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3-D network routing of brazil nut harvesting in tropical forests

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FOREST MANAGEMENT

ABSTRACT

Background: The aim of this research is to optimize the routing of Brazil nut harvesting in order to reduce labor costs and promote an equitable redistribution of placements among extractive interests. The study area was located in the Tahuamanu province, designated a Biosphere Reserve by UNESCO, in the Madre de Dios region of Peru. Planning for harvesting activities is vital to support sustainable use of the tropical forest by extractive communities, generating profit while minimizing adverse impacts on the forest. A location-allocation model was used to redistribute extraction placement areas, taking into account the number of trees and productivity for analysis. To optimize the order of nut load pickups at the placement areas, the vehicle routing problem (VRP) was used to minimize real distance and reduce traversal time.

Results: The time taken to cover the route without delays was 08:46', which is superior to the time taken to minimize the distance. However, the total delay time was 05:10'.

Conclusion: Network analyses were effective in achieving the reallocation of placement areas and optimizing Brazil nut harvest routes.

Keywords: *Bertholletia excels*; vehicle routing problem; optimization; network analysis; Amazon region.

HIGHLIGHTS

We optimized the routing for Brazil nut harvesting.
We examined the equitable redistribution of extractivist placements.
Network analysis was effective in optimizing the Brazil nut harvest routes.
The methodology serves as a basis for network analysis of extractivist placements.
The proposed methodology can be adapted to other areas of the world.

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INTRODUCTION

The Amazon rainforest holds a vast reserve of resources with diverse opportunities for utilization. However, this tropical forest has endured unsustainable exploitation and deforestation over the years. As a result, forest management has become increasingly important and necessary to enable the sustainable use and conservation of natural resources (MMA, 2005; Munaretti, 2016). Forest management encompasses a range of products and by-products derived from plants and animals, collectively known as non-timber forest products (NTFPs) (Silva et al., 2020).

Non-timber forest products (NTFPs) obtained through sustainable management practices not only generate income for local populations, but also contribute to the local economy and help reduce the devastating impacts on forests (Fiedler; Silva, 2008; Afonso et al., 2022). However, there is a lack of available information regarding the production processes (conservation and management) and commercialization of NTFPs (Afonso, 2022). This lack of data creates a barrier to the growth of these activities, affecting the development of market strategies.

The fruit of the Brazil nut tree (*Bertholletia excelsa*) is considered an economically important non-timber forest product (NTFP) in the Amazon rainforest that has the potential to be sustainably managed (Sonego et al., 2019; Souza, 2023). Brazil (Pará, Acre, Amazonas, and Rondônia), Peru (Department of Madre de Dios), and Bolivia (Department of Pando, part of the Department of Beni and La Paz) are among the countries that produce Brazil nuts at a profitable density. The collection of Brazil nuts for trade and industry is a socially and environmentally significant activity that enables extractive producers to increase family income while also contributing to the conservation of large areas of the Amazon rainforest (Brouwer et al., 2021).

To facilitate the sustainable management of Brazil nuts, it is essential to map and mark the trees using georeferencing techniques, select the trees for management, plan the harvest, and cut lianas (Souza et al., 2004). For the latter two activities, it is crucial to employ techniques that enhance efficiency and accuracy in data collection while optimizing extraction efforts and time (Munaretti, 2016). In this context, geotechnology plays a significant role in processing the collected spatial information. In the Amazonian environment, the use of geotechnologies contributes to efforts aimed at conserving and sustainably utilizing the forest's natural resources (Carmo; Amaral, 2012). The purpose of this study was to employ and modify an optimization methodology for trail mapping to access natural forest resources (Ribeiro et al., 2017) to optimize the Brazil nut harvesting route, minimize labor efforts, and redistribute placements (i.e., extractive concession units) (Santos et al., 2002) among extractivists.

MATERIAL AND METHODS

Data and Description of the Work Area

The study area comprises the Madre de Dios region in Peru, which was designated as a "Biosphere Reserve" by UNESCO (Dirección General Parlamentaria, 2016). The climate in this region is classified as tropical humid, with an average annual temperature of 26°C. The rainy season typically occurs between December and March, while the dry season takes place from June to August. The hydrography of the region is composed of several rivers and streams, which serve as the main means of transportation. The dominant vegetation in the area is tropical rainforest. Information on the location and georeferencing of Brazil nut trees, as well as productivity, was obtained from Nunes et al. (2012). The Brazil nut trees included in this study are located in the Tahuamanu province, which covers an area of 6,386 hectares. Within this province, there are eight areas designated for Brazil nut harvesting (Figure 1).

