating

operational knowledge, which is the "knowledge that specifically supports stakeholder decision-making and consequent actions" (Geertsema et al. 2016), on aspects related to biodiversity-based agriculture; and then **(b)** translating this knowledge into **operational tools**, accessible to a diversity of stakeholders, especially managers of agroecosystems, who are directly in charge of land use.

Even though researchers, farmers and rural extension actors are still poorly equipped with tools that can operationalize the ES concept (Duru et al. 2015), some methodological advances have been made. **Indicators** are methodological tools capable of aggregating and quantifying information about a complex system in order to simplify and render more visible certain processes of interest for the purposes of analysis, thus facilitating the decision-making process (Van Bellen 2005). Indicators have been used in the context of ES, but usually at a landscape scale and in a form that is not very accessible to local actors (Van Oudenhoven et al. 2012). **Multi-criteria analysis** (MCA) approaches are also appropriate for investigating ES provision in rural landscapes (e.g. Schaller et al. 2018), allowing the evaluation of complex land management pathways and their impacts in multiple dimensions, thus going beyond the limitations of ES economic assessments. **Mechanistic simulation models** are "models that include explicit assumptions about underlying mechanisms of a given process" (Wang et al. 2008). Some of these models have been developed for ecosystems. But most of them are designed to simulate nutrient flows between plants-soil-atmosphere systems (e.g. Damour et al. 2014); very few address the management of agroecosystems, mainly due to the complexity of and uncertainty about the variables related to these systems (Duru et al. 2015). **Game-based approaches** use games to support learning and knowledge sharing, thus facilitating decision-making processes in complex systems (Bousquet et al. 2002; Costanza et al. 2014). This type of tool has proven useful in allowing various stakeholders to explore aspects of the relationship between people and nature, including in studies focusing on the ES concept (e.g. Speelman et al. 2014; Lamarque et al. 2014; Verutes and Rosenthal 2014; Moreau et al. 2019). Other methods and tools for undertaking research on socio-ecological systems and on natural resource management in general – some of them suitable for studying ES – are also described in Brandt et al. (2013).

Among this set of efforts, Companion Modeling (Commod) represents an interesting approach to include different local actors in a dialogue (Étienne 2010) and to formalize and make visible the actors' knowledge in order to produce operational knowledge (Faugère et al. 2010). Commod combines the use of simulation models and role-playing games (RPGs) with a set of other methods in order to discuss different points of view and their consequences in terms of action (Bousquet et al. 2002; Voinov and Bousquet 2010). These tools may be useful when combined with empirical evidence originating from different case studies to "advance explanation and theorization of social-ecological phenomena" and build contextualized generalizations or middle-range theories[13] (Schlüter et al. 2019). Commod has been formalized from the numerous experiences of a collective of researchers on the interactions between social and ecological systems (i.e. nature and society) (Étienne 2010), which makes it suitable for use in research on ES (Barnaud et al. 2011).

A consistent work agenda has to be implemented, strongly rooted at the local scale, to overcome the above-mentioned challenges confronting research on ES, as well as on transdisciplinary themes in general, so that this concept can be operationalized in rural spaces (Brandt et al. 2013). The main role of researchers from different disciplines is to design and undertake this process of innovation (Martin 2015; Geertsema et al. 2016), which, however, requires the participation of farmers, as they are the only ones able to faithfully reflect the situation in which they find themselves (Altieri 2004; Duru and Therond 2015). For this to happen, coherent frameworks and tools must be designed, bridging the disconnect that exists between the different prisms through which these different actors view ES (Spangenberg et al. 2015; Barnaud et al. 2018).

5. Conceptual framework and research questions

The concept of co-production of ES, a central pillar on which we rely, provides the theoretical basis for exploring the **different contributions of natural and other forms of capital to the process of identification, generation and use of services**, which is generally observed in agricultural areas. In addition, we seek to explore the **perceptions of stakeholders and, to a lesser extent, the drivers involved in this process**, as well as the impacts of these drivers, especially on the provision of different services and on

[13] "An approach that aims to develop theory situated between a local working hypothesis and general theories that aim to explain all observed instances of a phenomenon" (Schlüter et al. 2019 citing Merton 1949).

agrobiodiversity in general. The scheme proposed in Spangenberg et al. (2014b) therefore represents an appropriate framework to differentiate and link all these elements that form part of the process of co-production of services and which we want to explore.

We consider the **agroecosystem** (herein represented by the farm level) to be our core analytical unit, because the organization of agricultural production units in the context we are analyzing takes place principally at this level. That is, even if there are some efforts at coordination between these units (associations and cooperatives), each agroecosystem represents an independent unit of management and use of natural resources (within the local ecological and social limits), and is therefore associated with specific practices that generate specific results in terms of co-production and use of services. The choice of this analytical unit is not intended to ignore the interrelationships (both social and ecological) established between each agroecosystem and the environment in which it is located. On the contrary, focusing on agroecosystems helps in understanding the flow (input and output) of material elements (i.e. production, inputs) and non-material elements (i.e. information, public policies, market) in each of these spaces, therefore in understanding how social and ecological elements are configured and distributed at large scales. We also consider the **municipality** as a secondary unit of analysis, since a set of contextual factors that influence agroecosystem management originates at this level. The decision to investigate two municipalities with contrasting realities, as we will further explain in the following sections, seeks to explore how local variations in ecological aspects and, in particular, in different institutional arrangements (actors, norms, laws, public policies) affect agroecosystem management.

In this context, the **agroecological transition** frameworks proposed by Gliessman (2014) and Therond et al. (2017) are relevant and can be used in a complementary way to analyze the different land-use management models at the agroecosystem and municipality levels (based on the use of natural capital and other forms of capital, as situated in the theoretical framework of co-production of ES) and the influence of the socio-ecologic environment. The scheme shown in Figure 4 lists the elements that we consider interesting for each of these studies, and that will in part be mobilized throughout this document. Applying these frameworks will also enable us to discuss how these frameworks (conceived in other parts of the world) can be applied in the Amazon, which presents a very specific social and ecological context that we will present in the next chapter.

Thus, the **general question** that we want to ask in this thesis is: How can the conceptual framework of ES serve as a cognitive and operational basis to support the agroecological transition?

For this purpose, we intend to analyze the empirical field data in the light of the elements described above in order to answer more specifically three questions:

(Q1) How do local actors supporting family farmers perceive ES and their co-production process?

(Q2) How do some different factors, internal and external to the agroecosystem, influence the co-production of ES?

(Q3) How to formalize knowledge related to ES co-production and enable stakeholders to discuss it through appropriate methodological tools in order to steer the agroecological transition?

We consider the individual perceptions of local actors as well as the exchange of perceptions between them. In our research, we involved a diversity of local actors relevant to rural issues in each municipality, including family farmers and various types of actors supporting these farmers. Accordingly, we implemented different methods and tools, rooted in companion modeling, with the aim of identifying and exchanging the perceptions (and to a lesser extent the action) of these local actors about the process of co-production of ES. These methodological aspects will be further described in the next chapter.

The answers to these questions are provided in three articles, with each focusing on one question. Some transversal points will then be addressed in Chapter 6, in which we engage in a general discussion. A summary is included at the beginning of each article in order to inform the reader of its key points. Each summary also notes possible redundancies between articles, since each of the articles is meant to be read independently.

Chapter 3 investigates how a diversity of stakeholders supporting smallholders in Paragominas and Irituia municipalities in Brazil perceive ES and agricultural practices. With this study, **we aim to identify which services are emphasized by stakeholders supporting smallholders, some factors influencing the differentiation between these perceptions and how they tie ES to agricultural practices (co-production).** This study resulted in the article: **Antonio Gabriel L. Resque**, Marie-Gabrielle Piketty, Emilie Coudel, Samir Messad, Christophe Le Page. *Co-production of ecosystem services through agricultural practices: perception of stakeholders supporting smallholders in the Brazilian Amazon.* Article accepted for publication on 17 March 2021 in a special issue of the journal *Cahiers Agricultures*, whose theme was agriculture and ES.

Chapter 4 deals with the importance of two institutional food procurement programs in leveraging agrobiodiversity in agroecosystems in the two municipalities under study. It also initiates a discussion on how ES and challenges confronting biodiversification are perceived by the stakeholders responsible for these programs. This enables us to identify **some drivers external to the agroecosystem (most notably the market) that can influence agrobiodiversity**. This study was published in the following article: **Antonio Gabriel L. Resque**, Emilie Coudel, Marie-Gabrielle Piketty, Nathalie Cialdella, Tatiana Sá, William Assis, Marc Piraux and Christophe Le Page. *Agrobiodiversity and public food procurement programs in Brazil: influence of local stakeholders in configuring green mediated markets.* Article published on 7 March 2019 in the journal *Sustainability*.

Chapter 5 proposes a tool (i.e. a co-built Role-Playing Game) to assess how ES are taken into account in the stakeholders' decision-making process concerning agroecosystem management (i.e. cropping systems and agricultural practices). It also assesses the tool's effectiveness for this purpose. We present **the characteristics of the tool, the different factors internal to the agroecosystem (e.g. labor, production costs) that influence land management, as well as the perspectives of stakeholders concerning the agroecological transition in these units**. This study resulted in the article: **Antonio Gabriel L. Resque**, Eva Perrier, Emilie Coudel, Layse Galvão, João Vitor Fontes, Renan Carneiro, Livia Navegantes, Christophe Le Page. *Discussing ecosystem services of management of agroecosystems: a role-playing game in the eastern Brazilian Amazon.* This article was submitted, in February 2020[14], to a special issue of the journal *Agroforestry Systems*

[14] This article is under revision, with a first decision requiring "minor revisions" made on 06 January 2021.

dedicated to publishing a few of the abstracts presented at the Fourth World Congress of Agroforestry (which was the case of this article), that was held in Montpellier, France, in May 2019.

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Chapter 2: Study area and methodological process

In this chapter, we introduce the study area and the methodological process used throughout the thesis. We aim at bringing a global understanding of the research carried out. More specific description on the methodology and details on the study area will be presented in each article.

1. Study area

1.1. Amazon and Northeast Region of the State of Pará

The Amazon biome covers an area of 6,700,000 km^2 located in northern South America, representing a vast and complex region, with very diverse biophysical and socio-economic aspects (Figure 1). This biome comprises nine countries (i.e. Brazil, Bolivia, Peru, Ecuador, Colombia, Venezuela, Guyana, Suriname and French Guiana), with about two thirds of it (i.e. 4,190,000 km^2) within Brazilian territory (Almeida and Ferreira 2015). The legal territorial delimitation of the Brazilian portion of the Amazon[15], named "Amazonia Legal", encompasses nine states of Brazil, 59% of the national territory and 12% of the national population, with about 62% of its surface covered by rainforest (Castro and Campos 2015; Souza et al. 2020).

Among the states that compose the Brazilian Amazon, the State of Pará located in the eastern Amazon is the second largest, comprising nearly half of the Amazonian population (i.e. 6,192,307 inhabitants in 2010, according to IBGE), one third living in rural areas. This state is of major socioeconomic importance for the region as, in addition to being home to the majority of the population, it has the wealthiest economy among those that compose the

[15] The "legal Amazon", a political-administrative concept established by the law 1.806 of 6 January 1953, extends over an area of 5,200,000 km2 and delimits the region legally recognized as Amazonia in Brazilian territory and which is subject to specific legislation and public policies, in comparison with the rest of the country. It encompasses, besides the Amazonian biome, some areas of transition to the cerrado and pantanal.

legal Amazon[16]. However, these economic results do not translate effectively into social benefits, with widespread low levels of human development rates (Costa 2012). The state is also strategic in environmental terms because of its territorial extension and its location that favor integration with the rest of the country, although this generates increased pressure on its natural resources, notably the forest (Castro and Campos 2015).

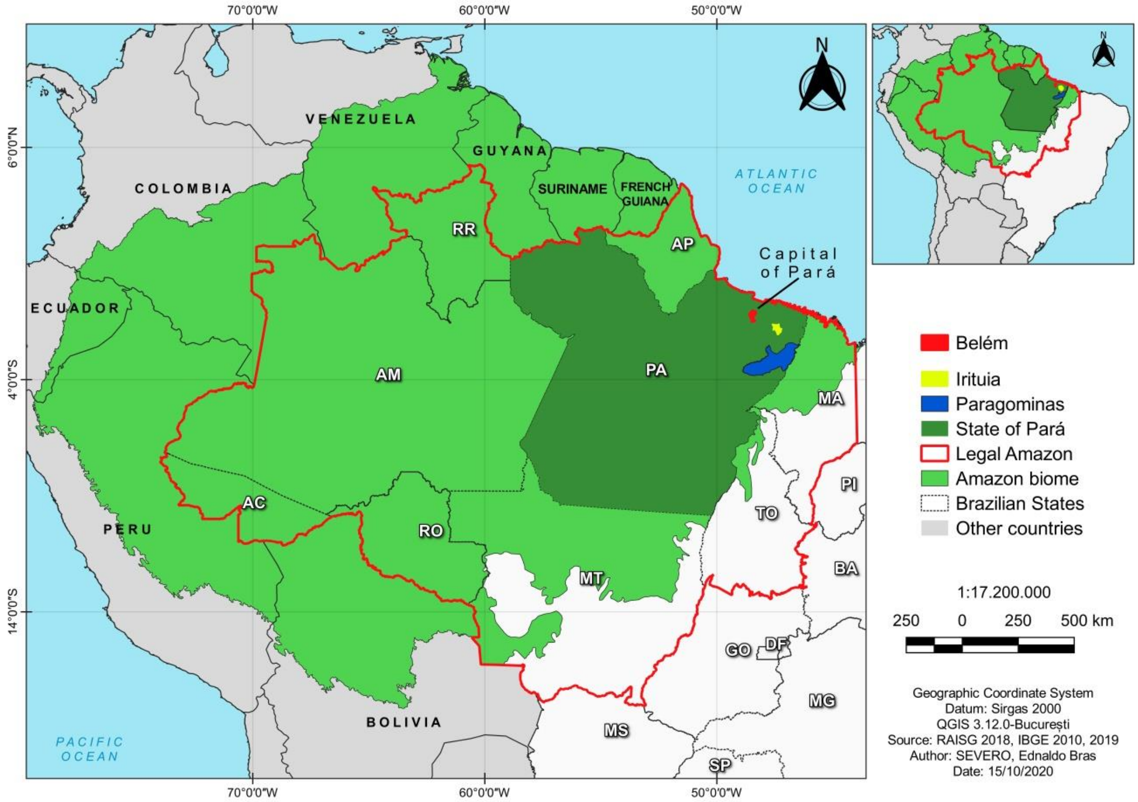

Figure 1. Location of the study area within the Amazon Biome and Brazilian Legal Amazon.

This research was conducted in the Northeast region of the state of Pará, which is one of the oldest areas of colonization in the Amazon, composed of a complex mosaic of cultures that have formed resulting from different cycles of settlement (CODETER 2006). This colonization process intensified and altered its dynamics in the 1960s in response to migration flows resulting from governmental incentives[17]. These incentives aimed at integrating the Amazon region within the economic and institutional modernization policy

[16] The state of Pará accounted for 25% of the GDP generated in the "Legal Amazon" in 2019. In the composition of Pará's GDP, 15% comes from agriculture (including large-scale agriculture and family farmers).

[17] This process began in Amazonia in the 1960s, with more amplitude in the 1970s with the "National Development Plans" promoted by the national government, which at the time was commanded by the military (Castro and Campos 2015).

prevailing in the country at that time (Castro and Campos 2015). This led to **(a)** reconfiguring the economic activities developed locally, **(b)** increasing the population, and **(c)** creating new municipalities (Paragominas, for example, founded in 1965). Agriculture represented one of the pillars of this process, being transformed through the precarious and incomplete incorporation of elements of the green revolution (Costa 2012). Integration in markets mainly occurred through timber extraction and extensive livestock farming, resulting in uncontrolled exploitation of natural resources, especially the forest. At the same time, a mass of smallholders arrived in the region, joining those who already lived there, primarily practicing itinerant slash-and-burn agriculture (Hébette 2004; Almeida et al. 2016; Souza et al. 2020).

Nowadays, the land use structure of northeast of Pará features a complex arrangement of large-scale and smallholder farms with distinct rationalities and technological production patterns[18]. Smallholders, in this context, produce more biodiverse landscapes, compared to larger units, usually more dependent on mechanical-chemical inputs (Pokorny et al. 2013). Large properties represent, however, the largest portion of land use in the region, being responsible for most environmental damage (Costa 2012; Souza et al. 2020). Conversely, although smallholder agriculture covers less surface than large properties, it represents the largest number of producers, hence their socio-productive importance (IBGE 2017).

This model of agriculture implemented in northeast Pará, as well as in many regions of the Amazon, has not yet rendered effective improvements regarding the environmental, social and economic dimensions of development (Homma 2005; Costa 2012). In addition to the various environmental impacts (Fearnside 1997; Pokorny et al. 2013), its economic results are restricted to certain groups (Costa 2012), and the large mass of rural population is exposed to diverse social problems (Costa 2016; Resque and Silva 2017), which leads to an intense process of rural exodus (Alves and Marra 2009). Nonetheless, amid this general scenario, a series of initiatives related to the agroecology paradigm have been emerging, conducted by entities of different natures and scales (Box 1).

[18] A more precise description of land arrangement in the municipalities of Paragominas and Irituia is presented in Chapter 4.

BOX 1: Institutional context of agroecological initiatives in the study site

In 2012, the Brazilian government defined and implemented a National Policy for Agroecology and Organic Production (Política Nacional de Agroecologia e Produção Orgânica, PNAPO) to improve coordination among institutions, centralizing different existing programs and policies to promote agroecosystem sustainability (Schmitt et al. 2017). This groundbreaking policy was the first in the world to promote agroecological transition at the state level, bringing together technical support and price and market support (Brasil 2012). Independent of this national policy, a series of other initiatives have emerged in recent years in Brazil, being conducted by state and municipal governments, or by non-governmental initiatives.

Two programs that were integrated into PNAPO have drawn scholars' attention due to their potential to drive agroecological transition (Miccolis et al. 2011; Hespanhol 2013): the **National School Meal Program** (Programa Nacional de Alimentação Escolar, PNAE) and the **Food Procurement Program** (Programa de Aquisição de Alimentos, PAA). Both programs purchase products from local smallholders and made them available to social and educational institutions.

PNAPO also encouraged rural extension services provided to farmers to be adapted according to the principles of agroecology. A series of public calls were undertaken with the objective of contracting more agroecological extension agencies to act in rural communities, as was the case of **COODERSUS** in Irituia.

It is also worth mentioning the creation of **Agroecology Study Groups** (Nucleos de Estudos em Agroecologia, NEAs), which are structures created mainly in universities and research centers with the objective of integrating these entities, with other rural actors (technicians, farmers) to discuss agroeocology. In Paragominas, UFRA created one of these groups to carry out different actions in the whole region.

At the state level, we highlight the "**Tijolo verde**" and "**Pará Florestal**" programs, conducted by state agency IDEFLOR-Bio, in Irituia and Paragominas respectively. These programs sought to introduce agroforestry systems and community seedlings nurseries in rural communities for the production of food, timber and firewood.

Within northeast Pará, we selected two municipalities, Paragominas and Irituia, for empirical field research. These municipalities were formed through distinct processes, resulting in strong differences in the socio-productive, cultural and institutional dimensions. These differences reflect, in terms of agriculture, different pathways of development, where: **(a)** in Paragominas, industrial agriculture predominates, with some initiatives of efficiency-based ecological modernization, and **(b)** in Irituia, smallholder agriculture is widespread, with growing biodiversity-based initiatives. We chose these municipalities with the strategy of comparing co-production of ecosystem services and agroecological transition between two contrasted realities, nevertheless representative of those that exist in the region.

When we started our field research, another thesis had started in Paragominas related to the STRADIV project. It focused on annual crop systems, from a more agronomic perspective. We sought to complement, through a socio-ecological approach, these agronomic results. The motivation to choose Irituia as a second study site stemmed from the need to seek a municipality with more innovations in terms of agroecology. The actions of the REFLORAMAZ project later focused in this municipality, as to integrate to my own thesis work. The fact that I work as a lecturer at the Amazonian Rural University (UFRA) in Paragominas (with actions also carried out in Irituia), having previous knowledge about these local contexts, also reinforced the choice of these locations.

1.2. Paragominas: an agricultural frontier municipality that operated a transition to a green municipality

Paragominas is a recent municipality, established in the 1960s as part of the intentional colonization of the Brazilian Amazon, when migrations intensified and the agricultural frontier expanded. The municipality is located at 2° 59' 42" south and 47° 21' 10" west, covering an area of 19,395 km² (i.e. which is equivalent to the size of a country like Belgium). Today, the municipality has a population of 111,764 inhabitants, features an urban center, which concentrates 78% of the population and is surrounded by a large rural area (IBGE 2017). This rural area is composed mainly of agricultural areas, mostly large properties but also a few smallholder communities (IBGE 2017; Hasan 2019).

Since its foundation, land use and land cover (LULC) has drastically changed in the municipality, initially from timber exploitation coupled with extensive livestock farming, partially replaced in recent decades by the large-scale production of grains (i.e. soybean and corn) with intensive use of chemical inputs, and less interesting zones were settled through agrarian reform by smallholders (Piketty et al. 2015; Hasan 2019). As a consequence, by 2008, 45% of the primary forest areas of the municipality had been converted to agricultural areas (Brito 2020). This intense deforestation process led the municipality to be blacklisted in 2008 as part of the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (Plano de Ação para Prevenção e Controle do Desmatamento na Amazônia Legal, PPCDAm). Paragominas, however, became the first municipality to leave the list after establishing a "Green Municipality Pact" with social stakeholders to stop deforestation (Viana et al. 2016). In this period, the stakeholders of the municipality initiated a debate regarding economic valuation and remuneration of environmental services related to forest maintenance. However, due to the fragility of markets for Payment for Environmental Services (Coudel et al. 2015), discussions remained inconclusive.

Since then, new practices have been introduced and promoted for large-scale agriculture, such as forest management, the intensification of livestock and plant production, and the restoration of permanent protection areas (Piketty et al. 2015; Hasan 2019). However, challenges persist in the municipality to promote a land-use transition based on intensification, reforestation or restoration of already deforested areas, mainly due to the high investments required and the inadequacy of soil types to develop agriculture in such areas (Piketty et al. 2015).

Family farming, comprising rural communities and agrarian reform areas, accounts for about 1,150 farms, which represent approximately 80% of the total number of rural properties, but only 17% of the agricultural land (IBGE 2017). These farms are threatened by environmental problems, primarily related to fire and deforestation (Piketty et al. 2015; Ballon et al. 2016). Possible solutions (e.g. mechanization to clean the plot without the use of fire; techniques for managing soil fertility) benefit only a small number of farmers who have more contact with agricultural support institutions (Viana et al. 2016). In general, family farming has not actively participated in the dynamics surrounding the creation and implementation of the "green municipality program", which was more related to large scale agriculture (Piraux et al. 2020; Piketty et al. 2015). There is, however, a diversity of actions dedicated to this type of agriculture being conducted in the municipality by different actors, which will be more detailed in chapter 4.

1.3. Irituia: A traditional municipality of ancient colonization

The colonization process of Irituia, which dates back to the end of the 19th century, is quite different from that observed in Paragominas, featuring a predominance of subsistence family farming (Leandro and Silva 2013). This municipality covers an area of 1,379 km², being located at 1° 46' 28" south and 47° 26' 29" west. Its population comprises 32,504 inhabitants, 76% living in rural areas. To this day, family farms are prevalent in Irituia, representing 98% of all properties and 56% of agricultural land (IBGE 2017).

Family farming in Irituia is recognized for the maintenance of traditional practices, particularly when compared to those practiced in neighboring municipalities, which underwent a process of incorporation of elements from industrial agriculture and monoculture cultivation, encouraged by the market (e.g. citriculture in “Capitão Poço”) (Costa 2012). Notwithstanding, deforestation related to family agriculture also persists here, as in other municipalities in the region, driven mainly by slash-and-burn practices coupled with a high population density, long-term colonization and scarcity of broadly available alternatives (Mattos et al. 2010; Almeida and Ferreira 2015). As a result, in 2011 remaining primary forest represented 10% of areas, not counting however secondary forests which are important in shifting agricultural landscapes (Almeida 2019). In recent decades, interesting processes of plant and animal diversity management have been initiated (Oliveira and Kato 2009), building on traditional practices (Costa 2012). These processes, mostly related to the cultivation of agroforestry systems, were encouraged by a diversity of recent initiatives conducted in the municipality to promote the biodiversification of agriculture, described with more details in chapter 4.

In this municipality, the concept of ecosystem services (ES) was introduced in the early 2000s through a pioneer federal program inspired by Payments for Environmental Services (i.e. PROAMBIENTE), which involved a diversity of local actors related to family farming (e.g. public managers, extension agents, researchers, trade unions, and social movements) (Mattos 2010). The objective of the program was to encourage (and remunerate) sustainable management of the landscape and rural establishments, so as to increase the provision of services (e.g. reduction of deforestation and fire use, protection of riparian forests, and adoption of biodiverse culture systems). The program was however extinguished, mainly due to financial restrictions that could not anymore guarantee remuneration to farmers (Coudel et al. 2015). Nevertheless, many of the farmers who participated in PROAMBIENTE still remain active, some of them participating in the initiatives occurring in the municipality related to agrobiodiversity, playing a key role in promoting this type of agriculture.

2. Methodologies applied and actors involved

A combination of different tools was used in this thesis to carry out the investigation of our research questions, inspired by the Companion Modeling approach (Étienne 2014). Different actors were involved in the study, among which farmers and representatives of different types of institutions related to the rural agenda in both municipalities. These actors took part in the research process at different moments and with different degrees of intensity (Figure 2). Direct participation of local actors (with greater intensity) occurred through semi-directive interviews (i.e. stakeholders) and questionnaires administrated during field visits (i.e. farmers) as well as during the co-production process of the game or the game sessions. Other actors have indirectly participated in the research by providing information through informal conversations or during participant observation.

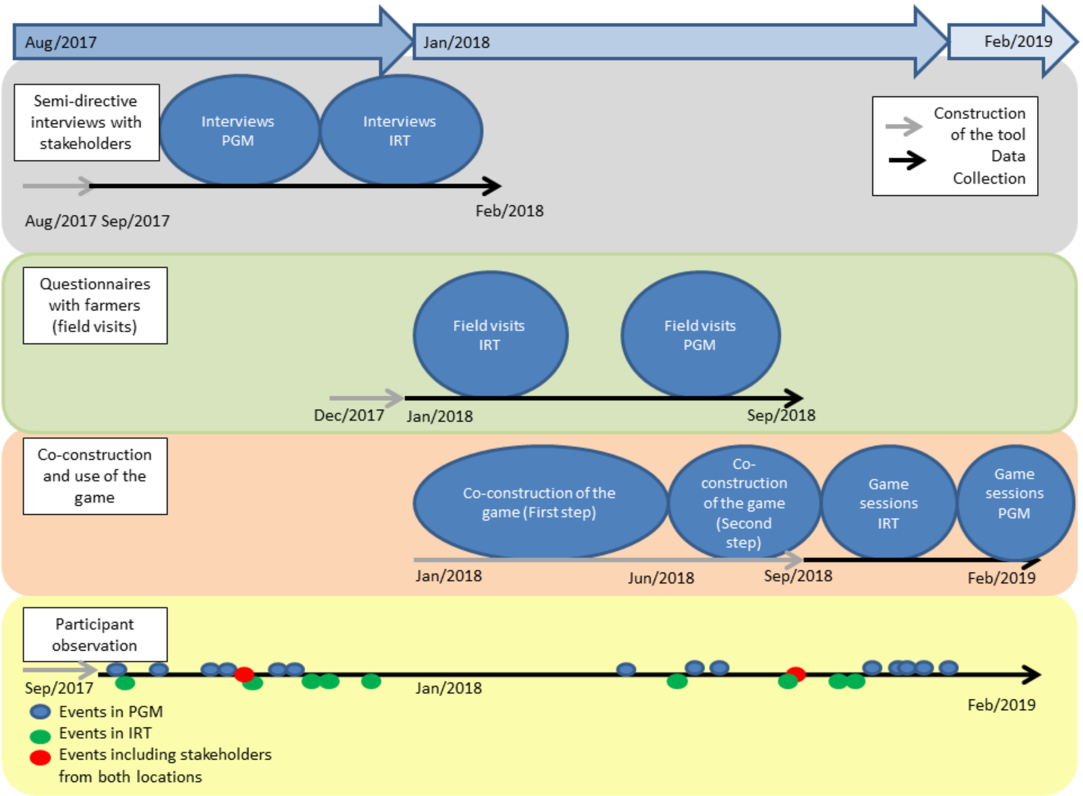

Figure 2. Field research stages.

The selection of participants varied according to the different methods used and the different objectives pursued by each method in terms of the type of knowledge to be generated (Table 1), as suggested by Faugère et al. (2010).

Table 1. Methodological tools, participants and expected outcomes from each of the tools.

Methodological tools	Participants	Objective
Semi-structured interviews	Diversity of stakeholders concerned with rural issues	Gathering perceptions of stakeholders about ES related issues (i.e. contextual factors, management practices)
		Co-producing knowledge about ES related issues (i.e. contextual factors, management practices)
Co-construction of the game	Technical, scientific and empirical experts	Co-producing knowledge about different processes underlying the functioning of agroecosystems
Game sessions	Diversity of stakeholders and farmers concerned with rural issues	Gathering perception of stakeholders about ES related issues (i.e. at agroecosystem scale)
		Co-producing knowledge about ES related issues (i.e. at agroecosystem scale)
Questionnaires with farmers (field visits)	Diversity of farmers	Co-producing knowledge about different processes underlying the functioning of agroecosystems
Participant observation	General	Exploratory research to design further field steps and better understand information obtained from other methods.

A more detailed description of these different stages of data collection and of the stakeholders mobilized in each of these stages is presented below.

2.1. Semi-directive interviews

The semi-directive interviews with entities involved in rural issues were conducted between October 2017 and February 2018. Initially, a first set of interviews was conducted with the actors of Paragominas, and then extended to those of Irituia. The main objective of this stage of the research was to investigate the perceptions of participants about the process of co-production of ES and to investigate the contextual factors that exist in each place that can affect this process. Thus, we selected respondents to represent a diversity of local entities which might potentially affect the co-production of ES, not necessarily those recognized as "experts" in ES-related issues.

The choice of these respondents (Table 2) was mostly based on our knowledge of the study area. We took as a starting point the set of stakeholders surrounding the mediated markets (i.e. PAA and PNAE) implemented in the two municipalities. Instigated by the STRADIV project, we aimed to pinpoint the existing arenas in the region to discuss agrobiodiversity. We identified these two programs as potentially interesting to gather a diversity of actors to discuss agrobiodiversity. Based on the results of these initial interviews and field observations, we used a snowball method (Vinuto 2014) to identify other entities and actors of interest for our theme. We thus returned to each municipality to conduct further interviews. As a result, we reached a total of 24 entities (11 in Paragominas and 13 in Irituia), interviewing at least one key stakeholder per entity, for a total of 30 interviewees, comprising 15 in Paragominas and 15 in Irituia. We interviewed the main representatives of each entity, taking into account their role in decision-making. In some cases, more than one representative per entity was interviewed, according to its importance in the context. A more detailed description of this set of stakeholders is included in chapters 3 and 4.

Table 2. Entities involved in Paragominas and Irituia.

Municipality	Entity (Brazilian acronym)	Type of entity	N°
Paragominas	Municipal Department of Agriculture (SEMAGRI)	Local government	2
	Municipal Department of Environment (SEMMA)	Local government	1
	Municipal Department of Education* (SEMED)	Local government	1
	Technical Assistance and Rural Extension Agency (EMATER)	Public extension agency	1
	National Service for Rural Apprenticeship (SENAR)	Civil society	1
	Forestry Develop. Inst. of the state of Pará (IDEFLOR)	Local government	1
	Federal Rural University of the Amazon (UFRA)	University	1
	Brazilian Agricultural Research Corporation (EMBRAPA)	Public research agency	1
	Institute of People and the Envir.onment of the Amazon (IMAZON)	Civil society	1
	Union of Rural Workers (STTR)	Civil society	4
	Cooperative of Smallholders of Uraim and Rural District of Paragominas (COOPERURAIM)	Family-farmer cooperative	1
Irituia	Municipal Department of Agriculture (SEMAGRI)	Local government	1
	Municipal Department of Environment (SEMMA)	Local government	1
	Municipal Department of Social Development* (SEPROS)	Local government	2
	Municipal Department of Education* (SEMED)	Local government	2
	Technical Assistance and Rural Extension Agency (EMATER)	Public rural extension agency	1
	Cooperative for Sustainable Rural Develop. Services (COODERSUS)	Private rural extension agency	1
	National Service for Rural Apprenticeship (SENAR)	Civil society	1
	Forestry Development Institute of Pará (IDEFLOR)	Local government	1
	Brazilian Agricultural Research Corporation (EMBRAPA)	Public research agency	1
	Federal Rural University of the Amazon (UFRA)	University	1
	Union of Rural Workers (STTR)	Civil society	1
	Agriculture, Livestock and Extractivist Cooperative of Irituia (COAPEMI)	Family-farmer cooperative	1
	Agriculture Cooperative of Family Farmers of Irituia (D'IRITUIA)	Family-farmer cooperative	1

Note: N: Number of interviewees per entity. * Entities in charge of the food procurement program.