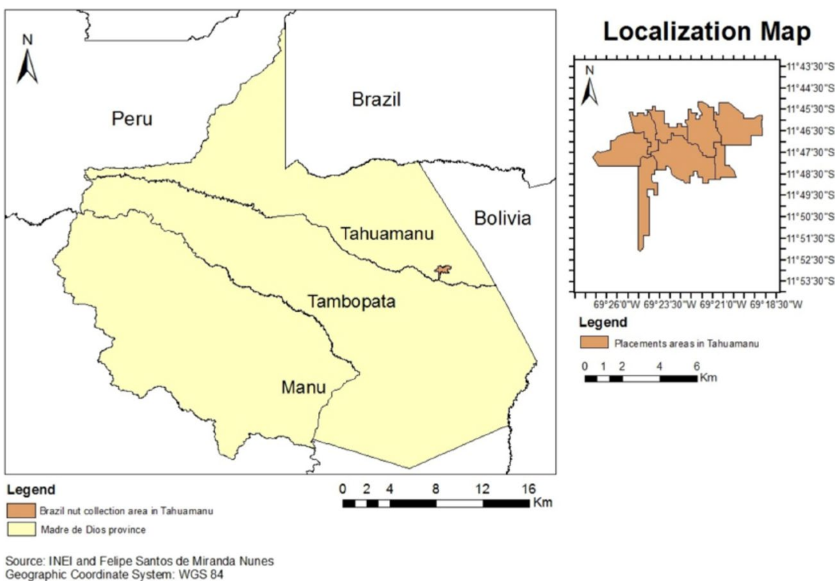

Figure 1: Geographical location of the Brazil nut collection areas.

Methodological steps

The following methodological steps (Figure 2) were followed to optimize Brazil nut harvest routes, reduce labor effort, and redistribute the extraction locations in the province of Tahuamanu.

Step 1. Digital elevation model (DEM)

The DEM was acquired through the Shuttle Radar Topography Mission (SRTM), which has a high level of detail with a spatial resolution of 30 m (Figure 3A).

Step 2. Roads and hydrography

The data for federal, state, and vicinal roads were obtained from the GEO GPS Peru website (http://www.geogpsperu.com/p/descargas.html). These data were converted to raster and then to vector format to match the two types of formats. Vector hydrography data used in this study, including rivers, lakes and islands of the Madre de Dios region, was available on the website of the Ministry of Education of the Government of Peru (http://sigmed.minedu.gob.pe/descargas/#).

Step 3: Network analysis

Network analysis involves a collection of interconnected linear arcs used to examine the movement of resources from one location to another (Miranda, 2015). It was constructed using a network of arcs that facilitated the simulation of extractivists' movements within the Brazil nut production areas, aiming to optimize production time, effort, and placement relocation (Ribeiro et al., 2017). To accomplish this, we first obtained a vector mesh of points created at the center of each cell, as well as the coordinate and elevation values (X,Y,Z) of each point.

To simulate a realistic environment where displacement can reach any neighboring location, a line segment was created to connect the generated points to their eight neighboring points. The nearest eight adjacent points were identified using a search radius of 45 m, which is approximately the maximum diagonal distance between two cells. This value was calculated as the diagonal of a square with a cell edge length of 30 m, resulting in a diagonal length of $30\sqrt{2}$ m or 42.43 m. Each row was individualized and defined by a unique identifier for the line that originated at point i and ended at point j, as well as another identifier for the line that originated at point j and ended at point i. This resulted in a line-like vector feature with distance, coordinates, altimetry, and connections between points (Figure 3C).

The altimetry information for the generated arcs was important in order to determine the slope of the arcs in both directions: from origin to destination and from destination to origin (Ribeiro et al., 2017). Different velocities were used in the analysis, considering the diversity of environments where Brazil nut extraction and transport take place, such as forest land tracks, state and interstate highways, and hydrography. Average speeds of 45, 60, and 80 km/h were used for roads, while average speeds of 25 km/h and 40 km/h were used for narrow and wider rivers, respectively. The velocity of foot transport through the terrain was calculated based on Tobler's function (Tobler, 1993) (Eq.1), with a velocity of 5.05 km/h at 0° and a maximum speed at -5% ramp inclinations. Where W is the walking speed (km/h), S is the ramp inclination, dh is the difference in elevation between the extreme points of the ramp, dx is the horizontal distance in a straight line between the ends of the ramp, and θ is the angle between the ends of the ramp.