A prior contact was made with the interviewee, in order to explain the objective of the research and to ask whether the respondent was interested and willing to participate in it. If the answer was positive, a meeting was scheduled for the interview. Only two contacted stakeholders opposed participating, alleging lack of time. The interviews lasted about one hour and usually occurred individually, except in two cases where there were two respondents. We prioritized conducting the interviews in the interviewee's own workplace, in order to make him/her more comfortable to answer the questions. All the interviews were recorded, except one by objection of the respondent. In this case, I took detailed notes.

The semi-directive interview guide used for interviews with stakeholders was structured around personal and institutional issues, the relationship between biodiversity and agriculture, and the stakeholder's knowledge and perception about ecosystem services (Appendix 1). The objective was to analyze the perception of ecosystem services co-production in local agroecosystems and of the benefits obtained from these services. Questions about ecosystem services were intentionally placed at the end of the interview to explore if this concept emerged spontaneously during the interview (Moreau et al. 2019).

2.2. Questionnaires with farmers (field visits)

The field visits were conducted between January and October 2018. We visited sixty family farmers (30 in Paragominas and 30 in Irituia) to observe agrobiodiversity (frequency and diversity of cropping systems), agricultural practices, the role of external intervention of different stakeholders, and perceptions regarding motivations and challenges for adopting biodiverse systems (Figure 3).

Figure 3. Field visits to farmers in Paragominas (A) and Irituia (B).

As was the case with the semi-directive interviews, the field visits aimed at investigating different situations related to the functioning of agroecosystems and co-production of ES. Thus, selection of participants was designed to include the full range of participation level in the local programs related to agroecology (e.g., PAA and PNAE, "Tijolo Verde", "Pará Florestal"), including no participation in any program. We also selected farmers located in different parts of each municipality, to take into account a diversity of conditions (e.g. biophysical aspects, distance from the city center). Although we recognize that a large set of factors can affect the performance of these farms, we tried to control for factors such as property size and labor force availability as much as possible.

The visits lasted two hours on average. First, we applied a questionnaire containing closed and open questions (Appendixes 2.a and 2.b). Then, a walk through the property was carried out in order to obtain more information about the cropping systems and agricultural practices. We asked that the main person responsible for the management of the farm answer the questions. In 80% of the interviews, it was a man (head of family or eldest son), but in some cases, women responded as they were the main responsible, or sometimes, because their husband was absent.

2.3. Co-construction and use of the game

A simulation model was co-constructed with local actors and served as a support for different workshops conducted to observe and discuss actors' perception of ES. The use of this model also served to stimulate discussion and knowledge sharing among actors regarding agroecosystem management and the process of co-production and use of ecosystem services. The co-construction of this tool was part of the expected outcomes of the Refloramaz project. The choice of the municipality of Irituia to start the co-construction process was based, in part, on the observations made during the first stages of the field research of the thesis (i.e. semi-structured interviews and participant observation), aiming to integrate the dynamics initiated by the thesis and the Refloramaz project. The stages of co-construction and use of the model are described below.

2.3.1. Co-construction phase

The co-construction process was structured around various collective key moments (Barreteau et al. 2014), including test sessions of the model, leading to progressive improvements until reaching a usable version. Two distinct stages can be distinguished in this co-construction process.

The **first stage**, supported by a master student of the Refloramaz project, focused primarily on the topic of forest restoration (for further details, see Perrier 2018). Implemented in Irituia, a diversity of local actors were involved in this stage, including **(a)** farmers (and students of a rural school, children of farmers) recognized for their high level of knowledge about cultivation of agroforestry systems and sustainable management of agroecosystems, whose role, in accordance with Geertsema et al. (2016), was to provide empirical knowledge and give legitimacy (i.e. respecting stakeholders' values and their management principles) to the model; **(b)** an interdisciplinary research team working on various themes in Northeast Pará, which helped to determine the parameters of the model, seeking to give credibility (i.e. scientific and technical trustworthiness) to the tool, as stressed by Giller et al. (2009). The hybrid knowledge resulting from this stage of co-construction gave rise to the basis of the model used for this thesis, which contained the general shape of the gameboard, the characteristics of the agroecosystems and crop systems. The inclusion of social, economic and environmental indicators related to the management of agroecosystems also begun at this stage, already considering the adaptation of the tool to investigate aspects of co-production of ES. Four pilot sessions of the game were conducted on the basis of this first model.

In a **second stage**, modifications were brought to the model in order to make it more apt to discuss the theme of ecosystem services. According to the attributes mentioned by Costanza et al. (2014) as necessary for a game that discusses this theme, these modifications aimed at: including natural and non-natural capital; considering the existing trade-offs between ES, and between ES and socioeconomic aspects; and providing a well-defined space-time dimension. All of this was contemplated by the inclusion of agricultural practices (chemical and organic) associated with cultivation systems and related to social, environmental and economic indicators, representing the different types of capital (i.e. human, financial, manufactured capitals in association with natural capital) (Appendix 3). These indicators were also co-constructed based on field information confronted with technical-scientific data and allowed to highlight the different social, economic and environmental trade-offs regarding the adoption of different forms of land management. The ES associated to the different management pathways adopted by the players remained implicit in the model, allowing, as stressed by Costanza et al. (2014), to infer their perceptions and knowledge about which ES are associated to the different management practices and to investigate their consequent choices in terms of management.

2.3.2. Game sessions

Five sessions of the game were held with this final version of the model, with the objective of testing the potential of this tool to understand the different perceptions of local actors about co-production of services and to create a platform to facilitate the discussion of this topic among these actors. Each session lasted about 4 hours and consisted of an introductory interaction, the role playing game (RPG) and a debriefing about the session and also about the tool. The purpose of the introductory interaction was to identify which practices the local actors considered most relevant, and whether these practices are (or not) directly associated with ecosystem services (Figure 4A). The participants were then invited to play the RPG, to deepen and confront their initial ideas with an experimental situation (Figures 4B and C). The session finished with a debriefing, first about the results of the session (i.e. the management practices discussed during the session) and then about the RPG itself (i.e. the participants' perceptions of the tool) (Figure 4D).

Figure 4. (A) Outcome of a group in the introductory dynamics; (B) Local actors playing the game in Irituia; (C) Farmers playing the game in Paragominas; (D) Debriefing.

A first session was held on 31 October 2018 in a community of Irituia, involving farmers. Later, two more sessions were held in Irituia, one on 16 January 2019 involving different local actors and another on 17 January 2019 involving farmers and students from a rural school that participated in the co-construction of the game. Finally, two sessions were held in Paragominas, the first on 12 February 2019 with local actors and the second on 14 February 2019 with farmers. Consistent with the objectives proposed for the model in the thesis, chapter 5 focuses on the results of the two sessions (one in each municipality) that included the participation of a diversity of local actors (unlike the others that included mainly farmers) (table 3).

Table 3. Number and diversity of participants (discriminated by group) in each session including a diversity of stakeholders.

Session	Property number	Composition of groups
Irituia (19/01/2019)	P1IRt	**Ins:** *Municipal Department of Agriculture* (1); **Emp:** D'Irituia (1); **Sci**: IFPA (1)
	P2IRt	**Emp:** D'Irituia (1); COAPEMI (1)
	P3IRt	**Tec:** EMATER (1)**; Emp:** D'Irituia (1)
	P4IRt	**Ins:** *Municipal Department of Social Development* (1); **Sci:** UFRA (1); IFPA (1)
Paragominas (12/02/2019)	P1Pgm	**Sci:** EMBRAPA (1); UFRA (1); **Emp.:** STTR (1)
	P2Pgm	**Tec:** EMATER (1); IDEFLOR (1)**; Emp:** STTR (1)
	P3Pgm	**Emp:** Cooperuraim (1); STTR (1); **Tec:** EMATER (1)
	P4Pgm	**Ins:** *Municipal Department of Agriculture* (2); **Tec:** EMATER (1).

As was the case of the semi-structured interviews, we invited to these sessions actors locally recognized for their representativeness (not necessarily experts in ES) seeking to reveal their different perceptions. Fifty-five percent of the actors that participated in the gaming sessions was previously interviewed on other phases of the research, in particular the semi-directive interviews. This number wasn't higher due to the refusal of some local actors to participate in the game sessions, mostly alleging lack of time. Conversely, all entities who participated in the sessions were involved in the other stages of the field research[19]. Thus, the game sessions were useful to discuss within a simulation context elements addressed in other moments of interaction.

2.4. *Participant observation*

In order to get a clearer overview of the extent to which the concept of ecosystem services is used and discussed locally, further qualitative information was collected through frequent observation of the involvement of these different stakeholders in their activities and by participating in events and field activities concerning issues related to the rural agenda (Appendix 4).

[19] In 45% of the cases, the representative of the entity that participated in the game was not the same person that was previously interviewed.

This part of the research mainly involved participation in three types of activities, including: **technical-scientific events** (Figure 5A), such as seminars, workshops and field days. Such events counted with the participation of a diversity of local actors, usually with the objective of presenting and discussing research results or technological innovations; **working meetings** (Figure 5B) involving stakeholders, generally to discuss a theme, or assess the execution of some ongoing activity; **field visits** (Figures 5C and D) related to the execution of projects or programs, or routine activities of the staff of local entities. Some of these different activities explicitly addressed the theme of ecosystem services or agrobiodiversity in their agenda. Others, even without explicitly addressing them, dealt with themes that related to this topic.

Figure 5. (A) Field day in Paragominas; (B) Working meeting in Irituia; (C) Delivery of products for school meals (PNAE) in Irituia; (D) Technical visit made by SEMAGRI in Irituia to a cassava producer.

Accompanying of these activities allowed a closer contact with the daily life of a diversity of local actors who were involved in the research process. Informal conversations allowed to go beyond the formal speeches held during the interviews, and returning to farms we had visited often enabled to deepen our understanding of the system. These activities also enabled contact (even if in a superficial way) with other actors who had not been consulted in previous stages of the research. This allowed us to form a more concrete and coherent view of the information obtained in the other stages of the research, as well as better comprehend the diversity of activities developed by these actors and the relationships among themselves. An observation guide and a field notebook were used as tools to follow these moments.

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Chapter 3

In chapter 3, we sought to analyze the perceptions of different actors supporting family farmers on ecosystem services (ES) and agricultural practices and the influence of certain factors on this perception. Based on 30 semi-directive interviews with key local actors from Paragominas and Irituia, we will first address in this chapter which ecosystem services are perceived by local stakeholders and how this perception varies according to local stakeholders, having as variables the type of knowledge they have, the type of activity and the locality. Subsequently, this chapter explores the perceptions of local actors on how agricultural practices positively or negatively influence the co-production of ES. In this regard, we intend to address with this chapter more specifically our first research question: How do local actors supporting family farmers perceive ES and their co-production process?

Co-production of ecosystem services through agricultural practices: perception of stakeholders supporting smallholders in the Brazilian Amazon.

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Abstract: This paper investigates the perceptions of a diversity of stakeholders supporting smallholders in the eastern Brazilian Amazon about ecosystem services (ES) and agricultural practices. Our results are based on 30 semi-structured interviews with key stakeholders in two contrasting municipalities in this region (Paragominas and Irituia). 17 different ES and 15 agricultural practices were identified. A Multidimensional Scaling (MDS) allows to differentiate the stakeholders' perceptions of co-production of ES. The ES that were most mentioned are food supply, regulation of water cycles, and soil fertility and erosion. On the whole, there is a positive perception that agricultural practices are providing ES. Biodiversity-based practices are associated with the provision of a broad range of ES whereas mechanical-chemical practices are mainly linked to food supply. Use of fire, deforestation and use of chemical pesticides are perceived as having most negative effects

on the provision of ES. The type of activity performed by the stakeholders and their municipality are the main factors influencing their perception of ES co-production. In conclusion, the concept of co-production of ES related to agroecosystems is relevant as local actors recognize a diversity of effects of agricultural practices on service provision.

Keywords: Co-production of ecosystem services; Agroecosystems; Agricultural extension; Low input agriculture; Multidimensional Scaling (MDS).

1. Introduction

Agroecosystems are complex systems resulting from the interaction of ecological and human management processes (Tixier et al., 2013). These systems are currently one of the main drivers of degradation of ecosystems worldwide, contributing to and suffering from many of its consequences (MEA, 2005). Ecosystem services (ES) are the *outputs of ecosystems from which humans derive benefits directly or indirectly* (Lamarque et al., 2014). ES are necessary to sustain agricultural productivity, but some of them (e.g. soil fertility, pollination) are often degraded by the conventional processes of managing agroecosystems that are designed to increase the production of goods (Dainese et al., 2019; Zhang et al., 2007). It thus becomes necessary to develop biodiversity-based agricultures, supported by intermediate ES (i.e. services that have a mediating function in generating goods), in order to face the challenge of maintaining or improving yields without compromising the integrity of agroecosystems (Duru and Therond, 2015).

Even though ES are frequently understood as “nature’s free gifts to humans” (e.g. Haines-Young and Potschin, 2010), in most cases they are the result of a co-production process involving “socio-technical systems activating the potentials offered by nature’s functions” (Spangenberg et al., 2014; Palomo et al., 2016). In this sense, ES are social constructions, since their recognition, mobilization and use depend on societal choices (Barnaud and Antona, 2014). This is especially the case with agroecosystems, in which most services are co-produced by humans and nature (Méral and Pesche, 2016).

The implementation of agricultural practices in agroecosystems depends on the availability of resources such as technology, inputs, labor or knowledge (Lamarque et al., 2014; Palomo et al., 2016). Different combinations of the use of natural resources and these anthropogenic resources determine the type of farming system (i.e. chemical input-, biological input- or biodiversity-based) (Therond et al., 2017), resulting in different impacts on productivity, workload and costs as well as on the delivery of a set of ES (Zhang et al., 2007). While farmers are the main actors responsible for land management decisions in agroecosystems, others stakeholders (e.g. policymakers, rural extension actors, unions, cooperatives, consumers) also influence their decision-making process, thus contributing indirectly to the co-production of ES (Tixier et al., 2013; Bennett et al., 2015). This contribution can take the form of specific interventions (e.g. supply of inputs, machines, technical advice; market access; rural credit) or of the establishment and implementation of formal and informal rules (norms, laws, policies) for farming activity (Duru and Therond, 2015).

The various stakeholders' perceptions of the different ES – and the values they accord to them – depend on the local socio-ecological context (Díaz et al., 2006) and on subjective aspects such as knowledge, information, ideologic positioning and the expectations they have of these services (Lamarque et al., 2014; Teixeira et al., 2018). However, there is little knowledge on the perceptions the different stakeholders have of the co-production of the various ES and of their links to agricultural practices (Bennett et al., 2015; Bernués et al., 2016).

The purpose of this paper is to contribute to fill this gap, answering two specific questions in the eastern Brazilian Amazon: **Which services are recognized by different stakeholders supporting smallholders? How do they relate ES and agricultural practices (co-production)?** We assume that knowledge about these services and co-production processes is essential for people to take conscious decisions about the management of agroecosystems (Bennett et al., 2015; Lewan and Söderqvist, 2002). A better qualification of such knowledge can feed methodological tools aimed at improving communication between different actors, which is critical for fostering an on-ground agroecological transition (Dendocker et al., 2018).

Discussing these elements is especially relevant in the Brazilian Amazon where a process of territorial and socio-productive reconfiguration in recent decades has resulted in the intensification of the conversion of ecosystems into agroecosystems through deforestation, with a strong negative impact on the provision of some important ES (Costa, 2008; Pokorny et al., 2013). With the emergence of environmental policies aimed at slowing down deforestation, smallholders are being incentivized to change their agricultural practices (Carneiro and Navegantes, 2019). It is therefore important to understand if and how stakeholders supporting these smallholders perceive ES and co-production processes, as a first step in assessing their willingness to consider ES provision in governance and policy making (Spangenberg et al., 2014; Bennett et al., 2015).

2. Material and methods

2.1. Context of the study

The land use structure in the Brazilian Amazon is constituted by a complex arrangement of large-scale and smallholder farms with distinct rationalities and technological production patterns (Costa, 2008). Smallholders here usually produce more biodiverse landscapes based on ES, whereas larger units are usually more dependent on mechanical-chemical inputs (Pokorny et al., 2013). Two municipalities, Paragominas and Irituia, located in the eastern part of the Brazilian Amazon and representative of these two agricultural models, were selected for our empirical field research.

In **Paragominas**, industrial large-scale grain agriculture based on the use of chemical inputs and livestock represents the predominant land use (Resque et al., 2019). Such farms coexist with rural communities and agrarian-reform areas which represent approximately 80% of the number of rural properties, but only 17% of the agricultural land (IBGE, 2017). Agriculture expansion has led to an intense process of deforestation in this municipality until 2012. In **Irituia**, family farms predominate, representing 98% of all properties and 56% of the agricultural land (IBGE, 2017). Slash-and-burn practices, high population densities (i.e. 23.5 inhabitants per km^2 in Irituia and 5.8 inhabitants per km^2 in Paragominas in 2010, according to IBGE) and long-term colonization also drive deforestation in this municipality, but interesting processes of managing plant and animal diversity are also observed, mainly related to the cultivation of agroforestry systems (Carneiro and Navegantes, 2019).

2.2. *The stakeholders involved in the research*

Based on our knowledge of the study area, we conducted through purposive sampling a survey of the main entities supporting smallholders. Recognizing that ES are managed through interactions of multiple actors who may have differentiated perceptions of these services (Spangenberg et al. 2014; Bennett et al., 2015), we sampled respondents from entities with distinct types of knowledge and from different sectors, undertaking different activities in their role of providing support to farmers. As a result, we approached 24 entities, interviewing at least one key stakeholder per entity, for a total of 30 interviewees, 15 in Paragominas and 15 in Irituia (Table 1).

Table 1. Entities and respondents (*in parentheses*) interviewed in Paragominas (PGM) and Irituia (IRT). Columns correspond to the type of knowledge mobilized and rows to the types of the entities' activities/sectors. Note: [1]Public/Private rural extension entities; [2]Family-farmer cooperatives; [3]Representatives of food procurement programs.

Type of activity	**Type of knowledge**			
	Institutional	**Technical**	**Research**	**Empirical**
Production support	**Municipal Dep. of Agriculture** (InsPGM1 and 2; InsIRT1)	**EMATER**[1] (TecPGM1; TecIRT1), **SENAR**[1] (TecPGM2; TecIRT3); **COODERSUS**[1] (TecIRT2)		**Cooperuraim**[2] (EmpPGM5); **D'Irituia**[2] (EmpIRT3); **COAPEMI**[2] (EmpIRT2).
Purchase of products	**Municipal Dep. of Education**[3] (InsPGM4; InsIRT6); **Municipal Dep. of Social Development**[3] (InsIRT3 and 4)			
Environmental regularization	**Municipal Dep. of Environment** (InsPGM3; InsIRT2)	**State Forestry Development Institute, IDEFLOR** (TecPGM3, TecIRT4)	**Inst. of People and the Envir. of the Amazon, IMAZON** (SciPGM3)	
Social support	**Municipal Dep. of Education** (InsIRT5)			**Union of Rural Workers** (EmpPGM1 to 4, EmpIRT1).
Knowledge production			**Federal Rural University of Amazon, UFRA** (SciPGM1, SciIRT2), **Brazilian Agricultural Research Agency, EMBRAPA** (SciPGM2, SciIRT1).	

Even recognizing different profiles and trajectories of each stakeholder, we considered that the type of knowledge they mobilize (e.g. scientific, empirical) is also related to the institution to which they are employed (Barreteau et al., 2010). Hence, in terms of the type of knowledge, entities were classified as: (a) institutional: knowledge on proposals and implementation of public policies; (b) technical: formal knowledge based mainly on technical information; (c) scientific: academic knowledge structured and validated through scientific experimentation; and (d) empirical: knowledge based on empirical experience, not necessarily formalized (Barreteau et al., 2010). Depending on the sector/activity, the type of support provided was classified as: (a) production support: stakeholders directly associated with supporting food production; (b) purchase of products: stakeholders responsible for the purchase of products; (c) environmental regularization: stakeholders undertaking field activities on the environmental adequacy of farms; (d) social support: stakeholders concerned with the social aspects of the farmer (access to rights, documentation, education); and (e) knowledge production: stakeholders involved in research and academic education (Resque et al., 2019).

2.3. Data collection and analysis

The semi-directive guide used for interviews with stakeholders was structured around personal and institutional issues, the relationship between biodiversity and agricultural practices, and the stakeholder's knowledge and perception of ES. The data collection was performed by the first author of this paper. The use of semi-directive interviews allowed the interviewee to present a broader view of their level of perception of the theme, and helped specify the different forms and terms associated with the perception of ES (Blanco et al., 2020). Questions about ecosystem services were intentionally placed at the end of the interview to explore if this concept emerged spontaneously during the interview or not.

All the interviews were recorded and transcribed, except one by objection of the respondent. In this case, detailed notes were taken. The language used for the interview was Portuguese. A glossary was later compiled with all mentions of ES in the interviews. These services were translated to English and divided into provisioning, supporting, regulating and cultural services (MEA 2005). Then the number and the diversity of ES mentioned by each respondent were quantified. Multidimensional Scaling (MDS) using R was performed to further explore variability in the stakeholders' perceptions. For these analyses, each stakeholder was considered as an observation and was characterized by the ES they cited as variables. The Monte Carlo test (Romesburg 1985) was also conducted to provide an overall indication of the differences between groups according to the three factors selected in our study: local context (municipality), type of knowledge, and type of activity.

Finally, we identified which practices were associated positively (i.e. increases the expression of a service) or negatively (i.e. reduces or provides a low expression of a service) with the supply of ES in the interviews. These practices were divided into 7 categories (Table 2). For optimal viewing, practices directly associated with biodiversity management (i.e. forest maintenance, riparian forest recovery, introduction of plant and animal species and genetic improvements), use of chemical inputs (i.e. use of fertilizers, pesticides and transgenic seeds) and use of organic inputs (i.e. fertilizers, mulching and pesticides) were grouped. Regarding “introduction of plants”, we consider any vegetal species (e.g. crops, repellent plants, shadow plants, native, exotic) introduced in the agroecosystem. The other practices mentioned (i.e. deforestation, use of fire, mechanization, irrigation) were considered without grouping. These categories were used to draw a series of graphs to distinguish how stakeholders performing different activities perceive the relationship between agricultural practices and ES.

3. Results

3.1. How are ES perceived by stakeholders supporting smallholder farmers?

3.1.1. ES perceived by stakeholders

Forty-seven percent of the stakeholders in Paragominas and 60% of stakeholders in Irituia had never heard of ES or did not understand the concept of ES. The fact that they do not know the concept itself does not mean that they do not implicitly refer to some ES. A total of 285 citations describing ES were collected from interviews, covering 17 ES types (Figure 1). Negative effects of ecosystem processes on humans (i.e. disservices) were little mentioned and were not considered. The number of citations in Irituia (154 citations) was slightly higher than in Paragominas (131 citations). Some citations covered different services and were counted more than once. A diversity of perceptions and ways of mentioning services was observed.

Even though local actors mentioned *provisioning services,* especially food, more than other services (as was to be expected), they also mentioned a number of different *regulating and supporting services*. However, notable differences exist between Paragominas and Irituia in the actors' perception of these intermediate services. While local actors in Paragominas mentioned services linked to water maintenance (mainly regarding the risk of degradation of this service), those in Irituia are more aware of services linked to soil issues and pest and disease control. These services are normally related to supporting agriculture production. In Paragominas, however, some services not directly associated with agricultural productivity were also often highlighted, such as C sequestration and climate regulation. In both municipalities, *cultural services* were little mentioned.

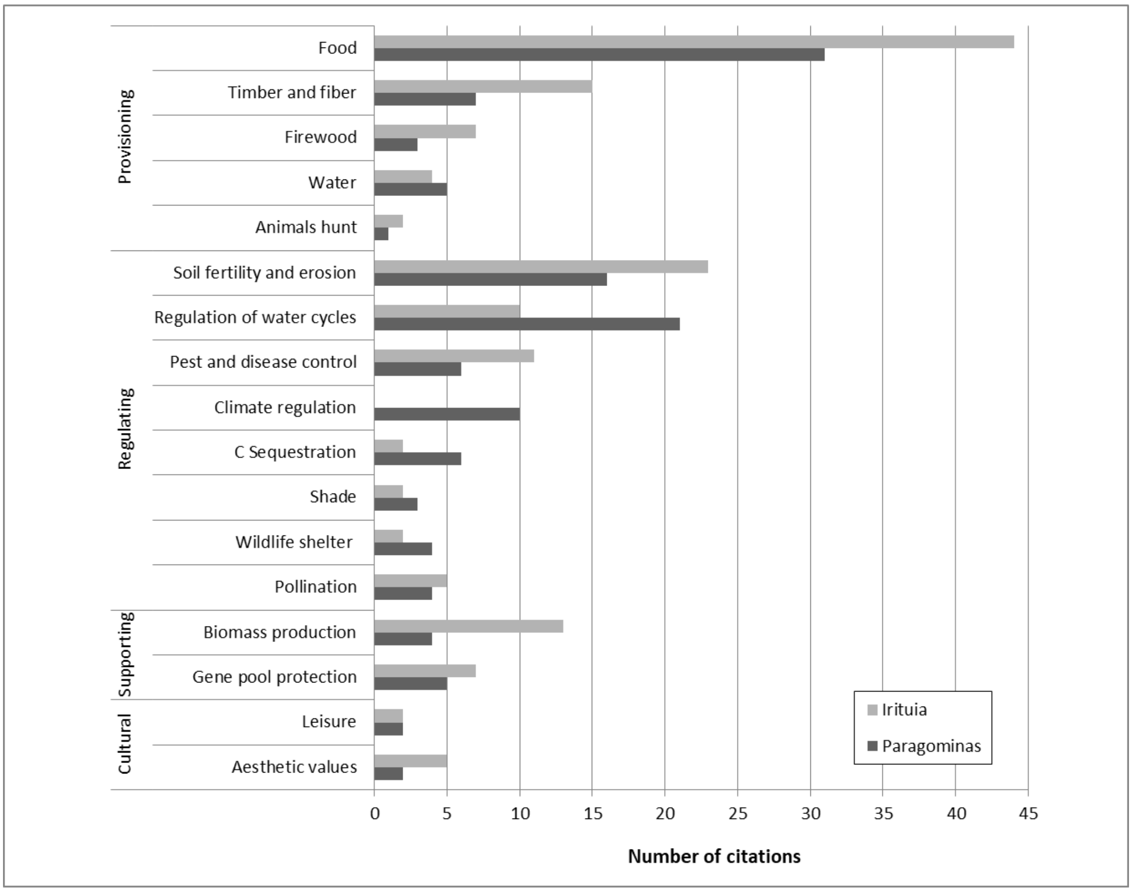

Figure 1. Number of citations of the different services by the stakeholders.

3.1.2. Differentiation between the stakeholders' perceptions

The MDS results (Figure 2A) revealed contrasting views between stakeholders. The horizontal axis distinguishes between the number and diversity of service citations by each actor and the vertical axis highlights the perception of the food supply service. According to the Monte Carlo test, the intergroup variance for location, activity and knowledge was respectively 0.065, 0.185 and 0.127; and for P-value respectively 0.017, 0.042 and 0.120. Hence, the activity variable demonstrated the highest intergroup variance, and activity and municipality were the most significant variables to distinguish stakeholders according to the diversity of services mentioned.

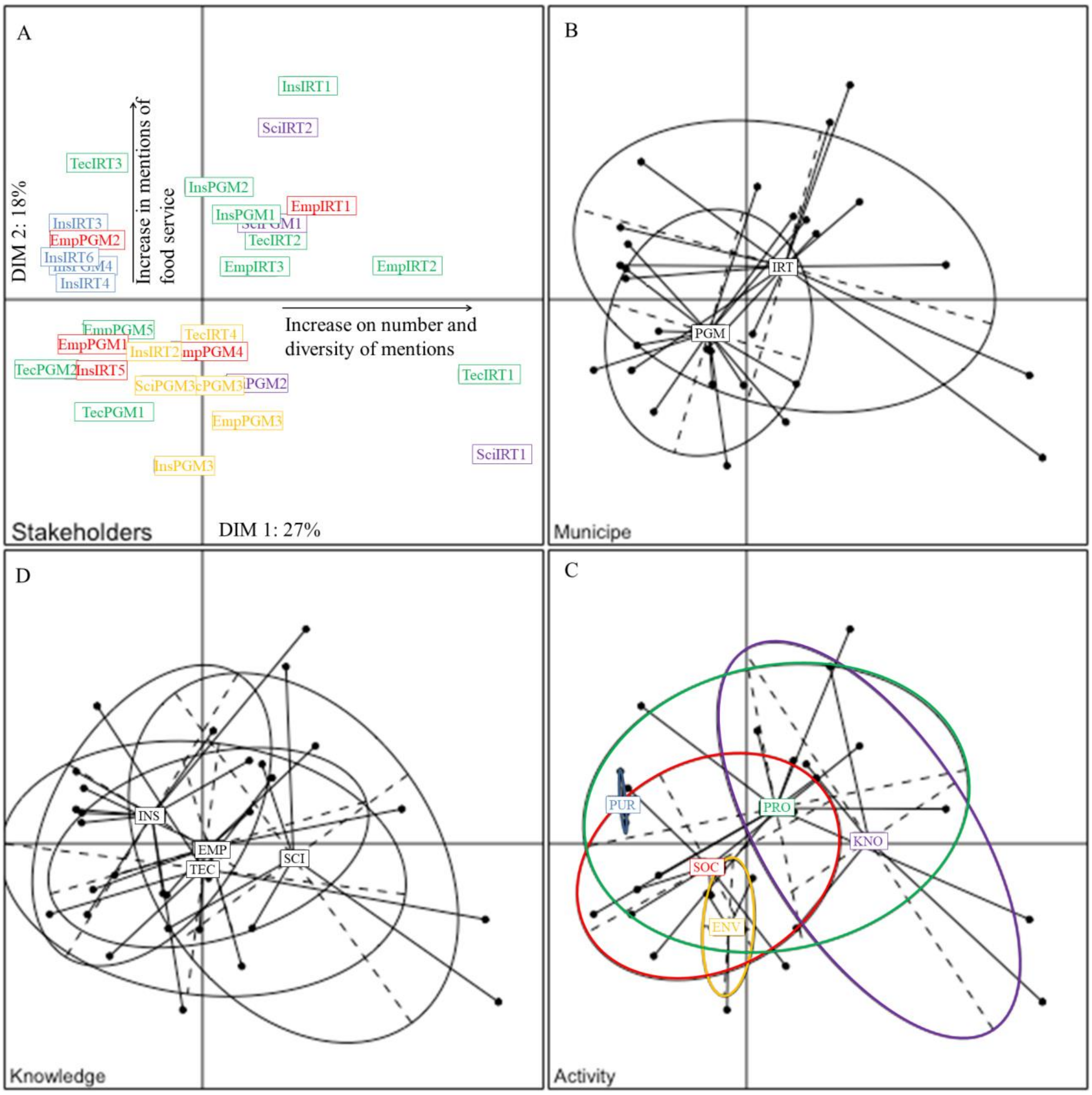

Figure 2. Multidimensional Scaling (MDS) outcomes: (A) Projections on the two first MDS axes of the stakeholders; (B, C and D) Variability of stakeholder responses according to: location (i.e. Paragominas, PGM; Irituia, IRT), activity (i.e. production support, PRO; purchase of products, PUR; environmental regularization, ENV; social support, SOC; knowledge production, KNO) and knowledge type (i.e. institutional, INS; technical, TEC; scientific, SCI; empirical, EMP). The label of each factor's modality appears at the average MDS coordinates of the stakeholders who belong to the modality concerned. An inertia ellipse containing 95% of the points is shown to illustrate the variability of the distribution of ES perception by stakeholders within each modality.

Comparing **municipalities**, Figure 2B shows that the actors who mentioned a greater number and diversity of services are from Irituia. Irituia also presents greater disparity in perceptions of different services. Figure 2B confirms that local actors in Irituia mention more the food supply service than in Paragominas.

As for the **type of activity**, Figure 2C shows that actors concerned with *production support* and *knowledge production* often mentioned a higher number and a greater diversity of services (right side of Figure 2A). The former were predominant in the upper half of the figure (prevalence of mentions of food) and the latter were divided between the two sides. Among the actors who mentioned fewer services (left side of Figure 2A) are mainly those responsible for the *purchase of products* (concentrated at the top) and *social support* (predominance at the bottom). Some actors linked to *production support* are found on the left side of Figure 2A; they are those who mainly favor an agro-industrial pattern of production. The actors responsible for *environmental regularization* were concentrated in an intermediate position of the horizontal axis at the bottom of Figure 2A (intermediate mentions of services, with little emphasis on food).

Regarding the **type of knowledge**, Figure 2D shows that there is less differentiation between groups according to this variable (also confirmed by the Monte Carlo test). However this figure reveals disparity between actors with scientific knowledge (mentioning a higher number of services) and those with institutional knowledge (mentioning fewer services).

3.2. How do stakeholders perceive ES and agricultural practices?

Seven categories of agricultural practices were identified as positively or negatively affecting ES provision (Table 2). There is an overall perception that agricultural practices have positive effects on ES (i.e. 77% of the total mentions), with a few exceptions for practices that were predominantly considered as negative (i.e. use of fire, deforestation and use of pesticides). Some practices have been mentioned as having both positive and negative effects on a same service (e.g. positive short-term and negative long-term effect on services such as food supply or soil fertility) or on different services (e.g. an increase in food production at the cost of contamination of water courses). To a lesser extent, these differences reflected differing opinions among actors.