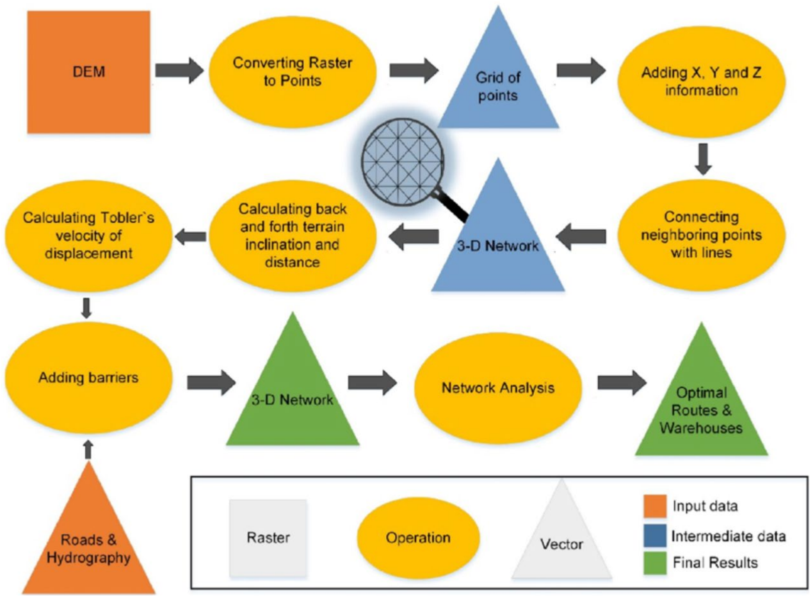

Figure 2: Methodological steps for optimizing chestnut harvest routes, reducing labor effort, and redistributing extraction locations in the province of Tahuamanu.

$$W = 6e^{-3,5\left|\frac{dh}{dx}+0,05\right|}; \frac{dh}{dx} = S = \tan\theta \quad (1)$$

To calculate the velocity of Tobler, we used the altimetry and slope information stored in the 3D arcs (Arcs with X, Y and Z data). Time spent in both directions to traverse each arc was obtained dividing the length of the arc by the velocity of Tobler.

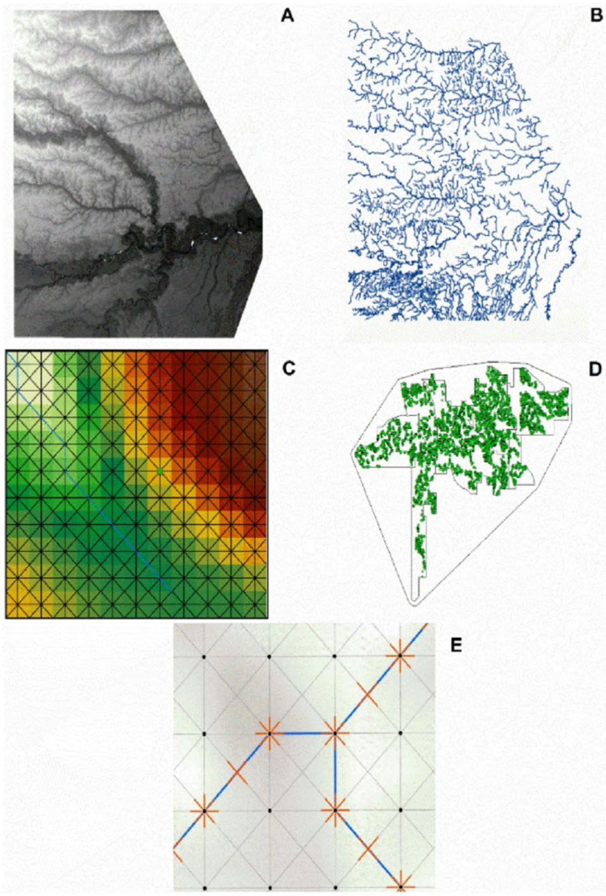

Figure 3: DEM of the study area (A); Single line hydrography (B); Arcs generated from the central points of the raster (C); Study area subset (D); and Barriers to add cross-border delays (E).

Step 4: Delimitation area and barriers present on the ground

After delimiting Tahuamanu area, a 250 m buffer was generated to ensure that no information was lost, including the Brazil nut trees present near the placement's border (Figure 3D). In addition to the slope of the terrain, barriers such as rivers and streams can affect the cost of the route (Ribeiro et al., 2017). Therefore, these barriers were identified and taken into account during the analysis. It was assumed that the extractivists could traverse the hydrographic network using a boat.