Table 2. Agricultural practices positively or negatively associated with ES. For optimal viewing, some practices are grouped. Color intensity indicates the frequency of citation of each practice. (n): number of citations.

Practices (n)	Sub-practices (n)	Positive relations		Negative relations	
		Pgm	Irt	Pgm	Irt
Biodiversity management (276)	Forest maintenance	36	16	0	0
	Riparian forest recovery	8	7	0	0
	Introduction of plants	68	100	3	3
	Introduction of animals	7	9	0	0
	Genetic improvement	2	5	1	0
Deforestation (37)	N/A	2	2	23	10
Use of fire (31)	N/A	2	1	15	13
Mechanization (20)	N/A	9	10	1	0
Irrigation (11)	N/A	8	2	1	0
Use of organic inputs (34)	Fertilizers	11	1	0	0
	Mulching	5	8	0	1
	Pesticides	2	1	0	0
	General	2	3	0	0
Use of chemical inputs (55)	Fertilizers	10	1	5	1
	Pesticides	2	2	12	8
	Transgenic seeds	1	0	1	0
	General	6	2	2	2

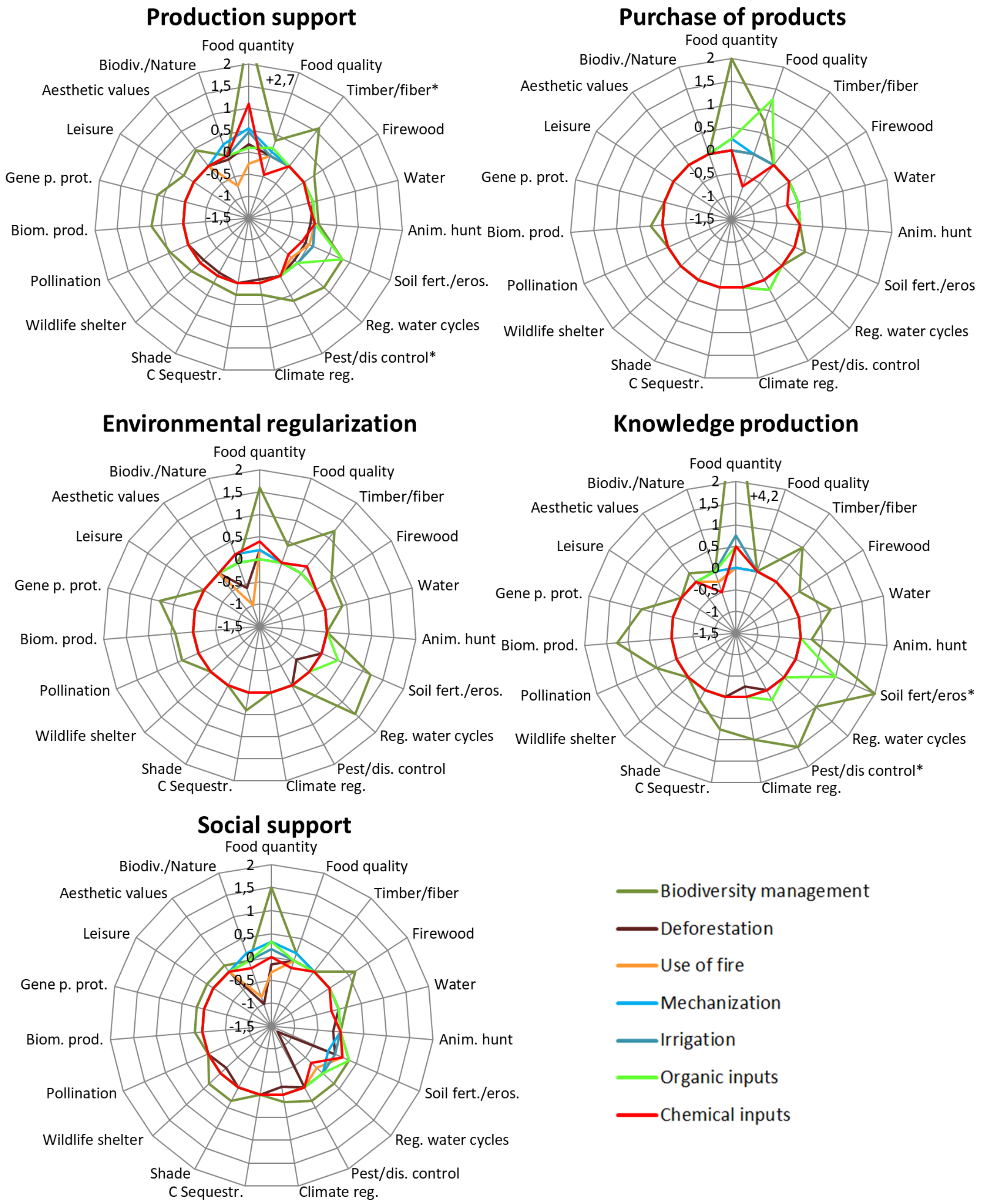

Figure 3. Stakeholder perception of the relationships between agricultural practices and ES. The positive and negative values indicate positive and negative relationships respectively. For services associated both positively and negatively with a same practice, the difference in the number of mentions was considered. Biodiversity/nature and food quality were included here as services as some practices were mentioned as directly affecting them. Since the groups are of different sizes,

the average number of mentions made by respondents in each group were used. *Cases in which only one or two respondents mentioned the particular service.

We constructed 5 separate graphs (Figure 3) grouping actors according to their type of activity to further explore correlations between ES and agricultural practices presented in Table 2. The positive effects of practices on services present different patterns. Some mechanical-chemical practices (i.e. use of chemical inputs, mechanization, irrigation) were mainly associated with food supply whereas biodiversity-based practices (i.e. biodiversity management, use of organic inputs) were associated with a broader diversity of services. Negative effects of practices were predominantly associated with biodiversity/nature (terms used by the interviewees), water regulation and food quality (Figure 3). Few contradictions were observed in the statements made by the different stakeholders about how a particular agricultural practice affects the provision of a given service. However, according to their activity, stakehoders mention different practices and correlations with services:

Production support: Interviewees from this group mentioned a combination of practices, pertaining, for the most part, to food provisioning. Intermediate services mainly concerned biodiversity management and organic practices (e.g. mulching, manure). The negative effect of some practices (e.g. chemical inputs; fire) was also mentioned, mainly linked to biodiversity and food quality.

Purchase of products: These stakeholders mentioned very few practices, focusing on biodiversity management for the provision of food and organic practices (e.g. manure, use of natural pesticides) for food quality. They associated almost no practice with other services, except the negative effects of chemical inputs on food quality.

Environmental regularization: In contrast to the other groups, there was no focus on food supply, cited in similar numbers to timber/fiber supply and intermediate services related to soil and water issues. In this group, a major role was attributed to practices related to biodiversity management. Some negative effects of practices were mentioned, mainly related to the impact of fire use and deforestation on biodiversity.

Social support: This group was unusual in its high number of mentions of negative effects, as opposed to positive ones, of agricultural practices on services. They mainly concerned the impacts of fire use and deforestation on biodiversity and on water regulation (mainly deforestation). Positive effects of practices primarily pertained to biodiversity-based practices, especially to supply of food.

Knowledge production: References to organic and biodiversity management practices were widespread in this group, predominantly linked to food supply, but also to other final and intermediate services. Few mentions of mechanical-chemical practices (mainly associated with food supply) and of negative effects of practices.

4. Discussion

4.1. Perception of ES

First of all, our results demonstrate that the difference in perception of ES is not directly linked to the **type of knowledge** of the stakholders (Figure 2D). Previous studies have suggested this influence (Altieri, 2004), but our analysis was not qualitative enough to confirm this (i.e. mentions of highly scientific or empirical observation of services). The **type of activity** (Figure 2C) undertaken by each stakeholder has more influence on the services perceived. Stakeholders with activities directly linked to food production and purchase, for example, are predictably more concerned by this provisioning service. Stakeholders involved in production are aware of other ES, notably those that support agricultural production. Investigating these perceptions is essential to help us understand the key services that are likely to be co-produced at each location, as these perceptions are an indicator of the benefits (and beneficiaries) that are recognized locally (Bennett et al., 2015; Spangenberg et al., 2014).

Different perceptions of ES are also observed when comparing the two municipalities (Figure 2B). In line with Díaz et al. (2006) and Haines-Young and Potschin (2010), this finding confirms that contextual aspects represent a major source of differentiation in perception of ES. These differences can arise from the strategic ES relevant to agricultural production in each municipality (either by the satisfactory provision of this service, or by limitations in its provision) or as a consequence of the predominant production pattern in the municipality (e.g. see Resque et al. (2019) for further elements). For example, in

Paragominas, the negative effects of deforestation on the regulation of water cycles is widely mentioned, as it has led to increased droughts and floodings. In Irituia, most services mentioned relate to the soil (i.e. soil fertility/erosion and biomass production) and highlighted the practices implemented to improve the conditions of these soils (e.g. mulching, manure use).

4.2. Perceptions of co-production of ES in agroecosystems

Biodiversity management practices (e.g. maintenance of forestry spaces, introduction of plants) were recognized by all categories of stakeholders as provisioning a large number of ES. Negative effects of agricultural practices, such as the use of fire and deforestation, have been reported by almost all groups as affecting biodiversity, which consequently jeopardizes the provision of diverse ES associated with biodiversity. A number of practices (e.g. mechanization, irrigation, use of chemical inputs) were also mentioned, primarily associated with food production. Regarding chemical inputs, trade-offs were acknowledged between food provision and other services. To a less extent, trade-offs were also associated to the other practices.

The perception of how agricultural practices and ES are linked also depends on the activity of the stakeholder. Actors related to food production mentioned mechanical and chemical practices more often (when compared to others) as a means of increasing the production of these goods, while those responsible for purchasing food focused on practices associated with biodiversity (more healthy). The latter actors also highlighted the negative impact of the use of chemicals on the quality of products. Actors linked to environmental regularization focused on practices that benefit the provision of ES and those linked to social support report the negative effects of practices for the provision of these ES. The positive and negative effects of the use of agrochemicals were more mentionned in Paragominas than in Irituia. Existing research has also shown that agricultural principles (i.e. agroecological, organic or conventional) influence this perception (Teixeira et al. 2018; Blanco et al. 2020). Reconciling (or not) these different visions in order to supply ES critically depends on how governance arenas and power relations are configured locally (Spangenberg et al. 2014).

Our results demonstrated that most services are indeed perceived as being co-produced (or degraded) by active human intervention according to their ressources (e.g. seeds, workforce, knowledge, machinery, chemical inputs). This can help assess the “inputs” necessary to improve (or that may compromise) the provision of ES (Palomo et al., 2016). Even services that are associated with the maintenance of forestry spaces, which can be considered as being “naturally generated”, can be understood as a human-driven form of improving the provision of services (as discussed in Barnaud and Antona, 2014, pg. 116) since the maintenance of these areas depends on societal motivation (e.g. compliance with environmental legislation, personal consciousness).

Stakeholders have to understand this set of relations before they can consciously change their attitudes towards ecosystem management (Lewan and Söderqvist 2002). However, a diversity of well-established correlations in literature (e.g. use of organic alternatives to reduce pest and diseases or negative impacts of irrigation on water supply) were rarely mentioned by the interviewees. This suggests a limited understanding by some stakeholders of certain ES, which, as noted by previous studies, may hinder the development of land use interventions for the sustainable delivery of multiple ES (Lamarque et al., 2014; Spangenberg et al., 2014).

5. Conclusion

In the context of both municipalities, a set of ES were listed as important for the functioning of agroecosystems, whether for the provision of goods or for intermediate services related to this provision. Furthermore, ES provision is mostly perceived as being positively induced by agricultural practices, especially by biodiversity-based practices. Thus, the concept of co-production is relevant since stakeholders, even if not exhaustively, recognize a diversity of effects of agricultural practices on ES provision. The type of activity undertaken by stakeholders and the local context proved to be important variables in differentiating these perceptions. Since cognitive elements are one of the factors in decision-making processes for managing agroecosystems in ways that can promote biodiversity and ES, further studies are necessary to investigate how such processes can be effectively implemented with farmers. A coordination process that engages these stakeholders between themselves and with farmers can be a promising approach to strengthen biodiversity-based practices in the Brazilian Amazon.

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Chapter 4

In chapter 4, we sought to identify some factors external to the agro-ecosystem that can influence agrobiodiversity, particularly the market, in a real world situation. Drawing on the experience of two institutional programs for the purchase of food products (i.e. PAA and PNAE), we demonstrate in this chapter how these two programs are currently valuing agrobiodiversity according to the local context in Paragominas and Irituia. For this purpose, we relied on: **(a)** 30 interviews with a diversity of local actors directly and indirectly related to the implementation of the programs in the two communes of the study; **(b)** observation of their participation in events and field activities; **(c)** interviews with farmers who have a different degree of contact with the institutions considered; **(d)** documentation provided by local actors on the function of the programs. We will partially address in this chapter our second research question: How do some different factors, internal and external to the agroecosystem, influence the co-production of ES?

Agrobiodiversity and Public Food Procurement Programs in Brazil: Influence of Local Stakeholders in Configuring Green Mediated Markets

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Abstract: The last few years have seen the emergence of different initiatives designed to promote the biodiversification of agroecosystems as a counterpoint to the global expansion of homogenized industrial agriculture. In Brazil, two food procurement programs demonstrate the potential to promote discussions related to this agroecological transition: the National School Meal Program (Programa Nacional de Alimentação Escolar, PNAE) and the Food Procurement Program (Programa de Aquisição de Alimentos, PAA). The objectives of this paper are to analyze: (a) how these procurement programs currently integrate agrobiodiversity (crops and cropping systems) according to the local context; (b) the main challenges that key stakeholders perceive for the adoption of biodiverse systems;

and (c) the extent to which the key stakeholders involved in these programs associate agrobiodiversity with the provision of ecosystem services. We carried out this research in 2017 in two contrasting municipalities in the eastern part of the Brazilian Amazon, Paragominas and Irituia. Our research shows that these programs have included up to 42 species in Irituia and 32 species in Paragominas. Perennial crop species are the most common type of culture in Irituia (up to 50%), while vegetables are the most common in Paragominas (up to 47%). Although in both municipalities stakeholders identify a large number of ecosystem services (up to 17), services mentioned in Irituia were more closely related to agrobiodiversity. Stakeholders indirectly associated with the programs have a broader view of ecosystem services. We conclude that these procurement programs can be useful tools to promote the biodiversification of local production systems, but their potential may depend on involving institutions not directly associated with their administration. Additionally, despite the observed differences in production context, providing more ecosystem services appears to be a compelling motivation for promoting changes in agroecosystems.

Keywords: Agroecological transition; Agrobiodiversity; Ecosystem services; Public food procurement programs; Mediated markets.

1. Introduction

Agricultural ecosystems, or agroecosystems, are ecosystems transformed through human intervention to produce food, fibers, and other raw materials (Gliessman 2001), along with a number of ecosystem services (FAO 2007). The expansion of monoculture cropping has jeopardized many of these ecosystem services, putting the production of food itself at risk (FAO 2007; Duru and Therond 2015). There is no doubt today that the only way for these agroecosystems to continue to sustainably supply food to the world's growing population is by conserving or producing higher levels of ecosystem services (Tscharntke et al. 2005; Griffon 2009). Agroecology, defined as the science of natural resource management (Altieri 2002), promotes agrobiodiversity, among other practices, as one way to increase the level of ecosystem services (MEA 2005; Isbell et al. 2011; Letourneau et al. 2011).

Agrobiodiversity refers to the "variety and variability of animals, plants and micro-organisms that are used directly or indirectly for food and agriculture, encompassing the diversity of species, genetic diversity and diversity of cropping systems" (FAO 1998). It has evolved over time in various local contexts, depending on the relationship between traditional knowledge and technical and scientific interventions (Toledo and Barrera-Bassols 2008), and thus reveals the existence of a process of co-production of ecosystem services based on human interactions with agroecosystems (Le Clec'h et al. 2016; Palomo et al. 2016).

Agrobiodiversity has been neglected in the international biodiversity debate for many years, with resulting disregard for the complexity of its preservation (Wood and Lenné 2011). Agrobiodiversity conservation policies are still incipient and require better coordination among relevant institutions. Although the legal recognition of agrobiodiversity has progressively improved, leading to the protection of traditional knowledge, these protections are still limited to very specific situations (Santilli and Emperaire 2001; Santilli 2012). It is crucial to protect people's rights, but policies need to address the root of the productive agriculture problem (Thrupp 2000) and encourage a strategy of on-farm conservation that has value for farmers (Smale et al. 2004; Wood and Lenné 2011). The maintenance/improvement of existing biodiversity-based agricultures (Griffon 2009; De Mattos 2015) cannot be just technical and technological, but must also be social, economic, and institutional (Tittonell et al. 2012; Duru and Therond 2015). Many studies show that biodiversified agroecosystems are designed through the synergistic effect of different stakeholders operating at different levels (Petersen et al. 2009; Piraux et al. 2012; Meynard 2017).

In some Amazonian communities, traditional agricultural practices based on the management of natural resources to enhance ecosystem services still prevail (Costa 2008; Silva and Martins 2009). It is critical to promote these practices before they disappear, although this form of biodiversity-based agriculture (Zhang et al. 2007) is not free of risks, such as the conversion of forests to croplands (Jan et al. 2007) and the introduction of external inputs (Silva and Martins 2009).

In 2012, the Brazilian government defined and implemented a National Policy for Agroecology and Organic Production (Política Nacional de Agroecologia e Produção

Orgânica, PNAPO) to improve coordination among institutions, centralizing different existing programs to promote agroecosystem sustainability (Schmitt et al. 2017). This groundbreaking policy was the first in the world to promote agroecological transition at the state level, bringing together technical support and price and market support (Brasil 2012).

Two programs that were integrated into PNAPO have drawn scholars' attention due to their potential to drive agroecological transition (Miccolis et al. 2011; Hespanhol 2013): the National School Meal Program (Programa Nacional de Alimentação Escolar, PNAE) and the Food Procurement Program (Programa de Aquisição de Alimentos, PAA). Both programs purchase products from local smallholders and make them available to social and educational institutions. These programs incorporate numerous principles related to agroecological transition and biodiversity, such as: "to promote and value biodiversity and the organic and agroecological production of food"; "to support sustainable development, with incentives for the acquisition of diversified foodstuffs produced locally"; and "articulation among the social stakeholders involved in the process of purchasing products" (FNDE 2016).

The PNAE and PAA programs established public mediated markets (Guerra et al. 2017), characterized by a particular structure of exchanges governed by rules and conventions negotiated by a group of stakeholders and organizations, with a fundamental role for the state (Grisa 2010). These procurement programs have been expanding in many countries, often spearheaded by local governments or civil society (Wittman et al. 2017). Assessment of these programs generally focuses on benefits for consumers, and significantly less on their influence on farmers (Buckley et al. 2013; Wittman et al. 2017). Recently, some studies have highlighted the combined benefits of these mediated markets for food security and rural development goals (Nijaki and Worrel 2012; Buckley et al. 2013; Wittman et al. 2017). Some studies mention the potential of these programs in favoring agrobiodiversity and associated ecosystem services, but few studies to date document this link (Sambuichi et al. 2014; Assis et al. 2017; Wittman et al. 2017). Wittman and Blesh (2017), for example, showed that agrobiodiversity purchased by PNAE in a specific region of Brazil (Mato Grosso state) was still very limited compared to the agrobiodiversity available on farms.

As a contribution to this growing debate, the objectives of this paper are to analyze: (a) how these procurement programs currently integrate agrobiodiversity (crops and cropping systems) according to the local context; (b) the main challenges that key stakeholders perceive for the adoption of biodiverse systems; and (c) the extent to which the key stakeholders involved in these programs associate agrobiodiversity with the provision of ecosystem services.

Our study is set in a post-deforestation frontier in the eastern Amazon, where traditional farming systems still exist, but are strongly affected by the expansion of cattle ranching and soybean production. We compare two municipalities with different environmental policy approaches: Paragominas, an agribusiness municipality that implemented a Green Municipality Pact to halt deforestation and initiate the transition to sustainable land use (Viana et al. 2016); and Irituia, a family farm municipality that was the stage of several environmental programs, such as Proambiente, the first Brazilian policy to support environmental services (Mattos 2010). This study intends to show the strengths and limitations of the mediated programs in each of these contexts for supporting agrobiodiversity a decade after their implementation. We do not analyze how they have affected the biodiversification process, but how they currently value the existing agrobiodiversity.

2. Study Area and Methodology

2.1. The National School Meal Program (PNAE) and the Food Procurement Program (PAA)

The choice of PAA and PNAE as the focus of our analysis stems from the observation that these programs play a key role in mobilizing many local stakeholders and bringing together numerous actions developed by these stakeholders in each municipality.

The school meal program was created in the 1930s in Brazil and in 1979, after restructuring, it became known as the National School Meal Program (Programa Nacional de Alimentação Escolar, PNAE), with the goal of improving nutritional conditions for children and their performance at school (Abreu 1995). Throughout this period, the program was managed by the federal government and products were purchased from the food industry

(Spinelli and Canesqui 2002). A decentralization process began in 1994 with the publication of Law No. 8.913, when states and municipalities became involved in the administration of this program. This law also made the first references to favoring the consumption of local products based on the agricultural vocation of each region (FNDE 2016). This process culminated in the enactment of Law No. 11.947/2009, which created real conditions for family farmers to participate in the process. The law established that at least 30% of the products destined for school meals had to be acquired from local family farmers. In this period, discussions on agroecology, organic agriculture, and sustainable development began to gain importance within the program (TRICHES 2015).

The Food Procurement Program (Programa de Aquisição de Alimentos, PAA) was created in 2003 by Law No. 10 696 in the context of the Fome Zero (Zero Hunger) program, conceived as a possible tool to improve rural conditions. This was the first Brazilian mediated market with an exclusive focus on family farming. Generally speaking, the program buys food and seeds from family farmers to send to social welfare entities and to create public food stocks (GRISA and PORTO 2015).

In order to participate in the programs, farmers must have a document certifying that they are family farmers (Declaration of Aptitude to Pronaf—DAP) and it is also desirable that they participate in a cooperative. The inclination to participate in the programs is usually associated with guaranteeing a market for the products produced by the farmer.

2.2. Study Area

Two municipalities located in the eastern part of the Brazilian Amazon, Paragominas and Irituia, were selected for empirical field research (Figure 1). Although these municipalities have similar conditions for agricultural production, they differ in the socio-productive (Table 1), cultural, and institutional dimensions. Moreover, despite their proximity, few exchange and commercial relationships exist between the two municipalities, allowing an analysis of distinct dynamics.

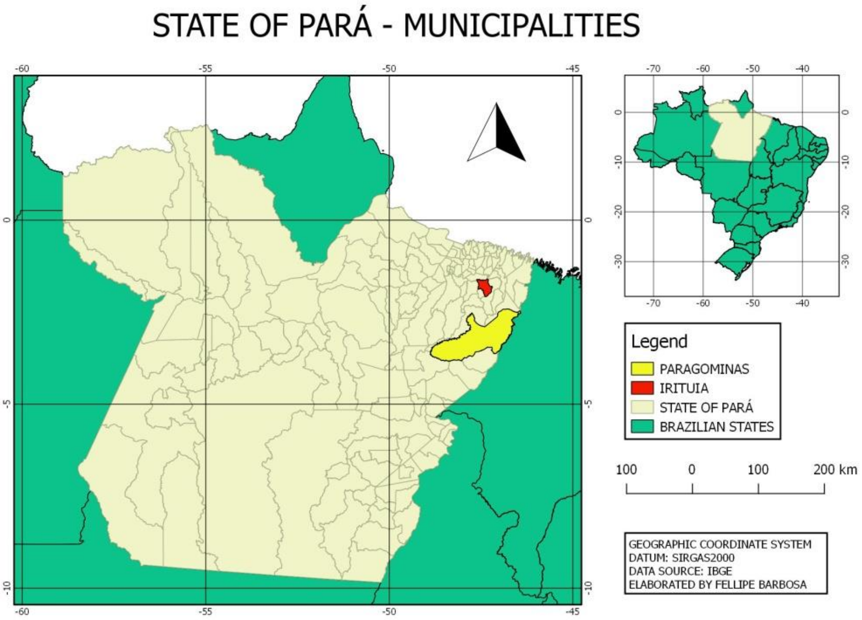

Figure 5. Study Area.

Table 1. Demographic and socio-productive aspects of the municipalities.

Characteristic	Paragominas	Irituia
Population (n)	111,764	32,504
Area (km^2)	19,342	1379
Human Development Index (HDI)	0.645	0.559
Percentage of the population living in rural areas (%)	22%	76%
Number of rural properties (n)	1446	2356
Percentage of family farmers (%)	80%	98%
Agricultural land (km^2)	8560	776
Percentage of agricultural land occupied by family farms (%)	17%	56%

Source: Review of literature (IBGE 2017).

Both municipalities have a warm and humid climate; in Paragominas, the climate is Aw according to the Köppen and Geiger classification, while in Irituia, it is Am. Average temperatures fluctuate around 26 °C and annual precipitation is high, concentrated between the months of December and May. However, average annual precipitation is lower in Paragominas (1805 mm) than in Irituia (2268 mm), with a more well-defined dry season. Dystrophic yellow ferralsols (oxisols), which are typical of the Amazon region, are prevalent in both places (Alves et al. 2014; Andrade et al. 2017). Irituia is 168 km from the capital of Amazon state, Belém (2.5 h by car), and Paragominas is 277 km from Belém (4 h by car).

Paragominas is known for having been included in a deforestation blacklist within the framework of the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (Plano de Ação para Prevenção e Controle do Desmatamento na Amazônia Legal, PPCDAm) in 2008, but also for being the first to leave the list after establishing a "Green Municipality Pact" (Viana et al. 2016) with social stakeholders to stop deforestation. Today, new practices have been introduced and promoted, such as forest and environmental management, the intensification of livestock and plant production, and the restoration of permanent protection areas (Ballon et al. 2016).

Large-scale grain and livestock farms, which practice industrial agriculture based on the intensive use of chemical inputs, represent the predominant land use in the municipality. Family farming, comprising rural communities and agrarian reform areas, represent approximately 80% of the total number of rural properties, but only 17% of the agricultural land. These farms are threatened by environmental problems, primarily those related to fire and deforestation (Piketty et al. 2015, 2017).

In Irituia, family farms are prevalent, representing 98% of all properties and 56% of the agricultural land. Deforestation related to family agriculture also occurs here, as in other townships in the region, driven mainly by slash-and-burn practices coupled with a high population density and long-term colonization (Mattos et al. 2010; Almeida and Ferreira 2015). Nonetheless, interesting processes of plant and animal diversity management, mostly related to the cultivation of agroforestry systems, can be observed (Oliveira 2006; Oliveira and Kato 2009).

2.3. The Stakeholders Involved in the Research

For this study, we identified the key stakeholders representing institutions directly and indirectly related to the programs in both locations. The set of stakeholders responsible for the administration of the programs at the local level includes: institutions directly in charge of executing the programs, such as the local government; product suppliers, which are either individual or collectively organized farmers; and beneficiaries, which are the entities that receive food—schools, in the case of the PNAE, and social assistance entities, in the case of the PAA. In addition, many other stakeholders may be indirectly involved in the implementation of these programs: rural extension, sanitary surveillance, etc.

We conducted an exhaustive survey of all institutions involved in the programs using purposive sampling (Tongco 2007). First, we made a list of institutions involved in the implementation of the programs, derived from our knowledge of the study area. Based on interviews and field observations, we examined other important institutions that had not been included in the initial sample. Indeed, both our observations of the local implementation, especially of meetings related to these programs, and the first interviews with key stakeholders, revealed that these mediated markets involve many more than the stakeholders directly linked to their implementation and are influenced by a broad network of stakeholders. As a result, we gradually added institutions and interviewed at least one key stakeholder per institution, for a total of 30 interviewees, comprising 15 in Paragominas and 15 in Irituia. We selected stakeholders whose responsibilities included aspects of production (e.g., selection of trade products and influence over the adoption of inputs). Stakeholders in other positions (e.g., administrative functions) were not considered. Although interviews were conducted in 2017–2018, many of the stakeholders interviewed had been in their positions from the beginning of the programs. Thus, they were able to provide accurate information on the history of the programs. According to their roles in the programs, they were classified as stakeholders directly in charge, product suppliers, or indirectly involved stakeholders. Since we aimed to analyze production-related aspects, we did not include the beneficiaries (food consumers).

The stakeholders included in the research embodied different types of knowledge, such as: a) institutional: stakeholders responsible for the implementation of public policies; b) technical: stakeholders associated with the extension process; c) scientific: stakeholders involved in research and education; and d) empirical: farmer representatives (Barreteau et al. 2010) (Table 2).

Table 2. Stakeholders interviewed and their role in the programs.

Municipality	Role	Stakeholder (number of interviews)

Paragominas	Directly in charge	**Institutional:** *Municipal Department of Education* (1); *Municipal Department of Agriculture* (2)
	Product supplier	**Empirical:** Cooperuraim (1)
	Indirect role	**Institutional:** *Municipal Department of Environment* (1); **Technical:** EMATER (1), SENAR (1), IDEFLOR (1); **Scientific:** EMBRAPA (1); UFRA (1); IMAZON (1); **Empirical:** STTR (4)
Irituia	Directly in charge	**Institutional:** *Municipal Department of Education* (2); *Municipal Department of Social Development* (2); *Municipal Department of Agriculture* (1)
	Product supplier	**Empirical:** D'Irituia (1); COAPEMI (1)
	Indirect role	**Institutional:** *Municipal Department of Environment* (1); **Technical:** EMATER (1), SENAR (1), IDEFLOR (1), CODERSUS (1); **Scientific:** EMBRAPA (1); UFRA (1); **Empirical:** STTR (1)

Further qualitative information was collected through constant observation of the involvement of different stakeholders in the two programs and by participating in 22 events and field activities concerning the execution of the programs and other issues within the rural context.

Sixty family farmers (30 in Paragominas and 30 in Irituia) received field visits to observe agrobiodiversity (frequency and diversity of cropping systems). Farmer selection was designed to include the full range of participation level in the procurement programs and other local programs (e.g., Tijolo Verde, Pará Florestal), including no participation in any program. Both in Paragominas and in Irituia, the farmers who participated in the programs were in different regions of the municipalities.

We asked the institutions involved in the implementation of the programs to create a random sample of these farmers and asked other institutions to refer farmers involved in other programs. Although we aimed to have 10 PAA/PNAE participants, 10 participants of other programs, and 10 non-participants, we were only able to interview nine participants of the Paragominas PAA/PNAE, as many of the farmers contacted did not return our calls, and 17 participants were interviewed in Irituia, as many farmers involved in other programs were also involved in PAA/PNAE. Because almost all sampled farmers in Irituia participated in both programs, and because in Paragominas, the products marketed to the two programs were almost the same, we did not differentiate between farmers participating in PAA and PNAE.

We selected non-participant farmers in the same vicinity of participants to assess farms exposed to similar conditions (i.e., distance from the city center, neighborhood relationships). Although we recognize that there is a variable set of factors that can affect the performance of these farms, we tried to control for factors such as property size and labor force availability as much as possible. The sample of non-participants cannot be considered representative of all non-participants in each municipality; it is representative of non-participants in the same environment as the program participants. Our intention was not to compare farmers participating and not participating in the programs, but to analyze the way that the farmers participating in the program implemented their crops.

2.4. Data Collection and Analysis

The semi-directive interview guide used for interviews with stakeholders was structured around personal and institutional issues, the relationship between biodiversity and agriculture, and the stakeholder's knowledge about ecosystem services. Questions about ecosystem services were intentionally placed at the end of the interview to explore if this concept emerged spontaneously during the interview. The interviews were transcribed and a thematic analysis was carried out based on the transcripts (Paillé 1996) to organize the qualitative information according to the different topics included in the guide. The diversity of ecosystem services mentioned in the interviews and the challenges of adopting biodiversified systems were also quantified. The structured interview guide used for field visits to farmers focused on quantitative information related to production aspects, such as the frequency and diversity of cropping systems.

Based on the survey data, we created a diagram of the set of stakeholders associated with the execution of the programs in each municipality, including the relationships among different institutions and the role of each institution in implementing the programs. We also analyzed the relevant legislation and documents provided by the executive branches of the programs. This document analysis was used to gather supplementary information—mainly quantitative data— on the diversity of products purchased by the programs in 2017 and the number of farmers registered in each of the two municipalities, and to refine some of the information obtained from informants.

To quantify the agrobiodiversity currently integrated in the different procurement programs, we made a list of crops purchased by each program in 2017 based on documents presented by institutional representatives. The most common cropping systems were described in another table, based on interviews, observation of events and field activities involving the stakeholders, field observations of farmers, and a review of the literature. Based on these two types of information, we propose a description of the agrobiodiversity related to the programs, both in terms of crops and cropping systems, in 2017.

It is important to note as a limit of the study that we are not measuring the area of each cropping system on a farm, but the diversity of cropping systems. The difficulty in measuring the size of each cropping system is due to the complex mosaic of systems found in many of the properties, which prevents the analysis of the real size of each one. However, since we are analyzing family farmers without major size dissimilarities, there are no major dissimilarities between cropping system sizes.

Lastly, we determined the level of knowledge of local stakeholders with regards to ecosystem services, with the goal of understanding whether biodiversity associated with mediated markets may be influenced by environmental concerns or whether it is largely driven by consumption issues and product availability. First, we focused on the knowledge of the conceptual framework of ecosystem services. Services mentioned by stakeholders during the interviews were listed, even if they were not explicitly referred to as ecosystem services. In addition, we identified the main challenges perceived by local stakeholders regarding the adoption of more biodiversified systems. For this analysis, we considered the number and diversity of services/challenges mentioned per interview. We sought to verify the extent to which this theme is debated among stakeholders to analyze how the knowledge of ecosystem services is being explicitly or implicitly mobilized for the execution of the programs and how these programs could reinforce actions related to the provisioning of ecosystem services.

We were unable to evaluate: (a) data on products purchased by institutions since the beginning of the programs (mostly due to the lack of organized administrative records); (b) more quantitative information on the area of cropping systems cultivated by farmers and the evolution of farmer practices (e.g. adoption of inputs, increase on biodiversification); and (c) the isolated effect of each initiative in promoting biodiversification. This prevented us from analyzing the evolution of the agrobiodiversification process, the extent of each cropping system, and the contribution of other specific initiatives to this process.

3. Results

3.1. Configuration of Mediated Markets and the Role of Different Stakeholders

3.1.1. Stakeholders Directly or Indirectly Involved in Mediated Markets

The PAA and the PNAE must be implemented by the municipal government. However, the configuration of these mediated markets and the roles of the different stakeholders are defined locally. The programs bring together different stakeholders to outline common objectives through several activities throughout the year, such as: meetings scheduled specifically to discuss the programs; other meetings where the programs are included in the agenda (primarily monthly cooperative meetings); and product deliveries (once a week), where both farmers and program managers are present.

In Irituia, the programs became operational in 2006; the PAA started first, followed by the PNAE. Currently, there are a number of institutions involved in the implementation of these programs in this municipality (Figure 2). The Municipal Department of Education (Secretaria Municipal de Educação, SEMED) and the Municipal Department of Social Development (Secretaria Municipal de Promoção Social, SEPROS) are the direct managers of the PNAE and PAA programs, respectively, and are responsible for purchasing products from cooperatives (PNAE) or individual farmers (PAA) and distributing them to the final beneficiaries. The Municipal Department of Agriculture (Secretaria Municipal de Agricultura, SEMAGRI) plays a direct role in administering the process as a whole. Other institutions have an indirect role in the implementation of the programs. Rural extension institutions, such as the public Technical Assistance and Rural Extension Agency (Empresa de Assistência Técnica e Extensão Rural, EMATER) and the private Cooperative for Sustainable Rural Development Services (Cooperativa de Prestação de Serviço em

Desenvolvimento Rural Sustentável, COODERSUS), as well as the National Service for Rural Apprenticeship (Serviço Nacional de Aprendizagem Rural, SENAR) and the Forestry Development Institute of the state of Pará (Instituto de Desenvolvimento Florestal e da Biodiversidade do Estado do Pará, IDEFLOR), provide training and technical assistance. The Union of Rural Workers (Sindicato dos Trabalhadores e Trabalhadores Rurais, STTR) helps organize farmers, and universities and research institutions, such as the Federal Rural University of the Amazon (Universidade Federal Rural da Amazônia, UFRA) and the Brazilian Agricultural Research Corporation (Empresa Brasileira de Pesquisa Agropecuária, EMBRAPA), which are very active and influential in the municipality, have enduring relationships with farmers and other institutions.

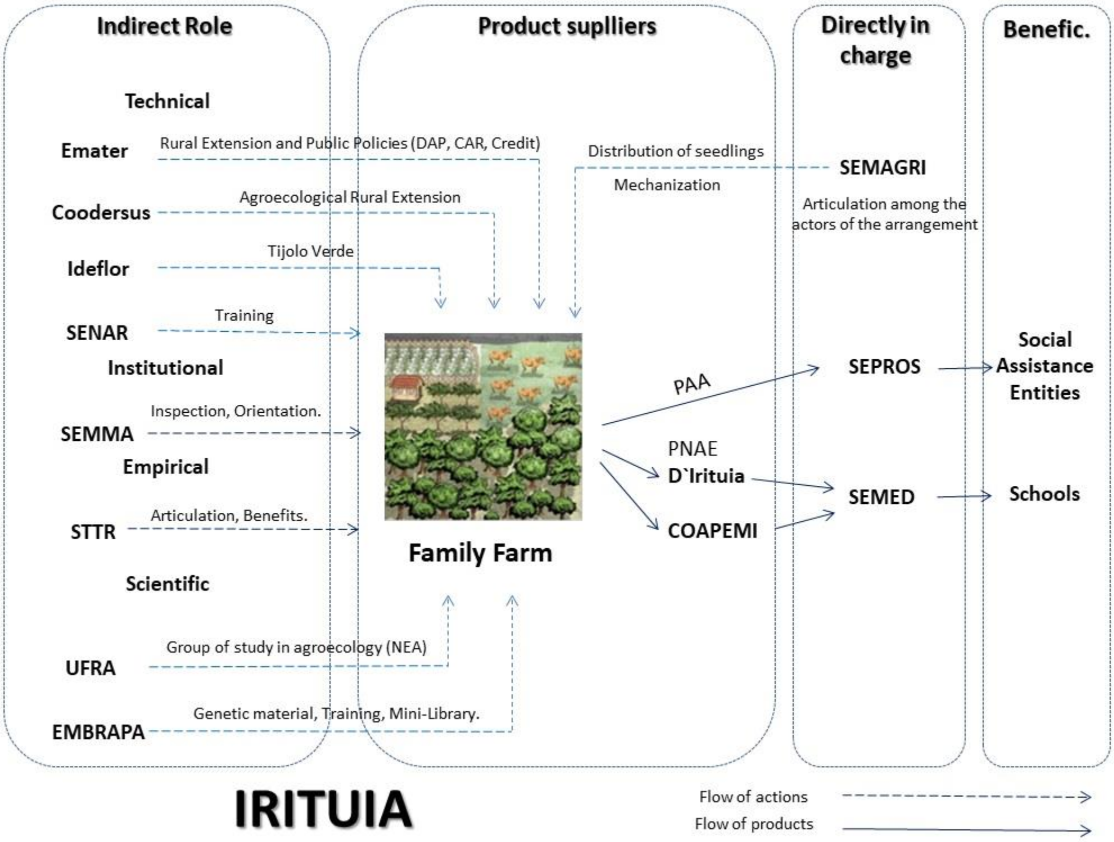

Figure 2. Stakeholders involved in mediated markets in Irituia.

In Irituia, the stakeholders we interviewed underscored the influence of previous programs in encouraging biodiversity and promoting environmental services, such as the Decentralized Execution Project (Projeto de Execução Descentralizada, PED), which was operational in the 1990s and was one of the first to discuss agroforestry systems at the institutional level in this municipality, and PROAMBIENTE, implemented in the following decade. In the mid-2000s, the municipality also experienced an important “movement” of visibility and valorization of Quintais through participatory action research (Oliveira 2006) supported by research institutions, such as EMBRAPA and Federal University of Pará (Universidade Federal do Pará, UFPA). The quintal agroforestry system refers to the diversity of animal and plant species around a farmer's house, whose primary purpose is feeding the family. This movement initiated knowledge exchanges with other municipalities that were already developing agroforestry systems, such as Tomé-Açú. Several initiatives linked to the promotion of biodiverse systems are currently being implemented in Irituia, such as Tijolo verde, an initiative of IDEFLOR employed to build seedling nurseries in the municipality to stimulate the adoption of agroforestry systems for food and firewood, and an agroecological rural extension project managed by COODERSUS. Therefore, many of these initiatives promoted activities directly linked to the improvement of local agroecosystems, such as the exchange of genetic materials and production practices, promotion of agroforestry systems, cultivation of organic vegetable gardens, and production of organic fertilizers. Discussions about reducing chemical inputs have also become quite common within these initiatives. Hence, PAA and PNAE were implemented in a context that already promoted agrobiodiversification.

In Paragominas, the PNAE worked with individual or informally organized farmers until 2009. After the promulgation of Law No. 11.947/2009, the program started working with formal groups of farmers (associations and cooperatives). The PAA began operations in 2015. Both programs also depend on a number of institutions to operate (Figure 3). The farmer cooperative COOPERURAIM serves both programs, interacting with the Municipal Department of Education (Secretaria Municipal de Educação, SEMED) for the PNAE and interacting directly with the National Supply Company (Companhia Nacional de Abastecimento, CONAB), a federal agency, for the PAA. As in Irituia, SEMAGRI plays a central role in organizing this process. Other partner institutions, such as rural extension, the Union of Rural Workers (STTR), and research institutions, have a less important role in the implementation of the programs compared to Irituia.

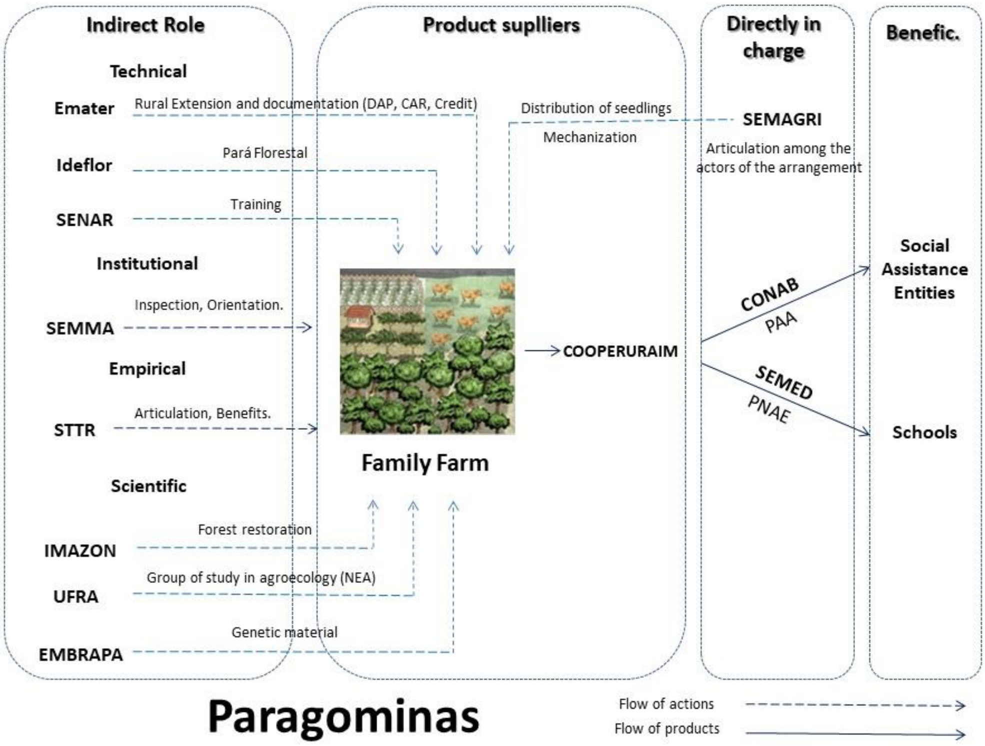

Figure 3. Stakeholders involved in the mediated markets in Paragominas.

There have been fewer initiatives directly promoting the biodiversification of production units in Paragominas. The environmental public policies of the municipality, such as the Green municipality pact, are largely directed towards large-scale agriculture. Even the IDEFLOR project Pará Florestal, which is similar to the Tijolo verde initiative in Irituia, but replaces firewood with timber, currently includes a very limited number of producers (less than 10). Most of the activities related to the biodiversification of family farming in Paragominas are carried out by specific university and research institution projects. Moreover, the representatives of the farmer union report that they do not believe their position is considered in the decision-making process in Paragominas.

Regarding the product suppliers (farmers), in 2017, there were 51 farmers participating in the PAA and 52 participating in the PNAE in Irituia (out of 2300 family farmers). In general, the same farmers participated in both programs. In Paragominas, about 78 farmers (out of 1150 family farmers) had access to both programs. The low level of farmer participation in the programs is largely related to the low availability of resources from the programs. Although the programs reached only a limited number of individuals compared to the total number of farmers in the municipalities, they encouraged the creation or revival of cooperatives, which have become important local stakeholders. This was the case of COAPEMI and D´Irituia cooperatives in Irituia, and of COOPERURAIM in Paragominas. In Irituia, the PNAE operates through cooperatives and the PAA purchases from individual farmers. The reason usually given by the farmers for not selling to the PAA through cooperatives, despite the fact that it would strengthen these cooperatives, is that they have greater autonomy as individuals, both in terms of choosing the products to be sold and in terms of getting paid for them; the payment goes directly to the producer, without a deduction for the cooperative's share. In Paragominas, both programs operate through the cooperative.

Apart from the cooperatives that were created, new relationships have been established, both formal—commercial agreements between producers and the local government—and informal—exchanges between producers on the day of product delivery.

3.2. Influence of Local Context on the Management of the Mediated Markets

Because the programs were conceived at the federal level, their operating rules were the same in both municipalities. However, we observed the establishment of a “local management”, aimed at facilitating the operationalization of the program based on the local context. In both municipalities, the selection of products to be purchased is a participatory process that takes into consideration both the farmers’ ability to supply products (e.g., availability of production, harvest) and the products of interest requested by the local government, defining both quantitative objectives (kilos of products to be delivered) and qualitative objectives (practices to be encouraged). The definition of these objectives depends on the stakeholders involved in the process. For example, in Irituia, the list of products that could be purchased was expanded; normally the inclusion of regional diversity is limited by federal rules, especially for products from the Amazon region:

> *“Regarding the list of products, they are even discussing its regionalization, because it is developed at the national level and it normally includes many products that are not produced or consumed locally. Important Amazon products are absent.” (SEPROS representative in Irituia)*

In order to expand the number of traded species, the PAA administration (mainly in Irituia) chose to purchase products that are part of the local food culture, even though they were not included in the official list. On this topic, the federal government recently enacted the Interministerial Ordinance Nº 284, which aims to increase product diversity and focuses on sociobiodiverse products. In addition, an informal rule has been followed in this municipality, where the products purchased by the programs were organic. Even if the federal program guidelines allow for 30% higher payments for organic products, the program managers in both municipalities are unaware of this possibility. However, the local stakeholders in Irituia have a tacit agreement and have enforced a tacit rule themselves, buying almost exclusively organic products and formally verifying the organic origin from time to time through laboratory analyses of produce samples. Some cooperatives also offer a participatory certification attesting that the farmers are organic producers, making this standard official. This is the case of the D'Irituia cooperative:

> *"Here we require products that do not use chemical pesticides. They have this concept of not delivering products with agrochemicals. No one needs to say anything. There was a year when some cassava flours were tested because some farmers would use poison to kill the weeds. One of the samples contained traces of agrochemicals. We no longer bought from that farmer." (SEMED representative in Irituia).*

This informal rule does not exist in Paragominas. The main obstacle raised by local administrators and representatives of family farmers is their proximity to large-scale farms that, as mentioned above, intensively use chemical inputs—pesticides, fungicides, and herbicides. This proximity results in direct contamination of family farms by these products, carried by the wind or by rivers, and even in the displacement of pests, such as the silverleaf whitefly. As a result, some family farmers also use chemical inputs to combat these pests:

> *"We also had some courses on organic farming that some farmers took, but it is difficult to implement it in the municipality because there are many conventional fields surrounding the municipality properties—mainly grains—with an intensive usage of chemical inputs that is ultimately detrimental to the small properties that follow organic practices." (Cooperuraim representative in Paragominas).*

Thus, although some elements are independent of local management, such as the availability of federal resources and operating rules, local stakeholders have a certain level of autonomy to influence the choices made by the programs.

3.3. *What Agrobiodiversity is Directly Associated with the Programs?*

3.3.1. Species Diversity

The choices made by the stakeholders involved in the programs largely impact the species that can be marketed. These may be classified as perennials, annuals, vegetables, and others (Table 3). According to annual purchase reports, the PAA program in Irituia had the largest number of traded species (42 species), followed by the same program in Paragominas (32 species). Compared to PAA, PNAE included a smaller number of different products, with greater diversity in Paragominas (30 species) than in Irituia (22 species). These species were cultivated in a variety of cropping systems, such as agroforestry, monoculture, slash-and-burn/mechanized annuals, vegetable gardens, and cattle breeding, as described below.

Table 3. Number of species traded by the programs in 2017.

Type of Culture	Irituia		Paragominas	
	PAA	PNAE	PAA	PNAE
Perennial crops	21	10	10	10
Annual crops	6	5	5	5
Vegetables	15	7	15	13
Others	0	0	2	2
Total	42	22	32	30

- *Perennial crops*

Perennial crop species were the most common type of culture in Irituia, both for PAA (50%) and PNAE (45%). In Paragominas, perennial crops were the second largest category for PAA (31%) and PNAE (33%), after vegetables. Some of these crops were traded in both municipalities, such as acerola (Malpighia emarginata), banana (Musa spp.), guava (Psidium guajava), orange (Citrus sinensis), lemon (Citrus limonum), papaya (Carica papaya), passion fruit (Passiflora edulis), and yellow mombin (Spondias mombin). Others were consumed specifically in one municipality. In Irituia, these products were bacuri (Platonia insignis), cashew nut (Anacardium occidentale), carambola (Averrhoa carambola), cupuaçu (Theobroma grandiflorum), soursop (Annona muricata), jackfruit (Artocarpus heterophyllus), muruci (Byrsonima crassifolia), peach palm (Bactris gasipaes), and tangerine (Citrus reticulate). The açaí berry (Euterpe oleracea) and the malay apple (Syzygium malaccense) were only recorded in Paragominas. Although açaí is the most common perennial produce present in the local diet (Cialdella and Alves 2014), it is no longer marketed in Irituia through the programs due to difficulties in complying with sanitary regulations.

In Irituia, our field work showed that perennial cultures were mostly cultivated as agroforestry systems. In most cases, these systems result from the progressive introduction of a diverse set of perennial species within slash-and-burn systems. This process is called the expansion of quintais (Oliveira 2006). Another form of implementing agroforestry systems is through the enrichment of forest areas (primary or secondary) with species of agronomic interest. In Paragominas, in contrast, perennial species are predominantly monocultures, often established following slash-and-burn.

- *Annual crops*

Compared to perennial crops and vegetables, species from annual crops had the lowest diversity in both programs in the two municipalities. In Irituia, they corresponded to 14% of the total number of species for PAA and 23% for PNAE. In Paragominas, annual crops represented 16% and 17% of the species purchased by PAA and PNAE, respectively. In addition to cassava (Manihot esculenta), the main annual crop, other annual cultures were beans (Vigna unguiculata), maize (Zea mays), pineapple (Ananas comosus), and yam (Dioscorea alata). Of these, only yam is commercialized in just one of the municipalities (Irituia).

Annual crops are usually planted using the slash-and-burn system, but in some cases, mechanization or herbicides may also be used.. This cropping system is locally known as roça. Despite the small number of species associated with this system, they also have an important level of intraspecific diversity, especially in the case of cassava (farmers commonly plant three to eight varieties of cassava). Slash-and-burn is the most widespread farming system in the Amazon region and the main cultural food staple. It is often associated with deforestation and may lead to a cycle of soil impoverishment, but when the rotation is well-managed, it creates landscape mosaics that can promote biodiversity (Padoch and Pinedo-Vasquez 2010).

- *Vegetables*

This category included many species traded in both programs and municipalities, since they are the most common in the modern diet. In Paragominas, they corresponded to 47% and 43% of the species for PAA and PNAE, respectively, and had the greatest diversity compared to other categories. In Irituia, 36% and 32% of the species acquired by PAA and PNAE were vegetables, respectively, making this the second most diverse category.

Many of these cultures were commercialized in both municipalities, such as pumpkin (Cucurbita spp.), lettuce (Lactuca sativa), paracress (Acmella oleracea), cilantro (Coriandrum sativum), waterleaf (Talinum fruticosum), culantro (Eryngium foetidum), wild cabbage (Brassica oleracea), welsh onion (Allium fistulosum), maroon cucumber (Cucumis anguria), watermelon (Citrullus lanatus), and green pepper (Capsicum spp.). Basil (Ocimum basilicum), okra (Abelmoschus esculentus), melon (Cucumis melo), and bell pepper (Capsicum annum) were sold exclusively in Irituia. The vegetables only found in Paragominas were cucumber (Cucumis sativus), cabbage (Brassica oleracea), spinach (Spinacia oleracea), and sweet potato (Ipomoea batatas). Most of these products were cultivated in vegetable gardens, but some were planted intermingled with the slash-and-burn system planted at the beginning of the rainy season, usually more diversified, and specifically known as roças de inverno. These vegetable gardens have been largely encouraged by the programs. However, these systems represent very small areas within the rural properties and mostly consist of exotic species.

- *Others*

In Paragominas, the programs also purchased dairy products, such as milk and yogurt. These products were processed in partnership with a local private dairy unit. The inclusion of only a limited number of processed products stems from the difficulty of producers complying with current sanitary regulations. As already noted in the case of the açai berry, the norms applied to processing units are very strict and individual producers have not been able to make the investment.

3.3.2. Cropping System Diversity

According to the diversity of species listed by local stakeholders, the programs are related to different cropping systems (Table 4). These normally coexist at the agroecosystem level. Slash-and-burn and mechanized annual cropping are traditional systems that are extremely common and independent of the programs. Other systems, such as vegetable gardens and perennial plantations (either as agroforestry systems or monocultures), were supported by the programs.

Table 4. Diversity of cropping systems and relation to agrobiodiversity and nature.

System	Objective	Description	Agrobiodiversity	Relation with Nature
Slash-and-burn/ Mechanized annual cropping	Household consumption and trading	Cassava as the main crop, usually combined with other annual crops	1 to 11 different species and significant intraspecific diversity	Transient production system, generally associated with the use of fire and secondary forest suppression
Agroforestry	Household consumption, but also trading	Combination of perennials (fruit, firewood, timber) with annual crops and/or livestock	Ranging from simplified systems with three or four species to more complex systems with about 100 species; there is also significant intraspecific diversity	Perennial production system, normally associated with forest regeneration
Vegetable garden	Mainly trading, but also household consumption	Mixture of fast-growing food species	Between 3 and 20 plant varieties, normally with low intraspecific diversity	Input-intensive system, but usually implemented in small areas
Fruit crops (monoculture)	Mainly trading, but also household consumption	Production system based on a single plant species	One species, normally with low intraspecific diversity	Perennial production system, normally requires inputs
Cattle breeding	Mainly trading, but also household consumption	Dairy cattle breeding	Low animal diversity in a pasture that is also not diversified	Transient production system, generally associated with the use of fire and secondary forest suppression

Source: Interviews, field observations, and review of the literature (Clement et al. 2007; Jan et al. 2007; Mattos 2010; Padoch and Pinedo-Vasquez 2010; Calado da Costa et al. 2013).

Often, these are not new cropping systems, but activities that used to be marginalized and gained greater visibility and validation with the creation of these mediated markets:

> *"Before the existence of the programs we used the products only for household consumption. We couldn't sell them. Today you can sell everything. [...] The main advantage [of the programs] is being able to sell the products you have. Last year we*

delivered a lot of tangerine and orange. The peach palm [Bactris gasipaes], for example, we'd never imagined before making money with it and today it has a lot of sales." (Family farmer in Irituia).

New crops were also planted specifically to address the programs:

"The participation in the programs is really good because the person will plant and know to whom they will sell. Before, I used to plant mainly beans, pumpkins. There was a variety of plants that I did not plant because there was no market, like spinach [Spinacia oleracea], waterleaf [Talinum fruticosum]. Today there is a market for these crops." (Family farmer in Paragominas).

These various cropping systems may promote the production of organic materials—litter, manure, and cassava peels—that can be reused by the system itself or in a different system, increasing the likelihood of implementing biodiversity-based agriculture. Thus, in addition to the diversity of cultures, it is important to note how these cultures are implemented. Table 5 provides a broader view of the diversity of cropping systems present on the farms, complementing the information provided by key stakeholders.

Table 5. Frequency of cropping systems among farmers in Paragominas and Irituia.

Cropping Systems	Paragominas		Irituia	
	Participants (*n* = 9)	Non-Participants (*n* = 21)	Participants (*n* = 17)	Non-Participants (*n* = 13)
Slash-and-burn/Mechanized annual cropping	78%	95%	94%	100%
Agroforestry	11%	38%	88%	38%
Fruit crops (monoculture)	55%	57%	17%	38%
Vegetable garden	88%	28%	35%	23%
Cattle breeding	22%	28%	11%	8%

Note: Among sampled farmers, the mean value and standard deviation (SD) of size and labor force were, respectively: (a) Irituia—26 Ha (SD 16.70) and 3.4 persons (SD 1.54) for participants; and 22.5 Ha (SD 12.66) and 4.8 persons (SD 2.4) for non-participants; (b) Paragominas—23 Ha (SD 13.31) and 3.8 persons (SD 1.90) for participants; and 24 Ha (SD 12.47) and 3.5 persons (SD 1.74) for non-participants. These values demonstrate that the sample is relatively homogenous regarding these indicators between and within the municipalities.

The field visits confirm that the differences in the orientation of the procurement markets between municipalities are linked to different cropping systems. In Paragominas, the dominant cropping system among participants is vegetable gardens (88% of participants), which are indeed the main products purchased (Table 3). In Irituia, the main cropping system, apart from annual crops which are widespread among all farmers, is agroforestry

(88% of participants). Moreover, in both cases, it is suggested that there is a difference between participants and non-participants (in Paragominas, only 28% of non-participants have vegetable gardens, and in Irituia, only 38% of non-participants have agroforestry systems). Another interesting difference is that in Paragominas, fruit crops are mainly from monoculture systems (55% of participants have monoculture fruit crops, but only 11% have agroforestry systems).

Our method and the data acquired do not enable us to conclude whether the programs determined differences between participants and non-participants. Additionally, we cannot measure either the extent to which the cropping systems have been influenced by the programs or whether the choice of the key stakeholders in orienting the programs was influenced by the available cropping systems. However, interviews with key stakeholders tend to show that both processes reinforce one another. Thus, this information generates valuable insight for future research on the biodiversification process influenced by the programs.

3.4. What Are the Main Challenges for the Adoption of Biodiverse Systems?

To identify whether the programs can contribute to supporting more biodiversification, we interviewed the key stakeholders regarding general challenges related to the biodiversification of cropping systems (Figure 4). In total, 20 different challenges were identified by local stakeholders, including 13 in Paragominas and 14 in Irituia. There was a great dissimilarity in the perceived challenges for each municipality, and 60% of the challenges were mentioned in only one of them.

In Paragominas, the most frequently listed challenges were related to the production paradigm, such as mentality (3) and culture (3), followed by a lack of interest (2), the coordination of actors (2), compensation mechanisms (2), and knowledge (2). In Irituia, the challenges were more closely related to elements supporting production, with a predominance of knowledge (8), followed by the coordination of actors (4), market (3), rural extension (3), public policies (2), and monetary resources (2). Mediated markets may be relevant to meet these challenges.

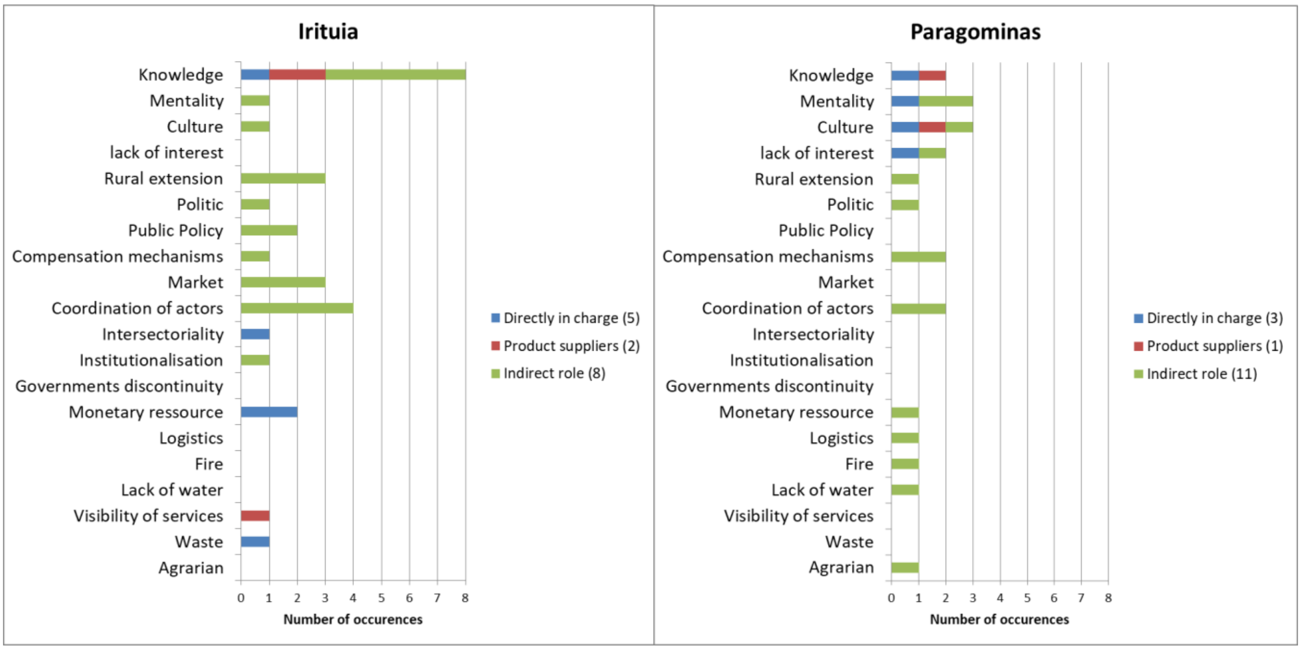

Figure 4. Main challenges identified by local stakeholders for the adoption of biodiversified agroecosystems.

Of the challenges identified in Paragominas, 69% were mentioned by a single type of stakeholder. Despite this, there was a balance among the three types of stakeholders in this municipality regarding the most mentioned challenges. In Irituia, 93% of the challenges were mentioned by a single type of stakeholder. In this municipality, apart from knowledge, the three most cited challenges were only brought up by stakeholders who were indirectly associated with the programs. This reveals how important it can be for stakeholders who are indirectly involved in the programs to participate in their delineation, as they have a broader view of the challenges to be met.

3.5. Which Ecosystem Services Are Mentioned by Local Key Stakeholders?

The concept of ecosystem services is not explicitly used by the different stakeholders, except those who are close to the scientific and institutional community. Forty-seven percent of the stakeholders in Paragominas and 60% of stakeholders in Irituia had never heard of this concept or did not know exactly what it meant. Almost all the stakeholders interviewed stated that it was not a normal topic of discussion in their circles. Nonetheless, many stakeholders referred to different types of services (Figure 5) and mentioned that they were frequently discussed in events they attended.

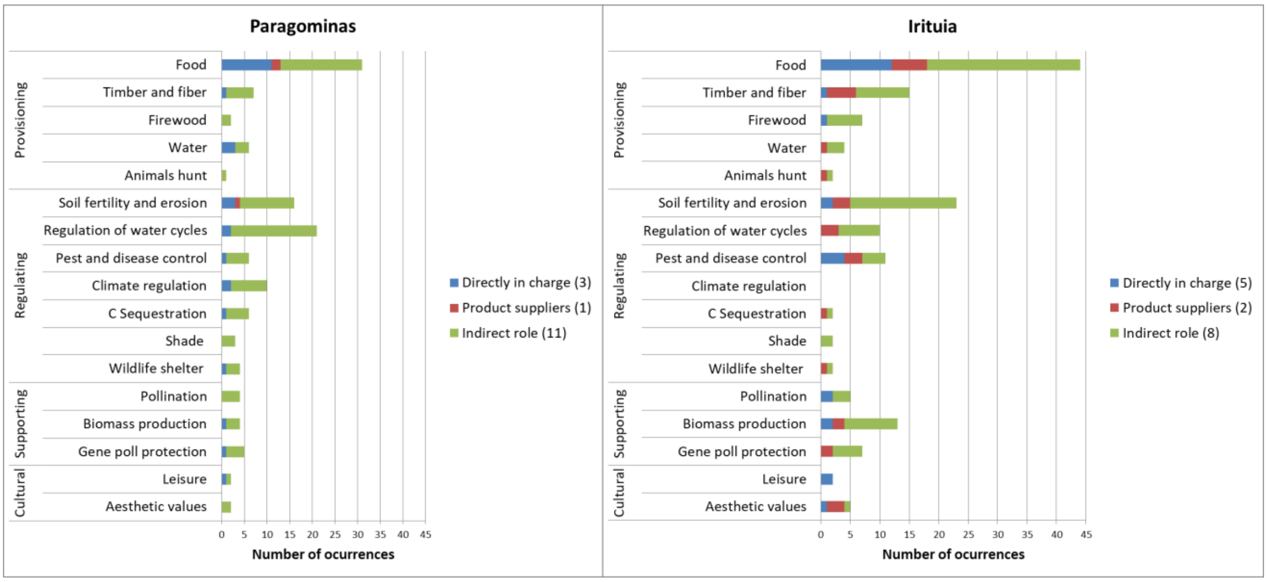

Figure 5. Number of citations made to the different services by the stakeholders. (Classified as (MEA 2005): (a) provisioning services, products obtained from nature; (b) regulating services, services provided by nature that regulate our environment; (c) cultural services, non-material benefits provided by nature that enrich lives; and (d) supporting services, which are necessary to produce the other three categories.)

Seventeen different types of ecosystem services were mentioned during the semi-directive interviews, including 17 in Paragominas and 16 in Irituia. In both municipalities, the highest number corresponded to regulating services (41% and 43% in Paragominas and Irituia, respectively), followed by provisioning (29% and 31%), supporting (17% and 18%)[20], and cultural services (11% and 12%).

Food was the predominant service in both municipalities, mentioned by all stakeholders in Paragominas and Irituia. In Paragominas, stakeholders frequently cited the regulation of the water cycle and the regulation of climate. In Irituia, stakeholders predominantly mentioned soil fertility and erosion, pest and disease control, biomass production, and

[20] Pollination have both direct (immediate) and indirect (via other ecosystem services) values, corresponding respectively, to their regulating and supporting roles (Millennium Ecosystem Assessment 2005). In this chapter, we considered pollination as a supporting service, since it was a key role that some local actors attributed to this ES. However, on the other chapters that deal more specifically with the relationship between agricultural practices and ES, we considered more coherent to classify pollination as a regulation service.

maintenance of the gene pool. These services have a strong relation with agrobiodiversity. This seems to confirm that the key stakeholders in Irituia recognize the environmental importance of agrobiodiversity.

In Paragominas, only 19% of the services were mentioned by the three types of stakeholders, but this figure was higher in Irituia (40%), especially because the stakeholders representing the product suppliers mentioned many ecosystem services. Stakeholders indirectly associated with the programs bring a broad view related to the provision of ecosystem services. This highlights the importance of involving these stakeholders to devise better ways to promote these services through the programs.

4. Discussion

4.1. Mediated Markets as a Way to Ensure the Sale of Agrobiodiversity Products

Our results show that procurement programs have created markets capable of absorbing a high diversity of products. Highly biodiverse systems often experience difficulties in marketing their products, which can discourage their expansion and even their existence. For instance, "quintais" are usually underused, because many of the products exceed the food demands of the family and are not consumed, and there are few market alternatives for these products (Coq-Huelva et al. 2017). In this context, a very positive outcome of mediated markets is the creation of a fair mechanism to absorb the surplus of these systems (Resque et al. 2016), and therefore stimulate the maintenance of this diversity (SILIPRANDI and Cintrão 2014). This greatly differs from the usual market logic based on a reduced number of products, leading to the homogenization of agricultural production systems (Gillespie et al. 2007) or dominance of highly marketable species (Major et al. 2005).

Despite the observed potential of these programs to absorb a high diversity of products, they did not sponsor actions directly linked to production. The mediated markets formed to implement the programs, the institutions indirectly associated with their implementation, and the local production context are of the utmost importance to define the level of biodiversity that may be promoted. In our case studies, while the programs were associated with significant agrobiodiversity in both municipalities, the number of different species, especially perennial crops, traded by the programs was higher in Irituia.

The interviews show that current and past actions and programs—public policies and other activities—carried out by the key stakeholders reflect the predominant production paradigm of each municipality. These actions shape intrinsic aspects of these institutions, such as objectives, mentality, and power of influence, that continue being present even after they end (Ostrom 2011; Barnaud et al. 2018). Thus, although the benefits associated with biodiversified systems may be acknowledged by local stakeholders in both municipalities, in Paragominas, there is skepticism about the feasibility of effectively applying this agricultural model in rural areas, even in the case of family farming. In Irituia, a favorable atmosphere was created by past initiatives and ongoing projects. The cooperatives had a very important role in this process. This type of mobilization is less common in Paragominas. Moreover, the very attitude of the institutions that manage the programs towards agroecological approaches is fundamental to stimulating a transition process. Conscious of this role, managers in Irituia have required all farmers to produce according to organic principals (although produce is not certificated).

These factors reflect current differences related to the programs, mainly in terms of agrobiodiversity. In terms of the diversity of crops acquired by the programs in 2017, we found that PAA in Irituia was the most diversified program, followed by PAA and PNAE in Paragominas and PNAE in Irituia. Considering the type of culture, perennial crops were prevalent in Irituia, while vegetables were the most common culture in Paragominas. This is valuable information, because the type of culture reflects the type of cropping system. As we have shown, perennial crops in Irituia were planted preferably as agroforestry systems (unlike in Paragominas, where they were primarily monocultures). In contrast, vegetables were planted mainly as vegetable gardens in both places. By encouraging agrobiodiversity, the key stakeholders in Irituia recognized agroforestry as a low-input cropping system that promoted the provision of ecosystem services.

4.2. Ways Forward to Strengthen the Biodiversification Process

How can the programs contribute to overcoming the main challenges faced by local stakeholders at each locality for the adoption of biodiversified systems? In Paragominas, the main challenges were more closely linked to paradigmatic issues, such as mentality and culture. This can be explained by the difficulty in suggesting “alternative” ways of production to replace production-based agriculture, which is widely disseminated in the municipality. This paradigm, as we have extensively discussed, was strongly adopted by large-scale farms and, in part, by family farmers. The procurement programs do not have any specific actions to solve these problems. On the contrary, the functioning of the programs is influenced by this production paradigm. Programs must be useful to overcome the challenges of coordinating actors and implementing compensation mechanisms.

In Irituia, in contrast, the main challenges were related to production issues, such as knowledge, market, coordination between stakeholders, and rural extension. Despite the efforts of some stakeholders to fill the gap in knowledge and rural extension, the dissemination of technical knowledge is still limited. Regarding markets, apart from mediated markets, they are either non-existent for many of the local products, such as those derived from agroforestry systems, or the products are commercialized through a middleman, with unattractive prices. Only a few farmers are included in mediated markets, and the markets are susceptible to disruption, especially given the current political instability in Brazil. Finally, coordination among actors was also perceived as a challenge, because even if many institutions operate in the municipality, there are weaknesses related to political incompatibilities and the termination of people occupying administrative positions.

Unlike in Paragominas, programs in Irituia could help overcome some of these challenges. In the case of markets, one logical step would be to increase the number of farmers who have access to procurement programs. Another good strategy would be to take advantage of frameworks created by farmers to access the programs (e.g., cooperatives) to secure additional agroecological markets. The programs could also improve coordination among actors. Despite the absence of a formal arena including the various institutions linked to the programs, which prevents better coordination among actors, some progress has been made in creating new structures and establishing formal contracts between the government and farmers' organizations. Nonetheless, in both municipalities, the discussion about the contribution of ecosystem services related to the biodiversification may bring an interesting perspective to overcome the potential paradigmatic conflict regarding agroecology and the possible role of biodiversification and to generate new relevant knowledge to support this biodiversification.

4.3. Agrobiodiversity and Ecosystem Services

Although several “services” are recognized by stakeholders, the conceptualization of ecosystem services is only disseminated in academic and institutional settings and rarely discussed in other circles. A negative aspect of this lack of knowledge is the difficulty in operationalizing anticipated elements of the programs and other associated public policies that aim to directly or indirectly improve the production of these services. More knowledge about the concepts could spur the demand for new public policy instruments. In Brazil, for example, the concepts of family farming and agroecology have been a major tool used to fight for new public policies related to these issues in recent years (Schmitz and MOTA 2007; Schmitt et al. 2017). Naturally, this process involved many stakeholders linked to these issues. In the case of environmental services, different agendas surrounding this issue have emerged in Brazil in the past few years, including water, forestry, socio-environmental, and agricultural issues, especially regarding PES programs. However, despite the involvement of various stakeholders in this debate (Coudel et al. 2017), most often, this subject is not included in federal public policies.

Regarding the perception of service diversity by local stakeholders, we observed that food provisioning is the most important perceived service in both places. This is coherent, since as a rule, the main objective of the production system is the production of goods, mostly food. Here, it is important to recognize that the type of cropping system, as well as the technological model adopted, are fundamental to determining whether the production of provisioning services, notably food, will improve or decrease the provisioning of other services (FAO 2007). For instance, agroforestry systems are normally associated with the production of ecosystem services, such as provisioning (e.g., food, timber), regulating (e.g., soil fertility and erosion, regulation of water cycles, climate regulation), and supporting services (e.g., biomass production) (Oliveira and Kato 2009; Cerdán et al. 2012; Wilson and Lovell 2016). However, other systems are also important. For instance, slash-and-burn systems, despite their potential to cause deforestation and soil impoverishment (Schmitz 2007; Jan et al. 2007), play an important role in protecting the gene pool in situ (Padoch and Pinedo-Vasquez 2010).

Both in Paragominas and Irituia, stakeholders identified a set of other services that may be used to increase the productivity of cropping systems. In Paragominas, they are related to the regulation of the water cycle and soil fertility and erosion. The frequent mention of water cycle management in Paragominas may be explained by the fact that this municipality has a more well-defined dry season compared to Irituia, or by problems related to river conservation. Soil fertility and erosion were also frequently mentioned in Irituia. This suggests that this is a well-recognized and important service in both localities. In Irituia, biomass production, which is related to soil fertility, was also frequently cited as an important service, along with pest and disease control.

The perception of some services differed between the two localities. For example, climate change and carbon sequestration were mentioned more often in Paragominas, which may be related to the substantial extent of large-scale agriculture in Paragominas. Indeed, studies have shown that climate change is more severe in soybean expansion regions (Sampaio et al. 2007). Moreover, in this Green Municipality, many discussions have been promoted to establish green business opportunities, such as Reduction of Emissions from Deforestation and Forest Degradation (REDD+), linked to carbon sequestration.

This result suggests that the perception of ecosystem services may be related to local issues and, for this reason, they could be a possible incentive for farmers and local communities to change their systems to improve production. However, we also observed that the perception of ecosystem services is not always reflected in stakeholder actions. This suggests that the perception by itself does not determine the actions of the stakeholders.

Promoting increased dialogue between stakeholders could enable them to share their perceptions of ecosystem services related to cropping systems, and thus steer the programs toward stimulating the adoption of cropping systems that have a greater potential for delivering services. For example, discussing how an agroforestry system could improve climate regulation in Paragominas may motivate farmers to adopt this cropping system, because climate regulation was an important service mentioned by stakeholders of this municipality. Another important discussion topic would be to analyze the extent to which the production of these services could be used to improve the agricultural production process and reduce the use of external inputs (Altieri 2002).

Although we did not have suitable data to assess the biodiversification process, empirical evidence about the current agrobiodiversity purchased by the programs in the two municipalities suggests that mediated markets are related to significant agrobiodiversity. Such markets could improve biodiversification as long as the key stakeholders involved in rural development at a given locality are interested in promoting this agroecological transition. We emphasize the importance of the synergistic contribution of all the other initiatives that take place in each municipality, especially because the PAA and PNAE do not act directly on productive aspects. As a result, they become a driver of support/reward of biodiversified agroecosystems as they create markets for products that might otherwise have little value. However, the persistence of this process will depend on keeping these public policies active and reinforcing the involvement of different institutions.

5. Conclusion

Both programs have the potential to promote the biodiversity of local production systems, as they can buy a diversity of products, but their impact depends on the local administration of each program, the key stakeholders associated with their implementation, and the local socio-productive context. Various elements could improve the programs: (a) strengthening cooperatives as intermediaries between executors and farmers; (b) including more farmers; and (c) formally establishing an organization to coordinate institutions directly and indirectly linked to the implementation of the programs. The stakeholders that are not directly involved have an important role to play, as they have the broadest view of the challenges to improving biodiversification and important ecosystem services. Thus, encouraging multi-actor discussions about the benefits and ecosystem services associated with agrobiodiversity as part of the programs would certainly promote the biodiversification process. However, the situation of these procurement programs is currently very fragile due to the political instability at the national level. As a result, despite the demonstrated potential of these programs to support local rural development, much uncertainty remains about their scope of operation, and even their continuity. Therefore, this article presents novel and valuable data showing the importance of such programs regarding agrobiodiversity. It also generates insight for future studies that might aim at effectively assessing the influence of programs on the adoption of cropping systems/inputs.

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Chapter 5

In chapter 5, we examined how ecosystem services are considered (among other factors) in the decision-making process of the local actors involved in agroecosystem management. For this purpose, we present a co-built role-playing game used to explore, in a simulation environment, how certain internal factors (e.g. labor, financial resources, knowledge) of the agroecosystems influence this decision-making process. We base our analysis on two game sessions held in Paragominas and Irituia. These sessions counted with the participation of different local actors linked to rural issues. We will address in this chapter more directly our third research question: How to formalize knowledge related to ES co-production and enable stakeholders to discuss it through appropriate methodological tools in order to steer the agroecological transition? We will also partially contribute in this chapter to answering our first (i.e. perception of local actors about co-production of ES) and second (i.e. importance of internal factors to the agroecosystem in the implementation of management practices) questions.

Discussing ecosystem services of management of agroecosystems: a role playing game in the eastern Brazilian Amazon.

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Abstract This research assessed how ecosystem services are taken into account in the decision-making process of stakeholders involved in the management of agroecosystems, in particular agroforestry systems, and how a Role-Playing Game (RPG) can serve as a tool to allow them to discuss the issues concerned. The study was conducted in two municipalities (Paragominas and Irituia) located in the Brazilian Amazon. The game was developed in 2018 using a co-construction process that mainly included farmers, students and researchers. Data was collected during two sessions of the game held in 2019, with participation by heterogeneous participants from different local institutions. Our results demonstrated that game sessions showed how the provision of ecosystem services, as well as other factors (e.g. values, availability of factors), is taken into account in planning the spatio-temporal configuration of the agroecosystem and associated agricultural practices. They also revealed some trade-offs involved in this decision-making process. We conclude that the RPG allowed stakeholders to synthesize and discuss different types of knowledge about this process. Bringing these elements to the discussion can contribute to an improved shared understanding of the challenges and possibilities of the ecological management of agroecosystems and can indicate solutions that are in line with local expectations.

Key words Agroecology – Farming management – Cropping systems – Serious game – Knowledge sharing

1. Introduction

Agroecosystems are defined as ecosystems modified by human intervention to produce food, fiber and other raw materials (Altieri and Nicholls 2005). Different arrangements of land management (e.g. chemical input- or biodiversity-based system) and farming activities (e.g. agroforestry systems, monocultures, annual crops) can be used to achieve this objective (Duru et al. 2015), directly affecting biodiversity and the flow of ecosystem services from agroecosystems (Tibi and Therond 2018). Since ecosystem services can be considered benefits that people obtain from nature (MEA 2005), understanding the perception farmers and local stakeholders have of the relationship between these services and the functioning of agroecosystems can help improve their management process (Lamarque et al. 2014; Tibi and Therond 2018). This relationship is however not so evident or easily apprehended (Tscharntke et al. 2005).

On managed land, ecosystem services are not produced by nature alone; they are instead co-produced from "the interaction of labor, technologies, financial capital and institutions with ecosystem processes" (Lele et al. 2013). This definition allows the ecological component of the co-production process to be distinguished from its non-ecological component (Boyd and Banzhaf 2007). It also clarifies trade-offs as those made within the provision of a bundle of services (in particular between food production and other ecosystem services) or changes in workload arising from the adoption of biodiversity-based practices (Griffon 2009; Palomo et al. 2016). Discussing these trade-offs in different local contexts is essential because actors interacting within agroecosystems in specific situations have differing perceptions of the importance of each particular service (Haines-Young and Potschin 2010), and thus adopt different practices regarding its use (Iniesta-Arandia et al. 2014). Bringing together these actors with their different knowledge helps the complexities of the human-nature relationship to be better understood (Altieri and Nicholls 2005; Díaz et al. 2018).

Companion Modeling (Commod), which combines the use of simulation models and role-playing games (RPGs) in order to discuss different points of view and their consequences in terms of action (Bousquet et al. 2002; Étienne 2013), represents an interesting approach in the context of ecosystem services for bringing different local actors into dialogue (Lamarque et al. 2014; Gissi and Garramone 2018; Moreau et al. 2019). The main goal of such an approach is to create platforms for promoting social learning (Muro and Jeffrey 2008; Reed et al. 2010). Simulation games are also used as part of knowledge-transferring approaches that help actors better understand the synergies and trade-offs between different ecosystem services (Costanza et al. 2014; Verutes and Rosenthal 2014).

In the Brazilian Amazon, a process of territorial and socio-productive reconfiguration has been observed in recent decades, shaped by interactions between a heterogeneity of social groups and institutions (Hébette 2004). This has resulted in a rapid and massive conversion of ecosystems into agroecosystems (Silva and Martins 2009). In the case of small producers, the cultivation of annual crops (e.g. cassava) represents an important activity and underwent a process of productive intensification during this period due to population growth and changes in market demand and public policies, leading to deforestation and soil impoverishment (Oliveira and Kato 2009; Jakovac et al. 2016). The adoption of agroforestry systems in this context, even though they are an interesting alternative because of their potential for providing ecosystem services (e.g. provisioning and other types of services)(Wilson and Lovell 2016), is being threatened by technical problems or lack of market demand for their products (Oliveira and Kato 2009; Coq-Huelva et al. 2017).

In order to promote realistic strategies for the adoption of these different land use systems in accordance with ecosystem services provision, it is essential to understand, the local actors’ perceptions of the opportunities, limitations and trade-offs associated with these different systems (Costanza et al. 2014; Verutes and Rosenthal 2014; Jakovac et al. 2016). However, few studies in the Brazilian Amazon have focused on that relation between environmental and social context as a driver in this decision-making process. On the basis of the use of a simulation and gaming tool in two rural towns in the Brazilian Amazon, this paper tackles the following questions: (a) How local actors take into account ecosystem services provision when managing agroecosytems? (b) What influences their choices about trade-offs among ecological and non-ecological components of ecosystem services’ co-production? (c) How can the RPG serve as a learning tool for heterogenous actors in this decision-making process and act as mechanism for the exchange of knowledge between them?

2. Materials and Methods

2.1. Context of the study

Two contrasting municipalities located in the eastern part of the Brazilian Amazon were chosen to build and implement the Commod approach. Paragominas, an agribusiness-oriented municipality, that implemented a Green Municipality Pact to halt deforestation and initiate a transition to sustainable land use (Piketty et al. 2015; Viana et al. 2016). In Paragominas, large industrial-scale grain farms (mainly growing soybean), based on the use of chemical inputs, and livestock farms represent the predominant land use (Viana et al. 2016), coexisting with rural communities and agrarian reform areas which represent approximately 80% of the number of rural properties, but only 17% of the agricultural land (IBGE 2017).

The second municipality is Irituia, oriented towards family farming. It has been host to several environmental programs, such as Proambiente, the first Brazilian program to support environmental services (Mattos et al. 2010). In Irituia, family farms represent 98% of all properties and 56% of the agricultural land (IBGE 2017). Deforestation by family farming occurs here (as it does in Paragominas), driven mainly by slash-and-burn practices, coupled with a high population density and long-term colonization (Mattos et al. 2010). Nevertheless, an interesting process of management of plant and animal diversity can be observed in this municipality, mainly in the context of agroforestry systems (Oliveira and Kato 2009).

2.2. The role playing game

2.2.1. Co-construction of the RPG

The game was developed mainly during the first semester of 2018, through a co-construction process that included, from its very beginning, farmers from Irituia municipality. They helped describe the main characteristics of local agroecosystems (i.e. size, structure, activities, agricultural practices). The farmers' contribution was sought to provide *legitimacy* (i.e. the respecting of the stakeholders' values and their management principles) to the model, which is recognized as an indispensable feature of learning tools (Duru et al. 2015). Technical and scientific knowledge was also used to determine the model's parameters in order to provide *credibility* (i.e. scientific and technical trustworthiness) to the tool (Giller et al. 2009).

An initial version of the model was developed and tested in several sessions involving farmers, students from a rural high school, and researchers. At every new session, the model was fine-tuned and improved, a process that continued until the version used for this study (Perrier 2018). Information from field visits and interviews with other local actors from Irituia and Paragominas was also indirectly used to improve the model. A major challenge of this process was to include the necessary level of information to make the model reliable in an easily playable format.

2.2.2. Conceptual model

The conceptual model of the game (Figure 1) that resulted from the co-construction process represents an agroecosystem consisting of two systems, as proposed by Tibi and Therrond, (2018). The first is the ***biophysical system*** (the game board), consisting of interactions between biotic (i.e. planned and associated biodiversity) and abiotic (e.g. the river) components existing in the environment. It also includes infrastructure such as a house and a road. The second is the ***socioeconomic system***, represented by the people who will manage (i.e. household) the biophysical system and the means used to support the production process (i.e. activities and agricultural practices). Some elements are implicit in this model, such as the ecosystem services related to the management of the agroecosystem and the role of the different actors (as players in the game) in carrying out its decision-making process.

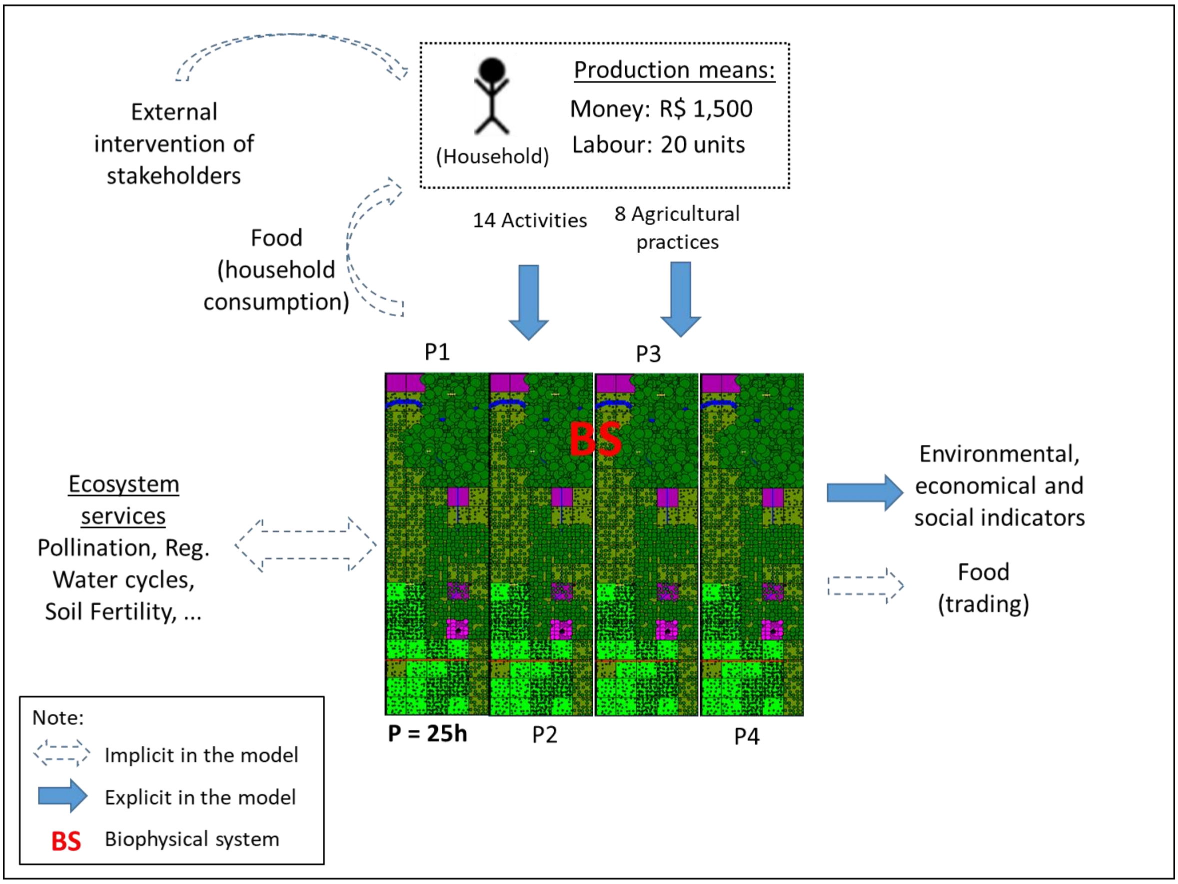

Figure 1. Simplified representation of the conceptual model of the game.

Each group starts with identical conditions (financial resources, amount of labor, and biophysical conditions of the property). During game sessions, participants are asked to select the activities they would like to perform, locate them on the game board and indicate the practices related to these activities. Each activity and practice is characterized by a financial and labor cost, a probable income and environmental impact (Appendix 1). These human decisions are inputted into a computer simulation model that simulates the dynamics of the agroecosystem and calculates a set of indicators to assess the balance between environmental and socioeconomic benefits.

2.2.3. RPG sessions

This study is based on two sessions of the game held in Paragominas and Irituia in January and February 2019. In order to encourage a knowledge dialogue, heterogeneous participants from different local institutions were invited to the sessions. This diverse group of participants was included because different types of local actors can assign specific values and usages to ecosystem services (Rives et al. 2016) and mobilize different types of knowledge (e.g. scientific, empirical) (Jankowski 2013). Each session was divided into 4 groups of participants. Each group consisted of two or three actors representing different types of institutions (Table 1). Each session lasted about 4 hours and consisted of an introductory interaction, the RPG and a debriefing about the session and also about the tool.

Table 1. Number and diversity of participants in each session.

Session	Property number	Composition of groups
Irituia (19/01/2019)	P1IRt	**Ins:** *Municipal Department of Agriculture* (1); **Emp:** D'Irituia (1); **Sci**: IFPA (1)
	P2IRt	**Emp:** D'Irituia (1); COAPEMI (1)
	P3IRt	**Tec:** EMATER (1)**; Emp:** D'Irituia (1)
	P4IRt	**Ins:** *Municipal Department of Social Development* (1); **Sci:** UFRA (1); IFPA (1)
Paragominas (12/02/2019)	P1Pgm	**Sci:** EMBRAPA (1); UFRA (1); **Emp.:** STTR (1)
	P2Pgm	**Tec:** EMATER (1); IDEFLOR (1)**; Emp:** STTR (1)
	P3Pgm	**Emp:** Cooperuraim (1); STTR (1); **Tec:** EMATER (1)
	P4Pgm	**Ins:** *Municipal Department of Agriculture* (2); **Tec:** EMATER (1).

Note : The participants are characterized according to their institutions. Ins: institutional (government); Emp: empirical; Tec: technical; Sci: scientific.

The purpose of the introductory interaction was to obtain an initial idea of which practices the local actors consider most relevant, and of whether these practices are (or are not) directly associated with ecosystem services. Each group was asked to describe the three main agricultural practices for the cultivation of annual crops and for agroforestry systems (since these are the two most important cropping systems in the region), and to explain why they implemented these practices. For some groups, questions were asked to clarify or complement some of the information provided.

The participants were then invited to play the RPG, to deepen and confront the initial ideas with an experimental situation (Figure 2). After the general rules of the game were explained to them around a central table, each team was sent to one of the 4 tables located at the corners of the room, where the team members could take decisions for their own property (each team was helped by an assistant). The central table was used to project the overall results of the groups at different times in the session and to encourage a collective discussion between the groups.

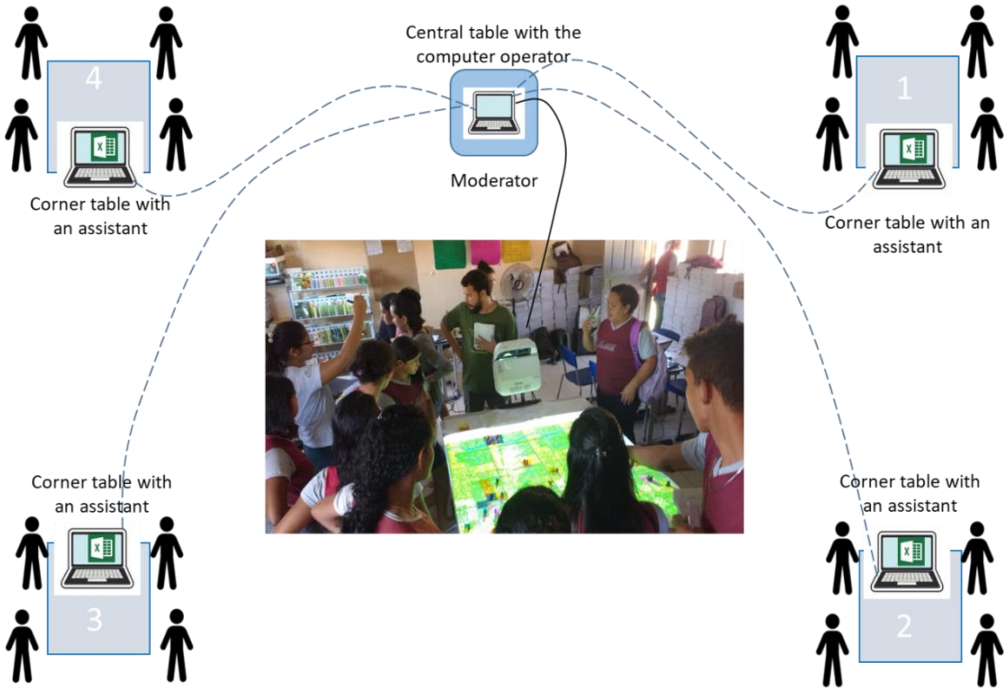

Figure 2. Layout of the spatial organization of the game session. Source: Perrier (2018).

Three agricultural years were "played" in each session. At the beginning of each year, each group plans out, while sitting at its corner table, the activities to be undertaken that year at its property. The groups then meet at the central table, place the tokens corresponding to their activities and explain their choices to the other groups. The modeler enters the choices in the computer and then presents the partial results of the environmental, economic and social indicators for each group. At the end of the third year, a computer simulation is run to project what the properties would be like after 10 years. The long-term results of the environmental, economic and social indicators provide an important perspective to be discussed by the participants. The session finishes with a debriefing, first about the results of the session (i.e. the management practices discussed during the session) and then about the RPG itself (i.e. the participants' perceptions of the tool).

A diversified set of quantitative and qualitative data was generated from these sessions. The quantitative data were obtained from the choices the players made while playing the RPG (board game recorded on the Cormas platform – cormas.cirad.fr). Qualitative information was obtained from the introductory interaction, the team and collective discussions, and the debriefing. The collective discussions and debriefing were recorded and each assistant was responsible for taking notes on the discussion process within each team.

3. Results

3.1. Introductory interaction

During this first stage of the session, the local actors mentioned several *agroecosystem configuration* and *management practices* (Table 2). Some of these practices are common to both types of systems (annual crops and agroforestry systems), though with different intensities (e.g. weeding and mechanization are more closely associated with annual crops). Some practices are specifically associated with annual crops (e.g. use of fire), others with agroforestry systems (e.g. pruning). In general, practices adopted in agroforestry systems are oriented towards the provision and use of ecosystem services. Almost all the practices included in the model were mentioned at this introductory stage of the session, which helped begin a reflection that would later be deepened by using the game. This exercise also supported the coherence of the elements included in the game, confirming that co-construction with local actors helped capture the local context.

Table 2. Agricultural practices used in the cultivation of annual crops and agroforestry systems that were spontaneously mentioned by the stakeholders and the results they expected from each of these practices.

Type of practice	Practice (n)	Expected output (n)	
		Annual crops	**Agroforestry system**
Agroecosystem configuration	Planting (2)	Increase production (1)	Increase production (1)
	Species diversification (2)	-	Increase production (1) Recovery of springs (1) Attract beneficial insects (1)

			Quality of and control over one's life (1) Biological equilibrium (1)
	Seed selection (4)	Increase production (3) Disease control (1)	Increase production (1)
	Seedling production (1)	-	Increase production (1) Plant resistance (1)
	Design location and plot size (5)	Increase production (1) Water supply (1) Clearing of land (1) Aeration of roots (1)	Increase production (1) Water supply (1) Reduce competition (1) Recovery of degraded areas (1)
Agroecosystem management	Slash-and-burn (2)	Clearing of land (2) Soil fertility (1)	-
	Mechanization (4)	Improve soil properties (1) Utilize the rainy season (1) Aeration of roots (1)	Increase production (1)
	Weeding (10)	Increase production (3) Reduce competition (3) Produce mulching (1)	Increase production (2) Clearing of land (1)
	Thinning (2)	-	Increase production (2) Reduce competition (1)
	Pruning (2)	-	Disease control (1) Strata optimization (1) Plant development (1)
	Organic fertilization (5)	Increase production (1) Quality of production (1)	Increase production (1) Quality of production (1) Soil quality (1) Fauna and flora recovery (1)
	Chemical fertilization (4)	Increase production (1) Improve plant nutrition (1)	Increase production (2)
	Liming (2)	Increase production (1) Soil fertility (1)	-
	Mulching (3)	Reduce water loss (1)	Soil protection (1)
			Moisture retention (1)
	Irrigation (1)		Improve plant nutrition (1)
	Taking care (2)	Balanced ambience (1)	Increase production (1)
		Spatial organization (1)	

Note (n): number of times that each practice was mentioned and the number of times each result was associated with the corresponding practice.

As exemplified in the Figure 3 (weeding), the expected outcome of most of the practices was the production of goods (e.g. cassava roots), even if these practices were implicitly linked to other intermediate ecosystem services (e.g. production of mulching, reduction of competition). Other practices that were mentioned directly addressed these intermediate services, revealing an elaborate vision of how to increase production or obtain other benefits from these services[21]. A diversity of other processes are also implicit in this relationship. Some have also been mentioned as the positive effects of mulching (e.g. moisture retention, soil fertility).

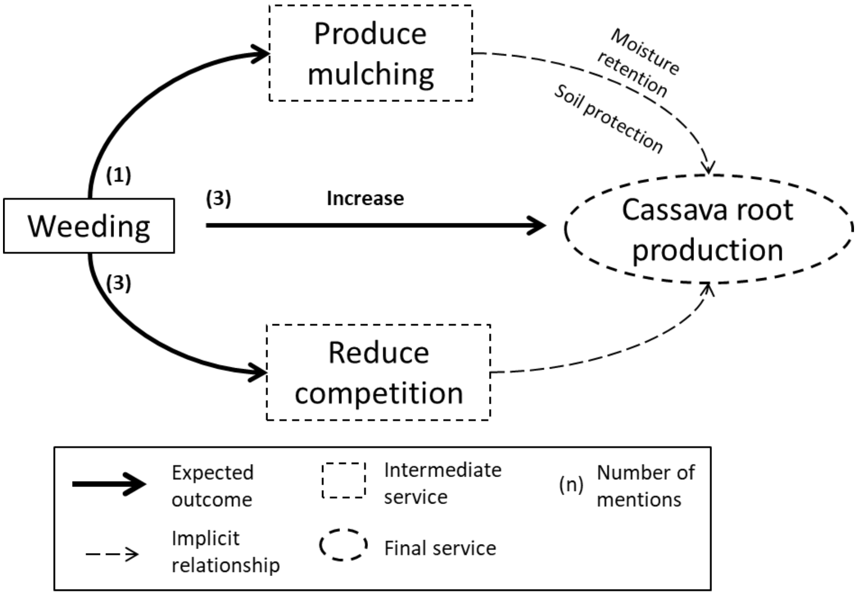

Figure 3. Relationship between weeding and the production of cassava root spontaneously mentioned by players of the RPG.

Irrespective of whether they are intended to provide final or intermediate services, management practices mentioned by stakeholders reinforce ecosystem processes (e.g. biological control, recovery of springs, attraction of insects) or link these processes with the use of inputs (e.g. chemical or organic fertilizers). The prevalence of practices focused on reinforcing ecosystem processes was observed in both municipalities. There were few mentions of the use of mechanical or chemical inputs (these were more frequent in Paragominas), possibly because these practices involve trade-offs between the provision of different services, or because of the stakeholders' personal values.

[21] Intermediate ecosystem services that contribute to improved production of goods can be called input services (Tibi and Therond 2018).

3.2. The role playing game

3.2.1. General results of the sessions

Table 3 presents an overview of the results obtained from the game sessions. It clearly shows that in both locations, participants have engaged in productive diversification. As for agricultural practices, the two municipalities exhibit divergent profiles, with a higher adoption of mechanical and chemical practices in Paragominas.

Although not explicitly present in the model, the provision and use of some ecosystem services (e.g. pollination, water regulation and supply, biomass production) was considered in the decision-making process concerning the configuration of the agroecosystem as was the adoption of other agricultural practices. It was observed that different teams used different strategies. Some teams (P1Irt and P4Irt) adopted strategies that explicitly address the use of ecosystem services, managing their properties in a way that contributes to the provision of these services. Others, even without explicitly considering the use of ecosystem services, also adopted strategies consistent with their provision (P2Irt and P3Pgm). In contrast, other groups, even if using these services to a greater degree (P3Irt, P1Pgm and P4Pgm) or a lesser degree (P2Pgm), adopted management strategies that might jeopardize their provision.

Table 3. Results obtained from the RPG sessions about the adoption of activities, agricultural practices and relationships with ecosystem services.

Property number/ Profile		Number of activities	Agricultural Practices								Type of farming system
			Mec	Irr	Herb	Cfer	CPes	OFer	OPes	Mul	
Irituia											
P1Irt	Inst	7						√	√	√	Based on ES provision and organic inputs.
P2Irt	Emp	6	√					√			Few mentions of ES and little utilization of organic inputs and mechanization.

P3Irt	Tec	5	√			√		√		√	Based on the association of ES, organic and chemical inputs and mechanization.
P4Irt	Inst /Sci	6						√	√	√	Based on ES provision and organic inputs.
Paragominas											
P1Pgm	Sci.	8	√			√		√		√	Based on the association of ES, organic and chemical inputs and mechanization.
P2Pgm	Tec	5	√		√	√		√		√	Based on organic and chemical inputs, mechanization with little consideration of ES.
P3Pgm	Emp /Tec	4	√					√		√	Few mentions of ES and utilization of organic inputs and mechanization.
P4Pgm	Inst	6	√		√	√		√			Based on organic and chemical inputs, mechanization with consideration of ES.

Note: Number of activities refers to the diversity of activities adopted by each group. Mec – Mechanization; Irr – Irrigation; Herb – Herbicide; Cfer – Chemical fertilizer; Cpes – Chemical pesticide; Ofer – Organic fertilizer; Opes – Organic pesticide; Mul – Mulching. The profile type (Institutional, Empirical, Technical or Scientific) represents the most representative profile of each team. The classification of the type of farming system is based on a balance between the players' choices (quantitative data) and on the justifications they provided for these choices (qualitative data).

We also observed different forms of playing depending on the type of actors. Farmers were more intuitive, mobilizing empirical knowledge originating from their experiences. The other professionals relied more on technical knowledge, taking decisions based on cost calculations, labor and crop yields, according to the indicators defined in the game, as well as on their personal experiences. Scientific knowledge was rarely discussed in the sessions (i.e. debating knowledge and values based on research results). Since scientific knowledge was mobilized in the co-construction phase of the model, the fact that it wasn't contested helped confirm that it was aligned with the participants' knowledge.

3.2.2. Selection and spatial-temporal allocation of activities

In choosing the **activities** (e.g. planned biodiversity), players could more specifically describe not only their underlying logic of the potential of these activities to contribute to service provision (i.e. goods and intermediate services), but also their perception of the necessity of using ecosystem services. As in the initial interaction, perennial crops were seen as a major provider (and user) of services: "*We put the açaí very close to the spring, to the water, because we needed to restore the area"* (P1Irt). In contrast, annual crops were perceived as more degrading: "*We did a cassava plantation* [...] *We didn't get close to the stream, because we're leaving this area to recover a little bit"* (P1Pgm). Annual crops were seen as an option in already degraded areas, especially when associated with mechanization.

This balance between types of activities and their relationships with ecosystem services was decisive for the teams in the allocation of these activities (e.g. spatial rationality), even if other elements (e.g. distance to the house or road) were considered. For this purpose, the association between activities and the biophysical system (i.e. the board game) as well as the association between different activities were considered. For example, forested areas or areas close to water courses were little used for annual crops (players in Irituia were most particular in wanting to preserve water courses). Priority for the use of these spaces was accorded to perennial crops, especially those more demanding in water (e.g. açai), sometimes associated with beekeeping to benefit from pollination.

As we are dealing with agroecosystems, players emphasized input services when allocating activities, such as regulation of water cycles and water supply: "*We put* [the açai] *along the river so it won't need irrigation or anything"* (P4Irt); production and use of biomass: "*We placed the annual crops in an area of secondary forest that is not so degraded. We chose slash-and-burn as an initial practice"* (P1Pgm); and, as already mentioned, pollination: "*We also installed a beehive, so that in the future we can even have pollination in the area"* (P3Irt). Services not directly connected to agricultural production were little considered.

Regarding the rationales underlying the temporal allocation of activities, the players mentioned the association between short- and long-term crops to increase the production of goods: "*We planted the citrus consortium* [...] *also thinking that these were species that had a faster payback. Passion Fruit, Orange, Tangerine"* (P2Irt); "*We will continue to manage the açaí, we increased the production from the beehives, we increased the production from the garden* [...] *Our intention is to start to earn money from the third year onwards"* (P3Irt). Some players explained in detail their crop succession plans: "*We will prepare the holes with organic fertilization here* [in an area that was planted with annual crops] *for the subsequent* *establishment of perennial crops"* (P1Pgm). A limitation of the model is that it fails to capture the temporal rationality during the farming year.

3.2.3. Agricultural management practices

Some factors such as the cost of practices, labor and effectiveness were observed during the sessions when it came to the choice of **agricultural practices** associated with particular activities. Biodiversity-based practices were prioritized in some cases because of their lower cost: "*We kept the bees because they work for free"* (P1Irt). Expensive practices, such as irrigation, were not adopted due to financial reasons: "*We started thinking about irrigating and planting açaí on dry land"* [but it wasn't feasible because of the cost] (P3Pgm). Instead practices of mulching and/or allocation of crops in flooded areas were chosen.

The players had divergent rationales as concerns labor. Situations of workforce scarcity often led to the adoption of mechanical (e.g. tractor) or chemical (e.g. herbicide) practices aimed at reducing the workload: "*We use herbicide in the cassava field to save labor"* (P3Pgm). However, there were cases in which players who found themselves in this situation chose to stop activities instead of adopting such practices, especially of using herbicide. This choice was often justified by values (respect of nature) or the possible impacts on the families' health: "*For the hardship of the work, we have to consider not only the quantity of work, but also the quality"* [in reference to the damage resulting from the use of herbicides] (P3Irt). There were also contrasting approaches to mechanization, but because of financial limitations: "*We set up one mechanized cassava plantation* [...] *Plus four plantations using slash-and-burn, because you can't mechanize everything"* (P4Pgm).

The expected results, the main one being increased crop yields, also influenced the choice of practices. This is amply demonstrated by soil fertilization practices: "*We maintained the chemical fertilization to support what is already planted, because after three years, both açaí and cocoa are already starting production"* (P4Pgm).

3.2.4. Evolution of properties

Figure 4 shows the results of two groups (P4Pgm and P1Irt). Each group was led by the coordinator of the department of agriculture of each municipality. These groups present similarities concerning productive diversification and perception of some ES, but differ mainly as regards the adoption of agricultural practices and the allocation of activities.

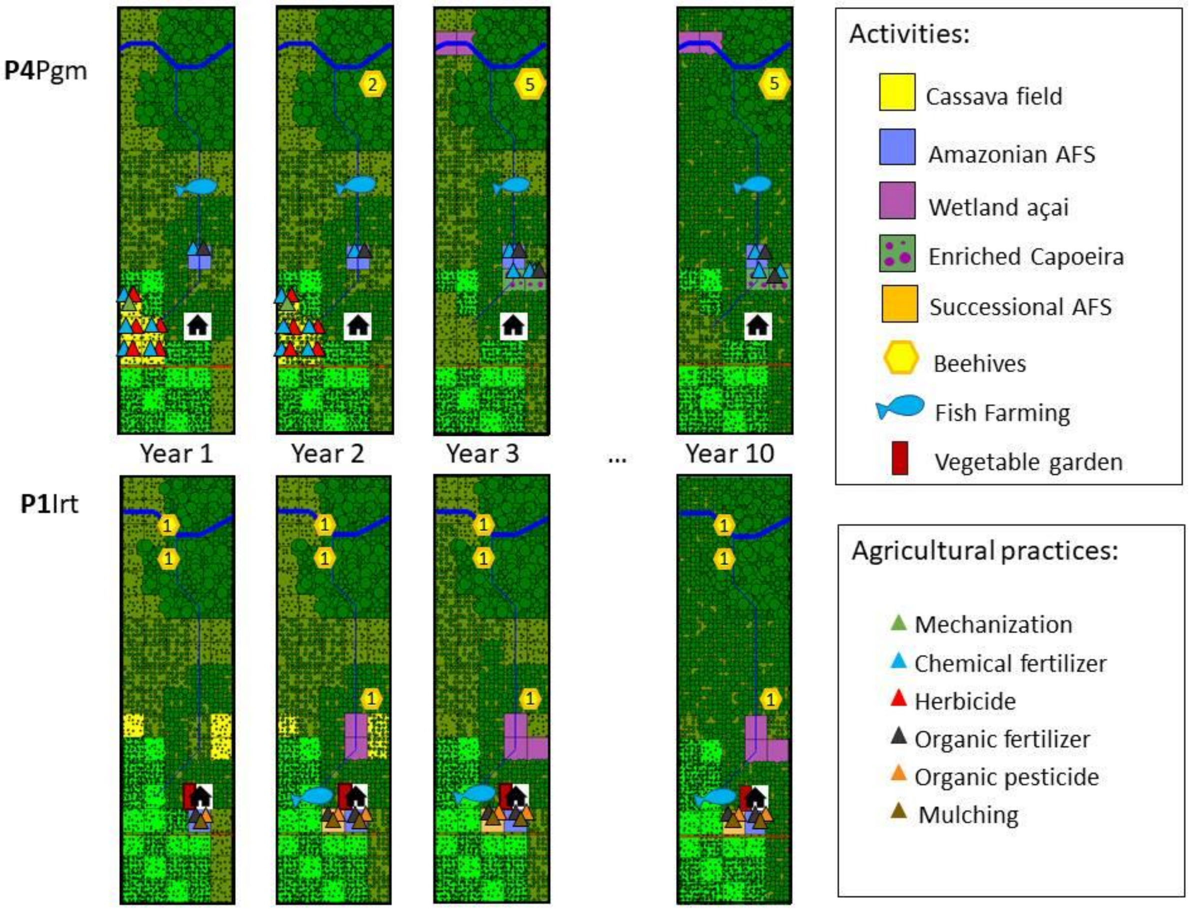

Figure 4. Representation of the results of two properties. The figure shows the 3 agricultural years played in the game and a projection of the condition of the property after 10 years.

For **P4Pgm**, the provision and use of other ecosystem services (i.e. water supply, pollination) was considered in the choice and allocation of activities, in addition to food supply. However, some decisions of this group (e.g. clearing of riparian forests for cultivating annual crops; use of herbicides and chemical fertilizers near rivers) may limit water availability in the future. The justification these players provided for the adoption of mechanical or chemical practices was the reduction in labor (through herbicide use and mechanization) and an increase in crop yields (by using chemical fertilizer). The wider adoption of some practices, such as mechanization and irrigation, was however limited due to financial constraints.

For **P1Irt**, the provision and use of services was considered a priority (i.e. water supply, pollination, pest and disease control). To this end, the players preferred to adopt organic practices for their environmental benefits and low cost. The group also tried to prevent deforestation by avoiding the allocation of annual crops near the river or in forested areas.

3.3. Debriefing

During the debriefing of the session results, perceptions were discussed, particularly of the feasibility of – and constraints and trade-offs associated with – implementing some practices. The diversity of situations that emerged in the game (cost of practices, workload) thus reflected local realities better.

As concerns the perceptions of the tool itself, the **similarity of the model with reality** was frequently mentioned by participants from both municipalities: *"I found this game interesting because I compared it to my property"* (Farmer, Irituia). Some players even suggested having the game match their own property. As one participant said, *"It would be really interesting if the picture of the property in the game could be based on the reality of the property, of the community where we are going to work"* (Technician, Paragominas). A second point discussed was the potential of the model to serve as a **planning and rural extension tool** to be used directly with farmers. "*I would find it interesting to play this game in all the communities or gathering associations so that they could learn to make a program for themselves. Many of them don't know how to do this planning. They arrive on the property, and they do things the way they think best and end up making losses"* (Department of agriculture agent, Paragominas). Many participants acknowledged the potential of the tool to **stimulate learning** by exposing elements of the rural reality in a clear format, and to help **exchange knowledge** by bringing together a diversity of actors. "*The game was a form of knowledge exchange. I learned many things from everyone. It's enjoyable, more practical and a simpler way to learn the practical aspects of rural activities"* (Student, Irituia). Participants also pointed out (and observed) that actors with different types of knowledge have different ways of playing, technicians being more influenced by the indicators and farmers being more intuitive: "*It was possible to see the difference between people who have the practice of rural activities* [farmers] *and people who are in the field, but not daily on the property* [technicians]. *Our group* [farmers' group] *was able to take decisions more quickly* *in an intuitive way, without looking at the cards. Other people had to make calculations"* (Group assistant, Irituia).

Finally, suggestions were made to improve the game. These included adapting it to local contexts (community, agroecosystem), better explaining the meaning of environmental, social and economic indicators, calibrating some indicators and including the influence of external elements of the context (public policy, rural extension, markets). Such suggestions indicate the interest of local actors in appropriating and using the tool at the local level.

4. Discussion

4.1. Ecosystem services expected by local actors when managing agroecosystems

We found that even though the main objective of agroecosystem management is the provision of goods, local actors do perceive (often implicitly) the importance of some intermediate services. It is important to understand how these intermediate services (linked to varying degrees to the functioning of the ecosystem) are perceived, because, despite their importance, they are often overlooked (Haines-Young and Potschin 2010) and there still exists some uncertainty (Fisher et al. 2009) and unawareness (Costanza et al. 2014) concerning them. Indeed, more applied research is needed to better apprehend these processes (Duru et al. 2015), but understanding the perception of stakeholders about them is an important step in that direction (Lamarque et al. 2014).

In this sense, we observed during the sessions how stakeholders perceive contributions (especially from planned biodiversity) to the provision of a set of ecosystem services and how they think these services can be used to improve the management of agroecosystems. An apt illustration is the comparison made between: (a) *annual crops*, mainly recognized for the importance of food production, but little associated with the provision of other services, and (b) *perennial crops*[22], recognized as more able to provide services (e.g. regulation of water cycles, biological control) and also as more dependent on them (e.g. water supply). This line of thinking was especially significant in determining where to place the crops (e.g. *How far from the river? In which type of land cover?*).

4.2. Local actor's choices about trade-offs among ecological and non-ecological components of co-production of ecosystem services

As concerns this question, the game sessions highlighted two situations. The first in which players *"freely" adopted their strategies.* For example, some actors decided to place *açaí* – a highly water-dependent crop – near the stream, possibly associating it with mulching (profiting from ecosystem processes). Other actors also placed it near the stream, but wanted to link it to an irrigation system to favor water supply (ecosystem processes combined with machinery). The second situation was when the players *were led to adopt a strategy*. In some cases (e.g. scarcity of money or labor), players had to decide between reducing their income (because of not implementing an activity) or adopting practices (e.g. herbicides) that could undermine the provision of ecosystem services but make it possible to implement the activity (e.g. for reducing labor charge). Different types of decisions were taken in these situations.

These two types of situations highlight that the adoption of different forms of land management (e.g. systems based on chemical inputs or on biodiversity) may be intentionally planned or driven by other factors (e.g. availability of capital) even though decision-making will finally depend on the farm manager's values, preferences and expectations. It reinforces the observation that the importance accorded to different ecosystem services by different actors depends on the local socio-economic context, rather than solely on environmental reasoning (Rives et al. 2016; Díaz et al. 2018). Thus, without considering these elements, we will not be able to understand the different possibilities of mobilizing this concept according to local contexts (Bennett et al. 2015).

[22] A differentiated degree of perception of these elements was also observed regarding the different types of perennial crops present in the game, varying according to the type of crop (e.g. citrus, palm trees) or the type of arrangement (e.g. more or less diversified).

4.3. *RPG as a learning and knowledge exchange tool*

As a learning tool, two different uses can be addressed to the game. The first concerns offering local actors the opportunity to improve their understanding of the processes and dynamics of the agroecosystems included in the model by playing the game (Costanza et al. 2014; Verutes and Rosenthal 2014). It could be observed from the game sessions that players with greater involvement in agricultural activities (i.e. farmers, technicians and managers) could mobilize and test the experience they have in managing their own properties (in the case of farmers) or the properties they support (in the case of technicians). For players with less direct involvement with agricultural activities (e.g. students and institutional managers), the tool helped to give them an idea of the challenges of managing agroecosystems.

The second refers to allowing researchers to infer the preferences of the actors in relation to agroecosystem management and ecosystem service provision, based on the choices and attitudes of these actors in the game sessions (Costanza et al. 2014). Even though this article goal did not include a comparison of the results of the sessions with real-world patterns, we noted that the results reflect the trends observed in both municipalities. For example, the higher adoption of chemical inputs in Paragominas as compared to Irituia is in accordance with the observations of Resque et al. (2019). The degree of adoption of different crops also corresponds to local realities. This suggests that the gaming sessions allow elements specific to local realities to be discussed. In this sense, since each group had the freedom to decide its own strategy, the players revealed what they thought was a well-managed agroecosystem. As noted by Moreau et al. (2019), an interesting point in not explicitly using the concept of ecosystem services during the game is to reduce the bias in players' behaviors, so as not to induce them in adopting similar positions and embracing environmental objectives that they would otherwise not have.

The game has also proven to be capable of being used as a knowledge sharing tool. Even if each type of actor had his own way of "playing" (more or less empirical or technical), the game sessions placed farmers and local actors in an experimental situation that allowed them to synthesize and discuss the different knowledge they have as well as their beliefs as to how agroecosystems should be managed (i.e. agricultural practices and agrobiodiversity, implicitly linked to ecosystem services). In this sense, the tool serves as a boundary object

(Martin 2015) for the creation of a shared language among the different types of participating actors, providing them with an arena and occasion of knowledge exchange.

5. Conclusion

The game sessions confirmed the potential of the model to serve for learning and knowledge exchange purposes. Since it is a flexible tool, the game can be adapted for use in different contexts. One example is to test suggestions of markets or public policies and see how the provision of ecosystem services can be encouraged. In this perspective, it can be of use to public managers. It can also be used for research purposes to improve the scientists' understanding of farmer practices or also with local actors to increase their awareness of a given socio-ecological system. From the game session's results, it was possible to observe not only the importance of ecosystem services for decision-making processes in the management of agroecosystems, but also that a diversity of other factors influences these processes (e.g. values, availability of factors). Bringing these elements to the discussion can help increase shared understanding of the challenges and possibilities of the ecological management of agroecosystems and indicate solutions that are in line with local expectations.

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Chapter 6: General discussion

In this last chapter, we summarize our research questions and discuss transversally how the chapters helped answer them. We conclude by underlining the importance of this research in the Amazonian context where the study was conducted, the limits of the study and future research perspectives.

The overarching objective of this thesis was to **explore the potential of the ecosystem services (ES) conceptual framework to support the agroecological transition of agroecosystems** in the Amazonian context. To achieve this objective, we initially focused on local actors with the potential to influence the co-production of ecosystem services in two municipalities of the Eastern Brazilian Amazon. We first aimed to understand their perception of ecosystem services and how the perception differs among them. This question was mainly tackled in chapter 3, which specifically explored the perception of local actors of ES and how they perceive the provision of these ES and agricultural practices. In chapter 5, our analysis of the game sessions explored the rationality of the actors in managing agroecosystems in a simulation environment, and provided qualitatively important elements related to it. Next, we sought to understand the importance of the perceptions in the decision-making concerning land use. To this end, we investigated the contextual factors that influence this decision making process, in chapter 4 by focusing on the factors external to the agroecosystem and in chapter 5 on the factors internal to the agroecosystem. Finally, we sought to understand how the knowledge generated in the previous stages could contribute to the agroecological transition in the context under discussion. We adopted a reflexive stance in selecting approaches to discuss these aspects with local actors (e.g. qualitative, game-based approaches). To this end, we relied on elements from the three chapters. We discuss these elements in more detail hereafter.

1. How do local actors who support family farmers perceive ES and their co-production process?

1.1. Recognition of ES and of associated management practices: What do local actors expect from agroecosystem management?

The concept of ecosystem services, that was proposed as a boundary object to discuss aspects of the relationship between Nature and human beings, is still rarely internalized by most of the local actors who participated in the research and the topic is seldom discussed in their circles. Results of the semi-directive interviews revealed that 47% of the stakeholders in Paragominas and 60% of stakeholders in Irituia had never heard of this concept or did not know exactly what it meant. What is more, the understanding of the concept also varied among stakeholders who were familiar with it. Despite this general lack of knowledge about the ES conceptual framework, several services were frequently mentioned by local actors. Seventeen different types of ecosystem services were identified in the semi-directive interviews conduted in the two municipalities, as demonstrated in fig 1 in the chapter 3. A similar result was observed during the game sessions described in chapter 5, in which a diversity of ecosystem services was spontaneously linked to the management of agroecosystems both in the activities that preceded the use of the game (i.e. the results listed in table 2), and during the game itself.

In both municipalities and methodologies, provisioning of goods (mainly food) was most frequently mentioned, but a number of regulating and supporting services were also highlighted. This makes sense since these services are more easily perceived and valued for consumption and in conventional markets (Lewan and Söderqvist 2002; Boyd and Banzhaf 2007). In this sense, it is important that stakeholders understand that even if the end-goal of these agroecosystems is the provision of goods, a range of intermediate services (e.g. production of mulch, reduction of competition) can support the provision of these goods. Recognizing the existence of these intermediate services and better understanding the mechanisms underlying their functioning is crucial (Haines-Young and Potschin 2010), which in addition to understanding the perception of the stakeholders concerning the mechanisms (Lamarque et al. 2014), requires further applied research to better apprehend these processes (Duru et al. 2015).

Our results also highlighted that in deforested agroecosystems in Amazon, the maintenance or restoration of ecosystem services (i.e. including goods) depends on the types of human interventions (e.g. planting or management of agroforestry systems; slash-and-burn agricultural practices). This stresses the importance of the concept of co-production of ES to better understand how agriculture is practised in these areas, in particular the different types of capital used by farmers. We observed, in agreement with the perception of ES, that the expected outcome of most agricultural practices is the production of goods (mainly food), from the different associations of mechanical-chemical (e.g. mechanization, irrigation, use of chemical inputs) or/and biodiversity management practices (e.g. maintenance of forested spaces, introduction of plants). The results of chapter 5 also demonstrated that even if in a smaller proportion, some practices (i.e. the most biodiverse or organic input based practices) were addressed by stakeholders with the primary objective of providing intermediate services, in other words, they are usually perceived as a way of increasing the production of goods through the services. In parallel, the results of chapter 3 demonstrated that biodiversity-management or organic-based practices are more likely to supply different services, both intermediate and final services.

We also provide evidence that different cropping systems were linked differently to agrobiodiversity and Nature (Chapter 4, Table 4) and consequently to the provision and use of ecosystem services (Chapter 5). This is one result of specificities of crops (i.e. phenology, susceptibility to disease, nutritional requirements, size) that consequently requires different cultural traits, as demonstrated in table 2 in chapter 5. For example, agricultural practices related to annual crops aim primarily to reduce disservices, while those implemented in agroforestry systems are more related to the provision and use of ESs. We consequently believe that it is imperative to consider the different cropping systems associated with agricultural practices in agroecosystem management.

Previous studies have linked trade-offs between provisioning and other types of services (e.g. Power 2010; Martín-López et al. 2012; Palomo et al. 2016; Landis 2017). Our results demonstrate how these trade-offs are more closely linked to the type of land management than to the exact type of service. These results are in agreement with those of Altieri (2002), who showed that it is possible to have high productive systems (in terms of goods) based on biodiversity-based-practices that supply a diversity of ES[23]. Thus, to conceive a perspective of the agroecosystem as a provider of "bundles of services[24]", the first step is to understand the synergies and trade-offs in the delivery of ES associated with different land management systems in space and over time**.** Building on the results of chapters 3 (relation between agricultural practices and ES) and 5 (spatial-temporal dynamics of agroecosystems according to different associations of activities and agricultural practices), it is possible to infer and discuss aspects related to the provisioning of bundles of services. This is important because adequate management of agroecosystems to make it possible to benefit from these processes is often jeaopardized by unawareness of the range of different connections (Duru et al. 2015).

Finally, the results of chapters 3 and 5 underline the logic of the understanding family farms as a space for the provision and use of multiple ecosystem services (and also disservices) that are interconnected. It is consequently more logical to conceive each of these units from a systemic view i.e including the synergies and trade-offs linked to the provision of the different services, rather than from a perspective that considers each service individually (as presented in Salliou 2017), which involves a risk of disregarding their interactions. This discussion thus reinforces the concept of multifunctionality[25] in family farming (Landis 2017), particularly if we consider the different ecosystem functions mentioned by stakeholders during our field research as useful, include multiple tradable and non-tradable elements (used for self-consumption) and also some functions that are recognized in addition to, or irrespective of, its use values (i.e. "value attributed just to the existence of the *service*", as proposed in De Groot et al. 2010). We thus reinforce the idea that a multidimensional rationality (economic, social and environmental) of valuation of services is imperative when dealing with smallholders as these units are related to both

[23] In this case, other challenges such as an increase in the workload or a lack of markets are observed. We discuss this aspect later on.

[24] "Sets of ecosystem services that repeatedly appear together in space or over time." (Raudssep-Hearne et al. 2010)

[25] As noted in Méral and Pesche (2016), pg. 31, the concept of multifunctionality, close to that of ecosystem services, was predominant especially in France before the emergence of the concept of ES, to depict the different functions of agriculture for society beyond the production of goods, such as environmental protection and cultural aspects.

economic and non-economic aspects of management of agroecosystems (De Groot et al. 2010).

1.2. How do the perceptions of ES and of associated management practices differ among stakeholders?

The results of the semi-directive interviews and of the game-sessions demonstrated that the perception of the different elements mentioned above related to the co-production of ES varies considerably among local actors. This raises the need to better explore what is behind the formation of these cognitive aspects. Although this topic has been little explored to date, a few previous studies (Lewan and Söderqvist 2002; Lamarque et al. 2011; Martín-López et al. 2012) demonstrated that a range of factors (e.g. local aspects, gender, human/rural, formal education, environmental education) influence people's perceptions of co-production of ES. Few of these studies were conducted in developing countries. This doctoral thesis contributes to this topic by demonstrating that, in agricultural areas of the Amazon, local aspects and the stakeholder knowledge and the activities performed by stakeholders are important factors in differentiating the perception of these stakeholders about ES and agricultural practices.

The results of chapter 3 demonstrated the relevance of local aspects in identifying which services are perceived by local actors (i.e. Fig. 1 and Fig. 2) and suggested that, in addition to other aspects (e.g. type of activity, ideological positioning), it also differentiates stakeholders' perceptions of how agricultural practices and ES are linked. For example, some ES that were perceived mainly or exclusively in Paragominas, such as Climate regulation and Carbon Sequestration, had been widely discussed in this municipality in connection with the "green municipalities program", which focused more on industrial agriculture. In Irituia, we observed an emphasis on the services more correlated with the logic of family agriculture, such as the production of food and intermediate ES that can support this production, such as those linked to soil fertility and pest and disease control. Moreover, the results of the game sessions presented in chapter 5 indicated a preference for mechanical-chemical practices in Paragominas compared to Irituia. This is consistent with the results of chapter 3 that suggested a greater perception of the importance of these practices for the production of goods, as well as of their negative impacts (worsened by deforestation) on services such as water supply in Paragominas. This constrated with Irituia, where stakeholders emphasized the negative effects, especially of the use of agrochemicals, on food quality, as well as the negative impacts of fire on biodiversity.

These different perceptions may arise from which ES are considered to be relevant for agricultural production in each municipality and also a consequence of the predominant production pattern (which includes land use forms and paradigmatic aspects) in the municipality (for further details, see chapter 2). For example, the “disservices” mentioned in Paragominas are possibly a reflection of the decades of destruction of the forest partly conducted by smallholders, but primarily by extensive livestock and timber extraction in the municipality and by planting soybean, the latter also being linked to the extensive use of chemical inputs. In Irituia, the accentuated perception of the negative effects of agrochemicals on food quality and of fire on biodiversity may be a response, to respectively, the orientation of the municipality in encouraging organic farming and to the predominance of slash-and-burn agriculture due to the lack of alternatives to the use of fire.

As a contribution to this debate, the results of chapter 3 demonstrated that perceptions of ES and the associated agricultural practices also vary depending on the type of activity undertaken by each stakeholder. These results are in agreement with those of Fontaine et al. (2014) wich states that, “stakeholders from different sectors (agriculture, forest and nature conservation, flood protection, etc.) tend to overlook the effects their plans may have on ES linked to other sectors”. For example, stakeholders concerned with the production of food are more likely to adopt behaviours to maximize production of these ES, which may entail in the adoption of mechanical and chemical practices, whereas stakeholders dealing with consumption are more concerned with healthier practices and better quality products. Enabling actors with different interests to exchange knowledge and perceptions could lead to mutual understanding. Nevertheless, reconciling (or not) these different visions in order to supply ES critically depends on how governance arenas and power relations are configured locally (Reyers et al. 2013; Spangenberg et al. 2015; Miler and Wiborn, 2018).

Finally, the results of chapter 3 demonstrate that differences in the perception of “which ES are perceived” by stakeholders are not directly related to the type of knowledge they have. That is, farmers and scientists, for example, may have the same pattern of perception of ecosystem services (e.g. the importance of soil fertility) in a given context. However, previous studies suggest that more qualitative aspects of the perception of services (i.e. the mention of highly scientific or empirical observation of services) are indeed influenced by the type of knowledge (Altieri 2004; Martín-López et al. 2012). This is consistent with the results of the game sessions described in chapter 5, where we observed different ways of playing the game by farmers representatives (decisions more based on empirical observations) and by other technical scientific actors (decisions more based on indicators) aimed at providing an ES or not.

In this regard, Lewan and Söderqvist (2002) suggested that some services may be perceived by the "senses" and can therefore be understood by experience or empirical observation, while others encompass invisible mechanisms and hence require theoretical background to be understood. This logic can also be applied to different ways of perceiving the same service, since, as demonstrated by Costanza et al. (1997) and reinforced by our results, the same service can be linked to different ecosystem functions. Hence, even if farmers and scientists perceive, for example, that soil fertility is an important ecosystem service, they may perceive this through different "lenses".

For example, farmers may be familiar with different plants that improve soil conditions through their daily observations (but also by taking part in training and development programs):

> *"It will make the land fertile again, it will restore the soil. This will depend on what you planted, like mango, inga, cocoa, the peach palm itself. In a way, that land that was there without profit will be fertile again." (STTR representative in Paragominas).*

Scientists, in turn, will have the scientific knowledge of the precise mechanisms through which these plants improve soil conditions based on theoretical knowledge:

> *"The design of a more diversified system will solve soil problems, nutrient cycling, biomass accumulation, biological activity [...] A plant that accumulates phosphorus, a plant that accumulates potassium, what happens in the process as a whole in the natural environment." (EMBRAPA representative in Irituia).*

The two types of knowledge can be complementary and thus broaden the perception of ecosystem services and land use (Altieri 2004). Empirical knowledge is important to design locally adapted management systems, including identification of the local crop varieties and animal breeds and their behavior in a given ecosystem, which should help conserve agrobiodiversity (Altieri 2004; Cerdán et al. 2012). Scientific knowledge is important to coordinate the learning process (Geertsema et al. 2016) by accessing traditional local knowledge and translating the principles into practical strategies for the sustainable management of agroecosystems (Altieri 2004).

Interestingly, some farmers undertake different activities with the aim of improving technical and scientific knowledge, and some technical-scientific actors originate from rural areas and/or actively participate in field activities with the farmers. Previous studies, such as Cerdán et al. (2012) and Jankowski (2013) suggest that these actors develop a hybrid knowledge and acquire a more complete view of the complexity of social and ecological features of the agroecosystem. However, to be effective, the co-construction of this "agroecological knowledge" based on empirical and scientific aspects requires the use of appropriate methodologies and the identification of the most relevant informants to provide coherent information (Faugere et al. 2010; Geertsema et al. 2016).

2. How do different factors that are internal and external to the agroecosystem influence the co-production of ES? From expected to co-produced ES

A decision is a preferential action taken by a person based on knowledge, values, and influenced by socioeconomic and ecological contextual factors (Lamarque et al. 2014). The results of chapter 5 help reveal what lies behind stakeholders' attitudes and decision making concerning agroecoystem management. In turn, the results of chapter 4 highlight the importance of certain contextual factors external to agroecosystems that influence land use management, notably institutional markets, but also other factors such as the supply of inputs, rural extension, and sanitary legislation related to the activity of local actors who influence different parts of the chain of co-production of ES (Spangenberg et al. 2014). We now explore these two situations.

2.1. Internal agroecosystem factors related to the co-production of ES

Game sessions allowed us to observe how some material and cognitive factors intrinsic to agroecosystem[26] (e.g. costs, workforce, knowledge, values) influence stakeholders' decisions concerning agroecosystem management (i.e. implementation of activities and agricultural practices) in a simulation environment. In the initial phase of the game sessions, each team had access to sufficient resources to adopt different activities and agricultural practices, which allowed players to implement their preferred decisions based on their cognitive assets (e.g. knowledge, preferences, values). In this case, practices based on biodiversity, mechanical-chemical practices or the association of both types of practices was adopted. As the game session progressed, most of the teams faced scarcity of some of these resources, which prevented them from implementing certain preferential decisions. In this case, different reasoning was observed. Some players decided to (a) implement an activity but not in the ideal way (e.g. to plant açaí but without irrigation); (b) adopt alternative practices or activities (e.g. to use herbicide to save labour; to use fire instead of a tractor); (c) or not implement an activity rather than apply a non-preferred practice (e.g. not plant a new field of cassava field rather than using herbicides to save labour).

What are the social, economic, and environmental costs of using the different resources mobilized by farmers in this decision-making process? Herbicides, for example, are important to reduce workload and chemical fertilizers to improve short-term yields. In this case, farmers who adopt these inputs save workforce and, probably increase their yields compared with other farmers who did not chose this pathway (both in the game and in the real world situations). By considering only these trade-offs, farmers may not feel encouraged to engage in biodiversity-based agriculture, especially if they are not paid or incentivized to do so and also because the negative aspects of using of these agrochemicals (e.g. on the health of farmers or the negative long-term effects on the productivity of goods and other ES) are not easily perceived in the short term.

[26] Van der Ploeg 2009, calls these factors the "self-managed resource base".

The results of the game sessions contribute to this debate by reinforcing what was proposed in Lamarque et al. (2014), i.e. that the balance of the availability and use of "physical resources" (e.g. money and workforce) are important factor in the implementation of management practices, but other factors are also taken into consideration by decision-makers. Notably, the actors' **values**: a decision not to adopt a particular practice (e.g. use herbicide), even in a situation where it was required, was usually justified in the game by a sense of value. The **provision of ES** was also recognized as one of these drivers, whereas **knowledge concerning ES** itself and about how management strategies can have an impact on the delivery of these services also plays an important role. For example, in the game, some teams mentioned the provision of some services as an objective of their strategy (e.g. the supply of water), but implemented forms of management that jeopardized the provision of these services (e.g. clearing of riparian forests to cultivate annual crops). These attitudes were partly the result of not knowing the effect of certain practices on service provision.

In this regard, Stern (2000) argues that the possibility of behaving according to preferred decisions is 'strongest when contextual factors are neutral and approaches zero when contextual forces are strongly positive or negative – effectively compelling or prohibiting the behavior'. Moreover, more concrete values and knowledge on a given topic, as opposed to the influence of contextual factors, will make local actors more confident in their decisions (Stern et al. 1999). We thus suggest, in terms of ES co-production, that a "positive" external context toward provisioning of ES (e.g. favorable policies, market incentives) may favor their supply, but that even in an adverse scenario like that described above, some farmers with greater knowledge and who recognize the importance of ES may continue along the path toward biodiversity. In the following section we discuss the influence of factors outside the agroecosystem on the provision of ES.

2.2. Institutional markets and co-production of ES

The food procurement programs[27] described in chapter 4 are **socioeconomic external contextual factors** that increased or created market for a wide range of crops. They

27 As described in chapter 4, these policies, which were incororated in the National Policy for Agroecology and Organic Production (Política Nacional de Agroecologia e Produção Orgânica, PNAPO),

consenquently altered the importance (i.e. use value attribution) given to these crops and improved farmers' welfare mainly through the income received from the sale of the products (Figure 1), but also indirectly improved the welfare of those who consume the products. As observed by Spangenberg et al. (2014), changes in human demand for an ES (and consequently in its "use value attribution") lead to alteration in the level of management of agroecosystems in order to increase the supply of this service, if allowed by other contextual factors (e.g. legal restrictions, lack of material resources, values, norms), with possible cascading impacts in a set of correlated ES.

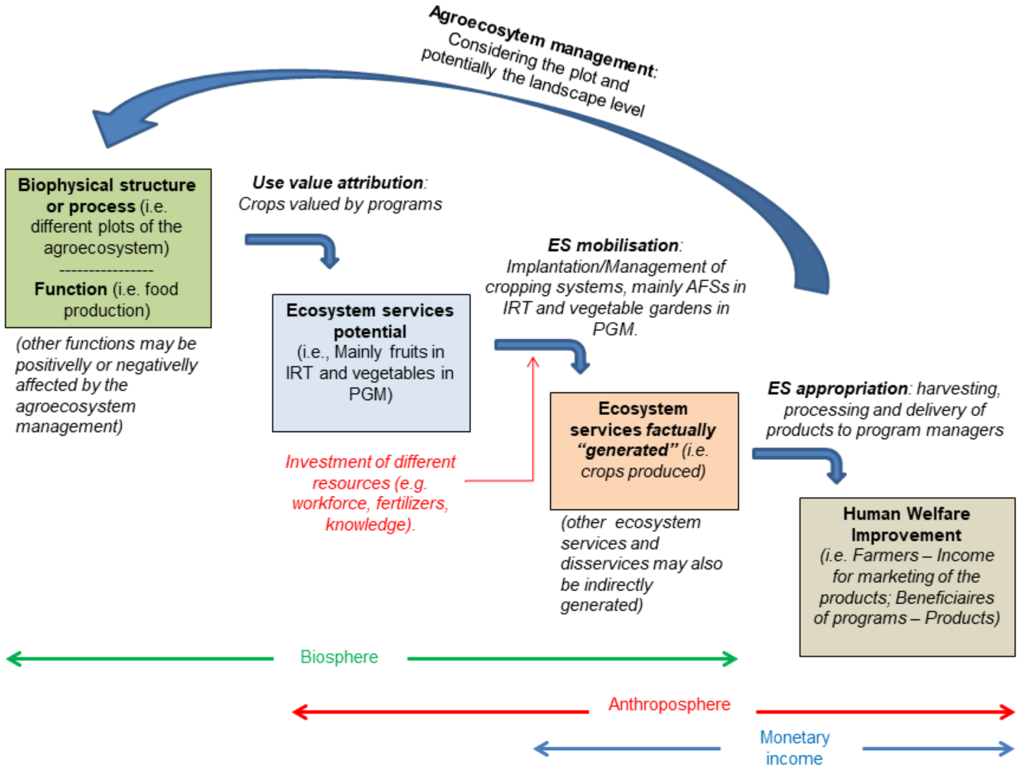

Figure 1. Scheme of generation and use of ecosystem services, contextualized to the food procurement programs (PNAE and PAA) in Paragominas and Irituia (Adapted from Spangenberg et al. 2014b).

In **Irituia**, mainly crops from Agroforestry Systems (AFS) were traded in such programs (Chapter 4, Tables 3 and 5). Many of these crops were underused locally because they had

purchased products from farmers (individually or from farmer cooperatives) for delivery to students (i.e. PNAE) or people living in poverty (i.e. PAA).

no market value and their production exceeded household needs but became "an economic good" thanks to the programs. AFS in Irituia are traditional low input systems based on biodiversity management (Oliveira and Kato 2009). The expansion of cultivation using these systems in this context has contributed to forest restoration in areas where this process has been most intense (Carneiro and Navegantes 2019) and (even if possibly unintended) normally to the provisioning of a set of ecosystem services (e.g., soil fertility and erosion prevention, regulation of water cycles, climate regulation) that previous studies associated with AFS (e.g. Wilson and Lovell 2016). In this sense, landscape management driven by programs and other contextual factors[28] may be recognized as sustainable and socially adapted to the traditional forms of land use practiced locally.

In **Paragominas**, mainly vegetables grown in home gardens were traded by the programs. Unlike the case of the AFSs, there was already an active market for these products in the municipality especially for farmers who live near the city centre. For these farmers, the vegetable gardens were extended and valued, and for farmers who did not yet have access to a market, vegetable gardens were a new source of income. Vegetable gardens cultivated in Paragominas, are generally systems that require different resources (i.e. workforce, fertilizers, pesticides/herbicides, irrigation). Even if there are some farmers associated with the programs who cultivate gardens without the use of mechanical-chemical inputs (possibly because they lack the necessary financial resources), most of the farmers do use such inputs. Unlike Irituia, in Paragominas the type of land management related to programs in this municipality (mainly vegetable gardens) has not led to improvements in the environmental aspect of the agroecosystem and has added some products that are culturally unusual in the local diet (e.g. spinach).

Some factors can explain the differentiation between municipalities in terms of decision and attitudes towards land use management through programs. The **local context** (e.g. local institutions, traditional land uses) represents a first point, already described in differentiating the different paths adopted. The different patterns of **knowledge** and **values** regarding the adoption of agricultural practices among stakeholders from both places may be another aspect. Figure 5 in chapter 4 shows that stakeholders directly responsible for the programs

[28] Procurement programs were one of a series of actions that were carried out over this period in terms of valorization of AFS. See Chapter 4 for a more complete overview of these actions.

in both places have little knowledge on the co-production of ES provisioning. They are more concerned about using healthier practices, as presented in chapter 3, Figure 3, which is normal because they are in the position of consumers. Nevertheless, in chapter 4, we demonstrated that demand for products produced using no chemical inputs through programs was only prioritized by the actors in Irituia, which, in addition to the programs, represents an effort to access agroecological markets at regional and national level, especially in the case of the “D'Irituia” cooperative. Our results also demonstrated that, among the stakeholders indirectly linked to the execution of programs (who are more aware of co-production of ES), the use of mechanical chemical practices was considered to be more relevant by those stakeholders in Paragominas than by those in Irituia. Moreover, the **ideological** and **cultural** factors that represent a sense of value, were broadly considered by stakeholders in Paragominas as an obstacle to the adoption of biodiversified systems, as shown in chapter 4, Figure 4.

In this sense, it would be interesting to conceive the scheme of the cascade of generation and use of services described in figure 1 (such as stairways), starting from the expected benefits (e.g. income generation from the products marketed; provisioning of other ESs) (Spangenberg et al. 2014), and end with the plans required to manage each farm (i.e. also considering the different plots) linked to the programs, first of all in order to produce the products to be marketed. In so doing, using a “demand side driven approach”, it will be possible to identify the necessary agroecosystem management and the impacts of this intervention on the supply of the targeted ES (i.e. crops) and on a set of associated ES. As long as the number of "individual" farms participating in programs in each municipality increases (i.e. in 2017, about 80 farms were participating in programs in each municipality, as demonstrated in chapter 4), it would be possible to think about landscape management[29].

In our example, program managers are the main actors responsible for determining which products will be required by programs (and the corresponding production rules) and also for dealing with the set of contextual factors discussed above. Farmers and other stakeholders also have considerable influence over this decision-making process. We demonstrated in

[29] Unfortunately, this is not the case, as the programs have been weakening since this period in these municipalities, mainly in response to recent political instability in Brazil. See Sabourin et al. (2020) for a recent analysis of the context of public policies related to rural areas in Brazil.

chapter 3, Figures 2 and 3, that these different stakeholders have different perceptions and expectations of the co-production of ES. Thus, in order to make virtuous progress towards the sustainable management of agroecosystems, it is necessary to: **(a)** understand the impact of different management pathways (i.e. crops and their production pattern) on the provision of the targeted and associated ES and on different socioeconomic indicators at agroecosystem scale; **(b)** help the different stakeholders become aware of these elements; and finally **(c)** try to identify feasible alternatives for management that account for the different constraints (i.e. from the other contextual factors) related to this process.

3. How to formalize knowledge related to ES co-production and enable stakeholders to discuss it using appropriate methodological tools to steer the agroecological transition?

3.1. Importance of the conceptual framework of ES to steer agroecological transition in our two study areas

We previously demonstrated the effectiveness of the conceptual framework of ES proposed by Spangenberg et al. (2014) to explain the different aspects of the ES co-production chain in order to correlate the benefits of ES and the possible impacts of adopting different management pathways on the supply of targeted and associated ES. This framework makes it possible to group together different social, economic and environmental aspects of land use that are relevant for the implementation of agroecological transition in real world situations. However, recent studies (e.g. Duru et al. 2015; Geerstema 2016) have demonstrated that the operationalization of the conceptual framework of ES is still jeopardized by knowledge gaps and by the lack of adequate methodological tools to explore the complexity of issues related to this concept in different contexts and at different analytical scales. Some of these gaps were highlighted at the end of the previous section.

In agreement with Salliou (2017), in this thesis, we considered that it is not possible to analyze the provisioning of ES only from an ecological perspective without considering human demands, as ES are social constructions (Barnaud et al. 2015), i.e. the result of human perception. **Hence, from a constructivist perspective, analyzing what services are perceived (and valued) by local actors to be co-produced at the scale of agroecosystems, our contribution to the operationalization of the ES concept consists in (a) generating actionable knowledge about the social system (i.e. knowledge of drivers and preferences of stakeholders) and ecological systems (i.e. knowledge about the ecosystem processes) that are complementary in supporting land use management capable of supplying multiple ES, and (b) trying to formalize this knowledge through appropriate methodological tools (e.g. model, indicators).** We discuss these implications in the following section.

3.2. Co-producing actionable knowledge about ES

Two distinct and complementary objectives were identified by analyzing local actors' knowledge about ES (Faugère et al. 2010): **(a)** to better grasp their level of understanding and preferences about ES; and **(b)** to generate new knowledge about the technical characterization of local agroecosystems and the logics underlying their functioning in relation to ES by eliciting this knowledge. In this thesis, we applied these different elements as follows.

Our results increase our **understanding of stakeholders knowledge and preferences about ES**, in particular:

- ➢ The results of chapter 3 reveal which services are perceived by different stakeholders and how they perceive the co-production of these services;
- ➢ The results of chapter 4 shed some light on the challenges that participants perceive in co-producing these ES;
- ➢ The results of chapter 5 enhance our understanding of how stakeholders are making decisions when dealing with the different trade-offs and drivers associated with ES delivery.

This kind of knowledge is useful to understand the different stakeholders' expectations regarding the co-production of ES, their reasons for valuing these ES, and also their expectations in mobilizing these ES, that can be used to look for feasible management solutions.

Building on local actors' knowledge, our results also help understand different aspects of ES and to co-producing **new local "scientific" knowledge**. This new knowledge includes:

- The correlation of agricultural practices and ES, from the results of the interviews described in chapter 3. In this case, even if different ES and agricultural practices were perceived, few contradictions were observed in the statements made by the different stakeholders about how a particular agricultural practice affects the provision of a given service. As mentioned by Faugère et al. (2010), the "same relationship expressed by different informants can be considered as potential new scientific knowledge". Thus, in the current state of scientific knowledge, investigation of these statements may make it possible to increase awareness about the local effect of agricultural practices on ecosystem services;
- The way elements of the social context and drivers that are external to agroecosystems affect the process of co-production of services (mainly access to markets), from the investigation of the implementation of the procurement programs described in chapter 4;
- The co-construction of the game allowed the hybridization of knowledge through the definition of indicators of certain internal drivers related to agroecosystem management. In this case, the information included in the game mostly relied on the knowledge of local actors who were considered as experts of the local agroecosystems, that was then articulated with technical and scientific knowledge, as detailed in Perrier (2018). The hybrid knowledge that was generated gave rise to a common formalism containing the information deemed relevant by the group of actors involved in the co-construction process, as advocated by the companion modeling approach (Etienne, 2009).

These results help formalize stakeholders' knowledge about land use management (and the expectations and factors that drive these actions) through the ES conceptual framework. It represents operational knowledge about ES issues in our two study areas, which was obtained from and can be used to feed methodological tools to support agroecological transition as discussed below.

3.3. Methodological implications: Generation of an actionable framework from actionable knowledge

A "mixed methods approach", combining qualitative and semi-quantitative elements (see Anguera et al. 2018 for a review), was used in this thesis to gather the different types of information about ES discussed above. This was necessary since, as noted by Satler et al. (2018), “monodisciplinary and single-method-approaches did not do justice to the complex issues of sustainable ecosystem service governance and management”. The combination of qualitative and quantitative methods has also proven useful, as demonstrated by Murray et al. (2016), as a research approach to investigate aspects of the perception and values of local actors.

Mainly in the early stages of this research, we used some standard qualitative methods used of social sciences, such as semi-directive interviews and participant observation. These methods were subsequently combined interactively with semi-quantitative methods, such as the use of questionnaires and the use of a co-built role-playing game. Qualitative methods were important for the exploratory research, as well as for capturing information about local socio-ecological systems and about the different perceptions and values of local actors concerning the research topics. Quantitative methods mainly served to translate abstract information into more easily observable and measurable indicators, which could support the decision-making process, especially on management strategies.

Concerning quantitative methods, Satler et al. (2018) highlighted the usefulness of "simulation and role playing games" in comparison with other research methods (e.g. social network analysis, qualitative comparative institutional analysis), as an appropriate way to discuss aspects of ES governance and management. The co-construction of the game in the framework of this thesis generated new knowledge about local agroecosystems that was subsequently incorporated into this tool and made it possible to investigate stakeholders' perception of ES (i.e. in the game sessions). In this sense, the game could transform and formalize a variety of elements of the conceptual framework of ES in a tool that is accessible to different types of stakeholders, thus becoming a transdisciplinary “boundary object”. The innovative features of the game as a tool for unraveling aspects of co-production of ES, are (a) bringing this discussion to the agroecosystem level (but also considering the plot level), since the vast majority of mapping and visualization methods for ecosystem services refer to the landscape level (De Groot et al. 2010); (b) being developed based on a context of smallholders in the Amazon; (c) representing a multidimensional tool, which includes different types of capital (e.g. natural, manufactured, social, financial) related to agroecosystem management.

Original information related to the different types of capital included in the model were translated, in a simplified manner, into environmental, social and economic indicators of land use linked separately to each activity, each agricultural practice and, in the case of environmental indicators, to the location (Appendix 4 of chapter 2). This feature of the game allowed players to make choices about how to invest limited resources in distinct land use options (i.e. activity and agricultural practice) and to assess and discuss the results of their choices in each dimension for each plot[30]. The game platform then enabled the generation of space-time information at the agroecosystem level of the environmental, social and economic costs and gains in relation to the different land use options[31].

Indicators are methodological tools capable of aggregating and quantifying information about a complex system in order to simplify and make more visible certain processes of interest for analysis, hereby facilitating the decision-making process (Van Bellen 2005). Indicators have already been used for ES, but usually at the landscape level and in a format that is not necessarily accessible to local actors (Van Oudenhoven et al. 2012). Hence, co-constructing with local actors a multidimensional *framework of indicators* correlated with agroecosystem management (like those included in the game in a simplified manner) that is easily monitored and understandable by the local actors, represents a useful tool for clarifying the complex process of co-production of ES in agroecossytems and for operationalizing the use of the concept of ES for best decisions on agroecosystem management (also considering the different plots), contributing to promote agroecological transition.

In this regard, a twofold challenge is **(a)** choosing the appropriate level of complexity of these indicators in order to insure the **framework** is adequate but not too complex (Van bellen, 2006); and **(b)** to deal with the uncertainty derived from the ecological and agronomic knowledge gap about the relationship between agricultural practices and ES supply (Barnaud and Antona 2014; Duru et al. 2015).

Especially concerning this last point, the role of the moderator in all the sessions was to make it clear that the model represents, for didactic purposes, a simplification of reality.

[30] These indicators have continued to evolve since the last session used for the thesis.
[31] This potetial of the tool was not fully explored in the game sessions.

Thus, the lessons shared throughout the sessions (sometimes about real life situations presented by the participants) should be considered in relation to each local context. In addition, validation by the the same local actors who participated in the sessions defining the model parameters represented a way to legitimize it. The contributions of the participants in the sessions also served to better calibrate these parameters, giving "credibility" to the socioeconomic indicators (e.g., labor, cost of practices, values) included in the game (Giller et al. 2009). Still related to the knowledge gap, the results of chapter 3 also helped clarify in a one-dimensional way, the relationship between agricultural practices and the provision of different ecosystem services. Information about contextual factors influencing ES co-production (e.g. markets and other drivers) described in chapter 4 may also be useful in this regard. The results of these 2 chapters could be used **(a)** to enhance the framework of indicators used in the game[32] and also **(b)** to build new methodological tools, such as the participatory framework of indicators (e.g. MESMIS).

The scientific results of the thesis (i.e. the social and ecological aspects of co-production of ES) and the methodological tools produced (and that remain to be produced) are thus, respectively, "actionable knowledge" and "actionable framework". They should facilitate the decision-making process for the implementation of a biodiversity-based agriculture (i.e. agroecological transition), by informing different aspects of the ES co-production chain, from the ecosystem process to the generation of human well-being and by enabling stakeholders to access and discuss this information.

4. Challenges, limits and future outlook

This thesis investigated several aspects of the relevance of ES as a conceptual framework as a cognitive and operational basis to support the agroecological transition. An initial remark in this regard refers to the specifity of the case studies and the limits of producing a discourse referring to 'the Amazon' by generalizing from two study sites. At different moments during the producion of this thesis, we were confronted with the difficult choice between deepening our knowledge of these two sites, and extrapolating, even if more

[32] Game sessions can be used to progressively improve these (and other) indicators through the contributions of participants.

superficially, to other study sites. As described in Schlüter et al. (2019), designing and using the same simulation tool in our two case studies allowed us to take a first step towards the creation of "middle-range theories", which in our case refers to exploring "causal mechanisms and processes" behind the co-production of ES in these contexts. In terms of scale of analysis, through the agroecosystem concept, we decided to focus mainly on the farm level (correlated with certain aspects at the municipality level). This prevented us from performing a more exhaustive analysis of the social and ecological factors of ES co-production at the landscape level, or even delving into the agronomic aspects at the plot level. However, our choice of scale allowed us to explore different aspects that are behind the decision-making process concerning land management, that are intrinsically related to farm level.

We highlight two current challenges to the agroecological transition in the Eastern Brazilian Amazon. The first is to enable farmers who continue to use traditional practices (which are the basis of many agroecological practices – See Wezel et al. 2014 for a review), either by choice, or because they lack the financial resources, or are not aware of the technological package offered by the green revolution, to improve their own welfare (e.g. higher yields, improved economic performance, enhanced labor conditions) and still remain "agroecological". The second challenge is to enable those who have already started the often precarious process of using external chemical inputs, to return to agroecological practices. As we have demonstrated, both challenges depend on a favorable institutional environment. Thus, the important contributions of the conceptual framework of ES to meet these challenges consist, above all, in the capacity to highlight **(a)** the different resources linked to the management of agroecosystems, **(b)** the social, economic and environmental impacts of the use of contrasted management practices, i.e., more or less agro-ecological; and **(c)** the contextual factors that influence the adoption of those contrasted practices. Discussing these elements in the Amazon is particularly relevant, as Amazonian farmers often have to deal with scarcity of different resources, which makes land management a reflex, rather than an intentional decision made by the farmer, to exploit available ressources. Our results are thus relevant for the region, as there are few references that address these questions from the lens of ecosystem services either in the Amazon[33] or in developing countries in general. The vast majority of empirical and theoretical studies on ES, many of which we used as a basis for writing this thesis, took place in Europe.

One methodological challenge we encountered was the difficulty involved in articulating social science methods and a simulation game. Implementing a “mixed method approach” allowed us to access a set of different sorts of qualitative and quantitative information that subsequently allowed us to create a platform that has proved to be useful both for learning and knowledge exchange on ES, and that could be used to promote new participatory patterns of governance. Despite this positive aspect, implementing such an approach is challenging in particular due to the time required for the co-construction of the model.

At least two perspectives in terms of research and actions could be developed by building on this thesis. The **first**, intrinsically related to the above mentioned methodological challenge, would be to deepen the discussion of indicators related to the use of agricultural practices. The development of multidimensional indicators related to environmental, social-cultural, and economic aspects of land use could be used to feed the game or through the adaptation of other methodological frameworks based on indicators (e.g. MESMIS, already widely used in the Amazon, as described in Silva et al. 2017). Further exploration of the results of the questionnaires filled in by the farmers who took part in this study will provide information for this purpose. Concerning the game, since the final version used for the thesis, we have started to improve it with the main objective of making it easier to use with different local actors, without requiring specialized people to handle it. We also aimed to improve some features of the model to improve the indicators that would allow the exploration of more situations. The construction of other tools (e.g. a framework of indicators) could be included in the work agenda of ongoing projects at the university where I work (e.g. agroecology study group) or academic activities (e.g. for a master's degree) conducted by students.

These tools could be used by different stakeholders and researchers, a **second perspective (a)** to help evaluate the effect of management interventions (like those

[33] References on this subject in the Amazon are often related to the theme of Payment for environmental services (PES), e.g. Eloy et al. (2012); Medeiros et al. (2007). Some other references are related to research conducted by the *Rede Amazônia Sustentável* (RAS): http://www.redeamazoniasustentavel.org/.

influenced by procurement programs) on the capacity of the agroecosystems (and also the landscape) to provide goods and services; **(b)** to investigate how different drivers influence preferences and possibilities for different management pathways; and thus **(c)** to support the design of development programs and public policies that are coherent with the co-production of ES and adapted to each specific context. The existence of these two types of tools, which share a common basis, would also allow comparison between real life information (i.e. collected from farmers) with the perceptions obtained in a simulation environment (i.e. through the game). In brief, we have seen that the conceptual framework of ES co-production goes beyond exploring elements directly correlated with agroecosystem management, but is also a viable tool to stimulate comunication between different actors on the subject. A better understanding of the many mechanisms underlying the co-production of ES and the sharing of different knowledge and perceptions will help raise more collective awareness of the agroecological transition.

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Appendixes

Appendixes of chapter 2

Appendix 1: Semi-directive guide used for interviews with local actors.

Roteiro Semi-Estruturado para Instituições *(Semi-directive guide for stakeholders)*		
1	**Informaçõs do entrevistado (*Personal informations*)**	
Nome (*Name*):		
Instituição (*Institution*):		
Contato (*Phone number*):		
Função (*Position*):		
Formação (*Academic qualification*):		
Tempo de atuação na instituição e no município (*Working period in the institution and in the municipality*) :		
Hora de inicio e fim da entrevista (*Duration of the interview*):		
2	**Percepções *(Perceptions)***	
	Questões *(Questions)*	Observações (se for o caso)
2.1	Qual o objetivo da sua instituição? (*What is the objective of your institution?*)	> Captar os pontos de vista dos diferentes representantes. (*Catch the points of view of the different representatives.*)
	Quais as principais instituições parceiras? (*What are the main partnerships?*)	
	Quais as principais culturas que vocês trabalham aqui no município? (*What are the main crops that you work with in the municipality?*)	
	Em que tipos de *sistemas de produção* essas culturas são implementadas? (*In what types of farming systems are these crops implemented?*)	> Focalizar no tipo de prática utilizada (*Focus on the type of practice used*)
2.2	Para você, qual a importância de ter uma biodiversidade nestes sistemas? *(What is the importance to you of having biodiversity in these systems?)*	
	Em quais casos você acha que faz sentido a associação de plantas (culturas ou outras plantas)? *(In which cases do you think it makes sense to associate plants - crops or other plants?)*	

2.3	Quais os benefícios e impactos negativos tirados destes *sistemas de produção*? Para as pessoas? Para a natureza/biodiversidade? *(What are the benefits and negative impacts of these farming systems? For people? For nature?)*	> Focalizar no tipo de prática utilizada (*Focus on the type of practice used*)
	Quais os benefícios e impactos negativos que a *natureza/biodiversidade* pode trazer para estes *sistemas produtivos*? E para as pessoas? *(What benefits and negative impacts can nature bring to these farming systems?And for people?)*	
2.5	Você já ouviu falar de *serviços ambientais/ecossistêmicos*? O que é para você? *(Have you ever heard of environmental/ecosystemic services? What is it for you?)*	> Perguntar se ainda não foi citado durante a entrevista. *(Ask if it hasn't been mentioned yet during the interview)*
	Você acha que é um conceito que ajuda a entender as relações entre cultivos e a natureza? *(Do you think it is a concept that helps to understand the relationships between crops and nature?)*	> Perguntar se a resposta anterior foi positiva *(Ask if the previous answer was positive)*
	Você acha que é um conceito utilizado/que faz sentido pelos outros atores? *(Do you think it's a concept used/that makes sense to other actors?)*	
	Questões *(Questions)*	Observações
3	Quais são os principais desafios no município em torno da manutenção da biodiversificação das culturas? *(What are the main challenges in the municipality around the maintenance of biodiversity-based agriculture?)*	
	Como você acha que se poderia incentivar isso no município? *(How do you think this could be encouraged in the municipality?)*Você ou parceiros tem alguma ação nesse sentido? *(Do you or partners have any action in this regard?)*	
	Você toparia participar de uma outra reunião sobre os resultados dessa pesquisa? *(Would you consider attending another meeting on the results of this survey?)*	

Appendix 2.a: Questionnaire used in field visits with farmers (i.e. Farm level).

QUESTIONÁRIO DE CARACTERIZAÇÃO DOS AGROECOSSSISTEMAS.

Nome :
Comunidade :
Idade :
Atividades :
Emprego anterior :
Tamanho do estabelecimento :
Tamanho da reserva florestal :
Tipo de propriedade :

Número Atividades
Unidade familiar
Homens |
Mulheres |
Jovens/crianças dispo |
Na escola | M.O. extér. |

1- Informações gerais do estabelecimento/parcela:

1 Uso atual da terra

Parcelas (Subsistemas)	*Tamanho (ha)**	*Número de "parcelas"*	*Tempo de implantação*	*Preparo de área*		
				Fogo	*Mecaniz*	*Outro*
SAF Implantado						
Quintal						
Roça						
Horta						
Capoeira						

**Utilizar GPS ou Aplicativo (por exemplo, Field Área Mesurement)*
Fazer um esboço de mapa da Unidade de produção (Usar o verso da folha):
Depois a gente pode visitar essas áreas? (Se sim, deixar para fazer as perguntas sobre cada parcela na parcela)

2- Inserção do agricultor:

Participação nos programas/iniciativas: Proambiente ( ) Cooperativas ( ) PNAE ( ) PAA ( ) Tijolo verde ( ) Outros ( )
O que você acha da participação nestes programas/iniciativas?

Tipos de trocas que tem com outros agricultores "vizinhos ou não" (espécies, praticas, mão de obra, etc)? Em que locais/momentos?

Tipo de ATER (qual instituição? o que acha dos conselhos dos técnicos? o que falam sobre agro-biodiversidade? o que falta?)

Tipo de mercado (feira, atravessador, institucional) e valor que é dado a produtos diferentes (variedades diferentes, orgânico ou convencional, beneficiado ou in natura).

3- Conhecimento sobre os SE:

Para você, qual a importância de ter uma variedade de plantas (culturas de produção e outras plantas) nos seus sistemas? E de outras espécies (animais "grandes", insetos, ...)?

Você acha que essa diversidade de plantas e animais pode influenciar (positiva ou negativamente) na produção de suas diferentes parcelas? Como (Se não ficar claro na pergunta anterior)?

Como você percebe a influência (positiva ou negativa) das suas diferentes parcelas na natureza?

Para você qual o maior desafio (dificuldade) para manter um sistema mais diversificado?

Você já ouviu falar do conceito de Serviços ambientais?

4- Situação atual:

-Quais seus principais pontos fortes hoje ?

-Quais seus principais entraves hoje?

-Quais as suas fontes de renda hoje (listar a ordem de importância de cada uma; em relação a renda agrícola, subdividir em culturas anuais, perenes e outras)?

Objetivos :

-Quais são seus projetos futuros?

- Se se aposentar, tem alguem para lhe substituir ?

Meios :

-Você tem recursos próprios para investimentos futuros?

-Você tem mão de obra suficiente?

Appendix 2.b: Questionnaire used in field visits with farmers (i.e. Plot level)**.**

QUESTIONÁRIO DE CARACTERIZAÇÃO DAS PARCELAS.

Agricultor:
Parcela:

a) Histórico da parcela (tentar captar o mais longe possível)

Por exemplo

2018									

- *O que levou você a implantar esse sistema?*
- *Você teve algum tipo de apoio para implantar esse sistema (Capacitação, crédito, projeto, ...)?*
- *Quais as principais vantagens desse sistema? E desvantagens?*
- *Você pretende ampliar, reduzir ou manter esse sistema como está? Porque?*

b) Manejo

- *Quais insumos químicos (herbicidas, defensivos e adubos) foram utilizados na área (quantificar a utilização para o ultimo período)?*
- *Quais insumos orgânicos (herbicidas, defensivos e adubos) foram utilizados na área (quantificar a utilização para o ultimo ano)?*
- *Outros tipos de práticas/plantas utilizadas para melhorar a capacidade de produção (relacionados a adubação, controle de pragas e doenças, polinização, manutenção da umidade do solo, sombreamento, ...) ex. Adubação verde, manutenção de mata ciliar, ...*
- *Mesmo que você não utilize, tem alguma outra prática/planta que conhece que possa melhorar a capacidade de produção dessa área?*

Descrição do sistema

Espécie	*Função*	*Origem das sementes/ estacas*	*Quantidade da produção (Ultimo ano)*	*Destino da produção (venda ou consumo)*	*Beneficiado ou in natura*	*Local de venda e renda obtida*

Appendix 3: Social, environmental and economic indicators included in the game.

ACTIVITIES

	ESTABLISHMENT	MANAGEMENT	PRODUCTION	Hardship	Environment
CASSAVA 1 tarefa	0 R$	harvest + flour process 0 R$	Year 1 900 R$/tarefa Year 2 900 R$/tarefa	Establishment 5 Management 5	+1
VEGETABLE GARDEN 1/2 tarefa	625 R$	0 R $	2000 R$/horta	Establishment 4 Management 2	0
FISH FARMING 1 fish pond	800 R$	300 R$	60 x 10 kg/pond R$/kg = 600 R$/pond	Establishement 3	0
PEPPER 100 feet	2000 R$	300 R $	400 x 25 Kg/100feet R$/kg = 10 000 R$/100feet	Establishment 3 Management 2	0
BEEKEEPING 1 hive	230 R$	80 R $	30 x 25 L/hive R$/L = 750 R$	Establishment 4 Management 2	+1
POULTRY 50 hens	1100 R$	750 R $	10 000 x 0,5 eggs R$/egg = 5000 R$	Establishment 2	0
PASTURE 1 tarefa	850 R$		Max 1 Cow/tarefa if the pasture is well managed 100 R$/cow	Establishment 5 Management 3	0
CATTLE 1 head	1250 R$ For 10 heads	50 R$ For 10 heads	1x 800 Calf/2years R$/calf = 800 R$		0

AGROFORESTRY SYSTEMS (AFS)

	ESTABLISHMENT	MANAGEMENT	PRODUCTION	Hardship	Environment
WETLAND AÇAI 1 tarefa	200 R$	0 R$	Year 3 2000 R$/tarefa until From Year 5 3000 R$/tarefa		+3
DRYLAND AÇAI 1 tarefa	800 R$	300 R $	Year 4 4000 R$/tarefa until From Year 6 6000 R$/tarefa	Establishment 4 Management 1	+2
CITRUS AFS	350 R$	300 R$	Year 1 4000 R$/tarefa until From Year 8 6000 R$/tarefa	Establishmen 3 Management 1	+2
SUCCESSIONAL AFS	200 R$	150 R $	Year 1 1000 R$/tarefa until From Year 9 7000 R$/tarefa	Establishment 3 Management 1	+3
ENRICHED CAPOEIRA	200 R$	150 R $	Year 1 1000 R$/tarefa until From Year 10 10 000 R$/tarefa	Establishment 3 Management 1	+4
AMAZONIAN AFS	400 R$	150 R $	Year 1 3000 R$/tarefa until From Year 9 8000 R$/tarefa	Establishment 3 Management 1	+2

Thin capoeira +	Dense capoeira +
Medium capoeira +	Forest +

PRACTICES

	ESTABLISHMENT MANAGEMENT	PRODUCTION	Hardship	Environment
MECHANIZATION  1 tarefa	100 R$ -	- 10 % After first harvest	- 2	0
IRRIGATION  1 tarefa	1000 R$ -	+ 30 %		- 1
MULCHING 	0 R$ +	+ 5 %		+1
ORGANIC FERTILIZER 	0 R$ +	+ 30 %		+1
CHEMICAL FERTILIZER 	100 R$	+ 50 %		0
ORGANIC PESTICIDE Neem 	0 R$ +	+ 10 %		0
CHEMICAL PESTICIDE Decis	60 R$	+ 10 %		- 2
HERBICIDE 	30 R$ -		- 2	- 2

Appendix 4: Events and field activities considered for participant observation.

Event	Type	Date	Local	Objectif
Best farming practices and use of GHG tool	Workshop	14/08/2017	Paragominas	Present a greenhouse gases (GHG) emission reduction tool to local actors.
Cofé with Agroecology	Rond-table	31/08/2017	Paragominas	To debate the importance of "agroecology study groups" for the promotion of research-action at the municipal level.
Grafting of "Caju do mato" and installation of hydraulic ram	Field day	30/09/2017	Irituia	Present techniques of grafting of the "Cajú do mato" and installation of the hydraulic ram.
Cofé with Agroecology	Rond-table	19/10/2017	Paragominas	To debate the importance of forest restoration for Family Farming.
Field day PRADAM (Projeto de recuperação de áreas degradas na Amazônia)	Field day	20/10/2017	Paragominas	Present technologies of sustainable agricultural production practiced in the municipality and a tool for C quantification developed by EMBRAPA.
Field day of Cassava production.	Field day	26/10/2017	Capanema	Discuss the new technologies for cassava production in NE Para (presence of representatives from Paragominas and Irituia).
D'Irituia Cooperative monthly meeting	Meeting	06/11/2017	Irituia	To debate the agenda of the month for the cooperative (including the elaboration of a project proposal to compete to the Amazon Fund together with UFPA).
Environmental and Territorial Governance of the Upper Guamá River Indigenous Land: Alliance for the Biological and Cultural Conservation of the Northeast Para State	Workshop	21 e 22/11/2017	Paragominas	To debate and develop strategies for the management of Indigenous Land.
Cofé with Agroecology	Rond-table	23/11/2017	Paragominas	To debate possibilities and challenges of food production by Family Farming.
Use of Acácia Mangium for charcoal in family farming areas.	Workshop	28/11/2017	Irituia	To debate strategies for using *Acacia mangium* as coal through the farmers participating in the "Tijolo verde" project.
Meeting –SEMAGRI	Meeting	29/11/2017	Irituia	To debate in which will be used the resource available for SEMAGRI in the exercise 2018.

Cont.

Event	Type	Date	Local	Objectif
Anual meeting of "Tijolo verde" Project	Meeting	20/12/2017	Irituia	Make a report with farmers about the implementation of the "Tijolo Verde" Program in 2018.
I Field day of Family Farm	Field day	08/06/2018	Paragominas	Visit to a diversified family production system.
Meeting - Memories of PROAMBIENTE	Rond-table	19/07/2018	Irituia	Make a debate with former participants of the PROAMBIENTE program.
Round-table with female farmers	Rond-table	23/08/2018	Paragominas	To debate the role of women in conducting the rural establishment.
Roud-table about perspectives of family farming in Paragominas	Rond-table	25/08/2018	Paragominas	To present and debate the panorama of Family Agriculture in Paragominas
Field visit – IDEFLOR	Technical field visit	18/09/2018	Irituia	Bring genetic material (seeds) and make a routine visit in two program nurseries of Tijolo verde Program.
Transition alternatives for Family Farm (promoted by CIRAD)	Workshop	23 a 25/09/2018	Belém	Discuss different forms of transition (in progress or desired) related to family agriculture in the Northeast Para.
School meal delivery	Technical field visit	12/11/2018	Irituia	Monitoring the delivery of school meals by farmers.
Meeting of D´Irituia cooperative with NATURA	Meeting	12/11/2018	Irituia	To present a purchase proposal of Tucumã from the Cooperative D'irituia by Natura.
Field visit - SEMAGRI	Technical field visit	20/11/2018	Paragominas	Repair a tractor and mechanize an area for planting cassava / Visit cassava experiment (master's research)/ Visit area for implementation of a collective oven for preparing cassava flour.
French bank delegation - Meeting with STTR	Meeting	26/11/2018	Paragominas	Discuss the union's prospects for participating in a financing project with a French bank.
French bank delegation - Meeting with large farmer.	Meeting	26/11/2018	Paragominas	To introduce the farm's production system to the French bank's entourage.
Field visit - SEMAGRI	Technical field visit	27/11/2018	Paragominas	To visit na AFS experiment implemented by farmer (master's research)
Field visit – UFRA	Technical field visit	30/11/2018	Paragominas	To introduce to family farmers a type of organic fertilization for grains.

Appendixes of chapter 3

Appendix 1: Quantity of ES mentioned by local actors during the semi-directive interviews.

Paragominas :

Code	Ecosystem services	InsPGM1	InsPGM2	InsPGM3	InsPGM4	TecPGM1	TecPGM2	TecPGM3	SciPGM1	SciPGM2	SciPGM3	EmpPGM1	EmpPGM2	EmpPGM3	EmpPGM4	EmpPGM5	Total
S1	Food	5	4	1	2	1	1	1	3	2	1	1	3	2	2	2	31
S2	Timber and fiber		1					2	1	1	2						7
S3	Firewood									1				1	1		3
S4	Water	1		1	1					1					1		5
S5	Animals hunt													1			1
S6	Soil fertility and erosion	2	1	2		1		1	1	2	1			3	1	1	16
S7	Regulation of water cycles	2		3		2	1	1	2	2		1	1	2	3	1	21
S8	Pest and disease control				1				3			1			1		6
S9	Climate regulation	1	1			1	1		2	2		1		1			10
S10	C Sequestration	1		1			1			2	1						6
S11	Shade					1						1		1			3
S12	Wildlife shelter		1			1							1		1		4
S13	Pollination					1		1	1	1							4
S14	Biomass production		1					1	1	1							4
S15	Gene poll protection	1	1	1				1			1	1					6
S16	Leisure		1									1					2
S17	Aesthetic values								1			1					2
Total		**13**	**11**	**9**	**4**	**8**	**4**	**8**	**15**	**15**	**6**	**8**	**5**	**11**	**10**	**4**	**131**

Irituia :

Code	Ecosystem services	InsIRT1	InsIRtT2	InsIRT3	InsIRT4	InsIRT5	InsIRT6	TecIRT1	TecIRT2	TecIRT3	TecIRT4	SciIRT1	SciIRT2	EmpIRT1	EmpIRT2	EmpIRT3	Total
S1	Food	4	2	3	2	1	2	2	4	4	2	2	5	5	3	3	**44**
S2	Timber and fiber	1	1					4	1		1	1	1		4	1	**15**
S3	Firewood	1						2			2			2			**7**
S4	Water		1									1	1		1		**4**
S5	Animals hunt											1				1	**2**
S6	Soil fertility and erosion	1	1			1		4	2		1	6	1	3	1	2	**23**
S7	Regulation of water cycles		2						1		1	1	1	1	3		**10**
S8	Pest and disease control	3					1	1				1	2		3		**11**
S9	Climate regulation																**0**
S10	C Sequestration												1		1		**2**
S11	Shade							1				1					**2**
S12	Wildlife shelter													1		1	**2**
S13	Pollination	2	1						1	1							**5**
S14	Biomass production	2			1			2	1		1	2	1	1	1	1	**13**
S15	Gene poll protection								1		1	2	1		2		**7**
S16	Leisure	2															**2**
S17	Aesthetic values	1						1							1	2	**5**
Total		17	8	3	3	2	3	17	11	5	9	18	14	13	20	11	**154**

Appendix 2: Correlation between ES and agricultural practices made by local actors (i.e. separated by actor typology) during the semi-directive interviews. Positive numbers are positive correlations. Negative numbers are negative correlations. The cells marked in red are those where there were positive and negative associations. In these cases, we are considering the difference between the number of citations.

Productive support:

	Biodiversity management	Deforestation	Use of fire	Mechanization	Irrigation	Organic inputs	Chemical inputs
Food quantity	30,00	2,00	-3,00	6,00	5,00	1,00	12,00
Food quality	4,00	0,00	0,00	1,00	0,00	2,00	-5,00
Timber and fiber	12,00	0,00	0,00	0,00	0,00	0,00	0,00
Firewood	3,00	0,00	0,00	0,00	0,00	0,00	0,00
Water	1,00	0,00	0,00	0,00	-1,00	0,00	-1,00
Animals hunt	1,00	-1,00	0,00	0,00	0,00	0,00	0,00
Soil fert. and erosion	9,00	-1,00	0,00	1,00	1,00	9,00	-2,00
Reg. of water cycles	9,00	-1,00	-2,00	0,00	0,00	0,00	-3,00
Pest and disease control	7,00	0,00	0,00	0,00	0,00	0,00	0,00
Climate regulation	3,00	-1,00	0,00	0,00	0,00	0,00	0,00
C Sequestration	3,00	0,00	0,00	0,00	0,00	0,00	0,00
Shade	2,00	-1,00	0,00	0,00	0,00	0,00	0,00
Wildlife shelter	3,00	-1,00	0,00	0,00	0,00	0,00	0,00
Pollination	5,00	0,00	0,00	0,00	0,00	0,00	0,00
Biomass prod.	8,00	0,00	0,00	0,00	0,00	0,00	0,00
Gene poll protec.	7,00	0,00	0,00	0,00	0,00	0,00	0,00
Leisure	3,00	0,00	0,00	0,00	0,00	0,00	0,00
Aesthetic values	5,00	0,00	0,00	0,00	0,00	0,00	0,00
Biodiversity/Nature*	0,00	-1,00	-8,00	3,00	0,00	0,00	0,00

Purchase of products:

	Biodiversity management	Deforestation	Use of fire	Mechanization	Irrigation	Organic inputs	Chemical inputs
Food quantity	8,00	0,00	0,00	1,00	0,00	1,00	0,00
Food quality	3,00	0,00	0,00	0,00	0,00	5,00	-3,00
Timber and fiber	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Firewood	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Water	0,00	0,00	0,00	0,00	0,00	0,00	-1,00
Animals hunt	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Soil fert. and erosion	1,00	0,00	0,00	0,00	0,00	0,00	0,00
Reg. of water cycles	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pest and disease control	1,00	0,00	0,00	0,00	0,00	1,00	0,00
Climate regulation	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C Sequestration	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Shade	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Wildlife shelter	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pollination	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Biomass prod.	1,00	0,00	0,00	0,00	0,00	0,00	0,00
Gene poll protec.	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Leisure	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Aesthetic values	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Biodiversity/Nature*	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Environmental regulation:

	Biodiversity management	Deforestation	Use of fire	Mechanization	Irrigation	Organic inputs	Chemical inputs
Food quantity	8,00	1,00	1,00	1,00	0,00	0,00	2,00
Food quality	2,00	0,00	0,00	0,00	0,00	0,00	0,00
Timber and fiber	6,00	0,00	0,00	1,00	0,00	0,00	1,00
Firewood	2,00	0,00	0,00	0,00	0,00	0,00	0,00
Water	2,00	0,00	0,00	0,00	0,00	0,00	0,00
Animals hunt	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Soil fert. and erosion	6,00	0,00	0,00	0,00	0,00	2,00	0,00
Reg. of water cycles	7,00	-2,00	0,00	0,00	0,00	0,00	0,00
Pest and disease control	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Climate regulation	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C Sequestration	2,00	0,00	0,00	0,00	0,00	0,00	0,00
Shade	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Wildlife shelter	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pollination	2,00	0,00	0,00	0,00	0,00	0,00	0,00
Biomass prod.	2,00	0,00	0,00	0,00	0,00	0,00	0,00
Gene poll protec.	4,00	0,00	0,00	0,00	0,00	0,00	0,00
Leisure	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Aesthetic values	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Biodiversity/Nature*	0,00	-3,00	-5,00	1,00	0,00	0,00	1,00

Social support:

	Biodiversity management	Deforestation	Use of fire	Mechanization	Irrigation	Organic inputs	Chemical inputs
Food quantity	9,00	-1,00	-2,00	2,00	1,00	2,00	0,00
Food quality	1,00	0,00	0,00	1,00	0,00	0,00	-1,00
Timber and fiber	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Firewood	4,00	0,00	0,00	0,00	0,00	0,00	0,00
Water	1,00	0,00	0,00	0,00	0,00	0,00	-1,00
Animals hunt	0,00	-1,00	0,00	0,00	0,00	0,00	0,00
Soil fert. and erosion	2,00	0,00	1,00	-1,00	0,00	2,00	1,00
Reg. of water cycles	2,00	-8,00	-1,00	0,00	0,00	0,00	-2,00
Pest and disease control	2,00	0,00	0,00	0,00	0,00	0,00	0,00
Climate regulation	1,00	-1,00	0,00	0,00	0,00	0,00	0,00
C Sequestration	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Shade	2,00	0,00	0,00	0,00	0,00	0,00	0,00
Wildlife shelter	2,00	-1,00	0,00	0,00	0,00	0,00	0,00
Pollination	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Biomass prod.	1,00	0,00	0,00	0,00	0,00	0,00	0,00
Gene poll protec.	1,00	0,00	0,00	0,00	0,00	0,00	0,00
Leisure	1,00	0,00	0,00	0,00	0,00	0,00	0,00
Aesthetic values	1,00	0,00	0,00	0,00	0,00	0,00	0,00
Biodiversity/Nature*	0,00	-6,00	-5,00	1,00	0,00	0,00	-1,00

Knowledge production:

	Biodiversity management	Deforestation	Use of fire	Mechanization	Irrigation	Organic inputs	Chemical inputs
Food quantity	17,00	0,00	0,00	0,00	3,00	2,00	2,00
Food quality	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Timber and fiber	4,00	0,00	0,00	0,00	0,00	0,00	0,00
Firewood	1,00	0,00	0,00	0,00	0,00	0,00	0,00
Water	3,00	0,00	0,00	0,00	0,00	0,00	0,00
Animals hunt	1,00	0,00	0,00	0,00	0,00	0,00	0,00
Soil fert. and erosion	9,00	0,00	0,00	0,00	0,00	4,00	0,00
Reg. of water cycles	4,00	0,00	0,00	0,00	0,00	0,00	0,00
Pest and disease control	6,00	0,00	0,00	0,00	0,00	1,00	0,00
Climate regulation	4,00	-1,00	0,00	0,00	0,00	0,00	0,00
C Sequestration	3,00	0,00	0,00	0,00	0,00	0,00	0,00
Shade	1,00	0,00	0,00	0,00	0,00	0,00	0,00
Wildlife shelter	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pollination	2,00	0,00	0,00	0,00	0,00	0,00	0,00
Biomass prod.	5,00	0,00	0,00	0,00	0,00	0,00	0,00
Gene poll protec.	3,00	0,00	0,00	0,00	0,00	0,00	0,00
Leisure	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Aesthetic values	1,00	0,00	0,00	0,00	0,00	0,00	0,00
Biodiversity/Nature*	0,00	-1,00	-1,00	0,00	0,00	0,00	-2,00

Appendixes of chapter 5

Appendix 1: Quantitative results of game sessions.

<u>Session held on 16 January 2019 with the participation of local actors in Irituia :</u>

Property1 Irt (P1Irt) :

Year	Activity	Location	Agricultural practice		
1	Beekeeping	C15_C16			
1	Amaz. Arrangement	D4	Organic fertilization	Mulching	Organic pesticide
1	Cassava Field	E8_E7_A8			
1	Vegetable Garden	D5			
1					
2	Wetland Açaí	D8_D7			
2	Successional AFS	C4	Organic fertilization	Mulching	Organic pesticide
2	Beekeeping	E9			
2					
2					
3	Fish Farming	B5			
3	Wetland Açaí	E7			
3					
3					
3					
Property	P1Irt				
Assistent	Layse				
Players	**Name**		**Type**	**Genre**	
	P1 (Cop. D´Irituia)		Empirical	Female	
	P2 (SEMAGRI)		Institutional	Female	
	P3 (Estudante IFPA)		Scientific	Female	

Property2 Irt (P2Irt) :

Year	Activity	Location	Agricultural practice	
1	Enriched Capoeira	E12		
1	Citrus arrangement	B5		
1	Cassava Field	B4	Mechanization	
1	Vegetable Garden	A4		
1				
2	Amaz. Arrangement	C3		
2	Wetland Açaí	D3		
2	Cassava Field	A3	Mechanization	Organic fertilization
2				
2				
3	Citrus arrangement	C2		
3	Wetland Açaí	D2		
3				
3				
3				
Property	P2Irt			
Assistent	Renan			
Players	**Name**		**Type**	**Genre**
	P1 (Cop. D´Irituia)		empirical	Female
	P2 (Coapemi)		empirical	Male

Property3 Irt (P3Irt) :

Year	Activity	Location	Agricultural practice	
1	Wetland Açaí	C16_D16	Mulching	Organic fertilzation
1	Beekeeping	E9		
1	Cassava Field	B5_B6_B7	Chemical fertilization	
1	Successional AFS	C5	Organic fertilzation	
1				
2	Beekeeping	E10_E11		
2				
2				
2				
2				
3	Beekeeping	E12_E13		
3	Citrus arrangement	B5_B6_B7	Mechanization	
3				
3				
3				
Property	P3Irt			
Assistent	Vitor			
Players	**Name**		**Type**	**Genre**
	P1 (Emater)		technical	Male
	P2 (Cop. D´Irituia)		empirical	Female

Property4 Irt (P4Irt) :

Year	Activity	Location	Agricultural practice	
1	Cassava filed	A3_A17_B17	Mulching	Organic pesticide
1	Wetland açai	D12		
1	Beekeeping	C14_D17_D17		
1	Successional AFS	D7	Organic fertilization	
1				
2	Fish Farming	B5		
2	Beekeeping	B7_B7		
2				
2				
2				
3	Poultry	E7		
3	Wetland açai	A18_B18		
3				
3				
3				
Property	P4Irt			
Assistent		Felipe		
Players		**Name**	**Type**	**Genre**
		P1 (UFRA)	scientific	Male
		P2 (Estudante IFPA)	scientific	Female
		P3 (SEPROS)	institutional	Female

<u>Session held on 12 February 2019 with the participation of local actors in Paragominas :</u>

Property1 Pgm (P1Pgm) :

Year	Activity	Location	Agricultural practice			
1	Cassava field	B8				
1	Wetland açai	D17				
1						
1						
1						
2	Beekeping	D2				
2	Poultry	D5				
2	Citrus arrangement	B8				
2	Sucessional AFS	D5	Mechanization	Organic fertilization	Chemical fertilization	Mulching
2						
3	Enriched capoeira	D2	Organic fertilization			
3	Beekeping	D2				
3						
3						
3						

Property	P1Pgm		
Assistent	Vitor		
Players	**Name**	**Type**	**Genre**
	P1 (EMBRAPA)	scientific	Male
	P2 (Estudante UFRA)	scientific	Female
	P3 (STTR)	empirical	Female

Property2 Pgm (P2Pgm) :

Year	Activity	Location	Agricultural practice			
1	Cassava field	A4_B4	Mechanization	Organic fertilizatior	Chemical fertilization	
1	Wetland açai	A17_B17	Mulching			
1	Sucessional AFS	B5	Organic fertilization	Mulching	Herbicide	
1	Beekeping	C12_C12				
2	Poultry	C5				
2						
3	Beekeping	C12_C12				
3	Wetland açai	C16_D16				
3	Cassava field	A4_B4	Mechanization	Herbicide	Chemical fertilization	Organic fert.
3						
Property	P2Pgm					
Assistent	Renan					
Players	**Name**		**Type**	**Genre**		
	P1 (Emater)		technical	Female		
	P2 (Ideflor)		technical	Male		
	P3 (STTR)		empirical	Male		

Property3 Pgm (P3Pgm) :

Year	Activity	Location	Agricultural practice		
1	Cassava field	C3	Organic fertilization	Mulching	
1	Sucessional AFS	D7_D8	Mechanization	Organic fertilization	Mulching
1					
1					
2	Sucessional AFS	D11	Mechanization	Organic fertilization	
2	Beekeping	B13_B13_B13_B13			
2					
2					
3	Cassava field	D3	Mulching	Organic fertilization	
3	Beekeping	B14_B14_B14_B14_B14			
3	Wetland açai	C16			
3					
Property	P3Pgm				
Assistent	Adrielly				
Players	**Name**		**Type**	**Genre**	
	P1 (Emater)		technical	Female	
	P2 (STTR)		empirical	Male	
	P3 (Cooperuraim)		empirical	Male	

Property4 Pgm (P4Pgm) :

Year	Activity	Location	Agricultural practice		
1	Cassava field	B5	Mechanization	Chemical fertilization	Herbicide
1	Amaz. arrangement	D8	Organic fertilization	Chemical fertilization	
1	Fish farming	D11			
1	Cassava field	B4_A4_A5_A6	Chemical fertilization	Herbicide	
1					
2	Beekeping	E15_E15			
2					
2					
2					
2					
3	Beekeping	E15_E15_E15			
3	Wetland açai	A17_B17			
3	Enriched capoeira	D7_E7	Chemical fertilization		
3					
3					

Property	P4Pgm		
Assistent	Gabriel		
Players	**Name**	**Type**	**Genre**
	P1 (Departament of agriculture)	institutional	Female
	P2 (SEDAP)	institutional	Female
	P3 (Emater)	technical	Female

Title : Can the concept of ecosystem services facilitate agroecological transition in the Brazilian Amazon? Results from a mixed methods approach in Irituia and Paragominas, Pará state.

Keywords : Co-Production of ecosystem services ; Agroecological transition ; Agrobiodiversity ; Knowledge sharing ; Rural extension; Amazon.

Abstract :

The proposal of a model of development that reconciles environmental conservation, especially of forest resources, and socioeconomic development is still a challenge to be achieved worldwide, especially in the Amazon region. Due to its amplitude, the Brazilian portion of the Amazon is a matter of great concern nationally and internationally. Agriculture stands out in the Brazilian Amazon for its socioeconomic importance and its tremendous potential to alter ecosystems and the provision of ecosystem services (ES). Among the different forms of agriculture (i.e. large and small farmers), family farms are key players for promoting rural sustainable development. Despite its importance, local actors supporting family farms face numerous challenges to promote agroecological transition of these farms. The general question that we want to contribute to with this thesis is: How can the conceptual framework of ES serve as a cognitive and operational basis to support the agroecological transition? We carried out this research in two contrasting municipalities in the eastern part of the Brazilian Amazon, Irituia and Paragominas. The farming sector of the first study site is dominated by family farming, which is often biodiversified. Contrastingly, large-scale industrial agriculture predominates in the second study site, although it coexists with family farming. We adopted a multi-actor perspective, with the participation of a heterogeneous set of local actors (e.g. policy makers, researchers, rural extension agents, farmers) related to rural issues. We implemented a "mixed methods approach" combining well-tested qualitative methodologies, such as semi-directive interviews and participant observation, with semi-quantitative methodologies such as questionnaires and a role-playing game. We first aimed to understand the perception of different local actors about ES and their co-production process. We observed that, in general, a diversity of ES is perceived by local actors. The perception of ES and the different possible ways to co-produce these ES differ significantly among actors. The type of activity performed by the stakeholders and their municipality are the main factors influencing their perception of ES co-production. The type of knowledge (more scientific or empirical) was also relevant to distinguish between the ways to perceive ES. We also sought to understand the importance of these perceptions in the decision-making process on land use. We investigated some contextual factors that influence this decision making process, focusing on factors external (notably institutional markets) and internal (e.g. labor, costs, cognitive aspects) to the agroecosystem. We realized that these markets are important for valuing agrobiodiversity, but this will depend on how they are managed at a municipal level and on the local institutional landscape. Accordingly, the agroecosystem may evolve towards agroecological or non-agroecological standards. Internal factors in the farm, such as labor, money, values also influence this decision making process. Finally, we sought to understand how the knowledge generated previously could contribute to operationalize the agroecological transition in our two study sites. Knowledge about ES issues generated in our research site contributed to disclose the expectations and factors that drive the actions of stakeholders regarding land use management. This knowledge was obtained through and was used to feed methodological tools to support agroecological transition. Finally, we highlight that the conceptual framework of ES co-production not only enables exploring elements correlated to agroecosystem management, it also serves as a viable tool to stimulate the communication of different actors on the subject. A better understanding of the mechanisms underlying the co-production of ES and the sharing of different knowledge and perceptions can support more collective awareness building toward agroecological transition.

Titre : Le concept de services écosystémiques peut-il faciliter la transition agroécologique dans l'Amazonie brésilienne ? Résultats d'une approche de recherche par méthodes mixtes à Irituia et Paragominas, dans l'État du Pará.

Mots-clés : Co-production de services écosystémiques ;Transition agroécologique ; Agrobiodiversité ; Échange de connaissances ; Extension Rurale ; Amazonie.

Résumé :

La proposition d'un modèle de développement qui concilie la conservation de l'environnement, en particulier des ressources forestières, et le développement socio-économique reste un défi à relever globalement, spécialement dans la région amazonienne. En raison de son ampleur, une attention particulière est portée à la portion brésilienne de l'Amazonie et plus précisément à ses différentes formes d'agriculture en raison de leur importance socio-économique et de leur potentiel d'altération des écosystèmes et des services écosystémiques (SE). Dans ce contexte, l'agriculture familiale apparaît incontournable pour promouvoir le développement rural durable. Malgré son importance, les acteurs locaux qui soutiennent les exploitations agricoles familiales sont confrontés à de nombreux défis pour promouvoir la transition agroécologique. La question générale de cette thèse est : Comment le cadre conceptuel des SE peut-il servir de base cognitive et opérationnelle pour soutenir la transition agroécologique ? Nous examinons deux municipalités contrastées situées dans la partie orientale de l'Amazonie brésilienne : Irituia, dont le secteur agricole est dominé par une agriculture familiale qui se tourne vers la biodiversification ; et Paragominas, qui présente une prédominance de l'agriculture industrielle à grande échelle, qui coexiste avec l'agriculture familiale. Nous avons adopté une perspective multi-acteurs, impliquant une diversité d'acteurs locaux (e.g., des décideurs politiques, des chercheurs, des agents de vulgarisation rurale, des agriculteurs). Nous avons implémenté une « approche de méthodes mixtes » combinant des méthodologies qualitatives, telles que des entretiens semi-directifs et l'observation participante, avec des méthodologies semi-quantitatives telles que des questionnaires et un jeu de rôles. Nous avons d'abord cherché à comprendre la perception qu'ont les acteurs locaux sur la coproduction des SE. Une diversité de SE est perçue par ces acteurs locaux. La perception des SE et de leur processus de coproduction diffère sensiblement selon le type d'activité exercée par les acteurs et leur municipalité. Nous montrons également comment la nature de leurs connaissances (plus scientifique ou empirique) joue sur leur manière de percevoir les SE. Nous avons par ailleurs cherché à comprendre l'importance de ces perceptions dans le processus de prise de décision sur l'utilisation des terres en étudiant l'influence sur ce processus de décision de certains facteurs contextuels externes à l'agroécosystème (notamment les marchés institutionnels) et internes (e.g., la main-d'œuvre, les coûts, les aspects cognitifs). Nous avons constaté que la réussite de la valorisation de l'agrobiodiversité au moyen de marchés institutionnels dépend de la manière dont ils sont administrés au niveau municipal. Des facteurs internes à l'exploitation, tels que le travail, les revenus, les valeurs, influencent également ce processus de prise de décision. Finalement, nous avons cherché à comprendre comment les connaissances générées lors des étapes précédentes pouvaient contribuer à rendre opérationnelle la transition agroécologique dans les sites d'étude. Ces connaissances ont contribué à révéler les attentes et les facteurs qui motivent les actions des acteurs locaux relatives à la gestion de l'utilisation des terres. Elles ont été obtenues par et utilisées pour alimenter des outils méthodologiques visant à soutenir la transition agroécologique. Au final, nous avançons que le cadre conceptuel de la coproduction des SE permet d'aller au-delà de l'exploration des éléments corrélés à la gestion des agroécosystèmes. Il constitue également un outil pertinent pour stimuler la communication sur le sujet entre les différents acteurs. La compréhension des mécanismes qui soutiennent la coproduction des SE et le partage des différentes connaissances et perceptions associées éveillent une prise de conscience collective en faveur de la transition agroécologique.