To identify the barriers present in the hydrography and on the roads, an intersection between arcs crossed by roads or hydrograph was created, and they were divided in half. The median points of the diagonals were generated, and to preserve the altimetry, the Z value was calculated based on the average of the Z origin and the Z of the destination. A "Buffer" of 30% of the edge of the smaller value of the diagonal (21.21 m) was then applied. The "Buffer" generated carried information from the central node of the cell and associated arcs. This led to the generation of a "star" with 56 possible routes for walking, but without allowing the return in the arc of arrival during the network analysis. The points created by the meeting of the edges of the pixels resulted in 16 possible routes for walking, of which four were not feasible due to the inability to return in the arc of arrival (Figure 3E). These arcs were assigned impedance values calculated using the attribute table (Table 1). This was done to best approximate the reality of the extractivist, thus incentivizing them to avoid unnecessary crossings in the hydrography. A delay of 20 minutes was considered in the route between hydrography, terrain, and road. A delay value of zero creates a preference for this path. These values were considered as delays and were generated for the terrain, roads, and hydrography.

Table 1: Delays related to the arcs of origin and destination.

Walking direction			
Arc of origin	**Intersection**	**Arc of destination**	**Delay (minutes)**
Road	Road	Road	0
Road	Road	Terrain	0
River	Road	River	0
River	River	River	0
Terrain	Road	Road	0
Terrain	Road	Terrain	0
Road	Road	River	20
Road	River	River	20
River	Road	Road	20
River	Road	Terrain	20
River	River	Road	20
River	River	Terrain	20
Terrain	Road	River	20
Terrain	River	River	20
Road	River	Road	40
Road	River	Terrain	40
Terrain	River	Road	40
Terrain	River	Terrain	40

Step 6: Network Analysis tools

Location-allocation

Location-Allocation" module from the "Network Analyst" extension in ArcGIS software was used for network analysis. The goal of the location-allocation analysis was to choose facility points from a set of potential sites that would result in an ideal and efficient distribution of resources, with the aim of minimizing costs and maximizing accessibility (ESRI, 2018; Fardin et al 2018). The problem considered was that of maximum coverage, which aims to maximize the number of demand vertices covered within an analyzed impedance by locating a fixed number of facilities (Church; Revelle, 1974; ESRI, 2018). The mathematical formulation of this problem is described as follows (Equation 2) (Fardin et al., 2018). *I* is a set of vertices that demand coverage; *J* is the set of facilities; *S* is the distance beyond which the demand point is considered not covered (the value of *S* may be different for each demand point if desired); *dij* is the shortest distance between vertex i and vertex *j*; *Xj* = 1 if the facility is located in j, and 0 otherwise; *Ni* is {*j* ∈*J* ∈ *dij* ≤ *S*}; *ai* is the population served by the demand at vertex *i*; *p* is the number of facilities to be located, and *Ni* are the possible locations of facilities that provide coverage for each demand point *i*. A vertex is considered covered when the nearest facility is less than or equal to *S*. Constraint (1) allows *Yi* to be equal to 1 when one or more facilities are located within the set *Ni*. In constraint (2), the number of facilities allocated is limited to *p* (Fardin et al., 2018).

$$\text{Maximize } z = \sum_{i \in I} a_i y_i$$

$$\text{Where } \sum_{j \in N_i} X_j \geq Y_i \, \forall i \in I; \;\; \sum_{j \in J} X_j = p; X_j = (0,1) \forall j \in J;$$
$$\text{and } Y_i = (0,1) \;\; \forall i \in I$$

The demand points considered were georeferenced Brazil nut trees; the impedances considered were Tobler velocity and arc priority, where the lowest values were preferred (Table 2), delays caused by barriers, and 3D distance. The sampling tool was used to generate 1,500 points, which were considered as possible locations for the installations in the analysis tool. This tool was developed and made available by Ken Buja. (https://www.arcgis.com/home/item.html?id=28f08ca526ae44e8ac107a2a0d5f50e3). Thiessen polygons were created to delineate the areas of Brazil nut trees. This method allowed for the definition of the "domain" areas (Alcântara et al., 2018) for each Brazil nut tree. The data were grouped based on similar attributes, and the placement of Brazil nut trees was then redistributed using the maximum coverage problem.

In the Tahuamanu area, the distribution of 5,500 Brazil nut trees among eight exploration placements was not equal among the extractivists responsible. To achieve a balanced division, approximately 688 Brazil nut trees would need to be included in each of the eight areas. However, the analysis considering the 3D distance of the arcs, the hierarchies to traverse them, the "Dissolve" of the polygon of the trees, the delays, and the 1,500 points indicated the need for a new division of placement areas to solve the problem of maximum coverage. In the attribute table of the georeferenced Brazil nut trees, a production value per collection vessel (can) was included. Among the initial 5,500 trees, 974 unproductive trees were identified. Each can can hold a volume of 18 liters, which is approximately 10 to 15 kg of Brazil nuts with seeds (Nogueira, 2011), resulting in a total production of 9,561 cans. With this productivity data, a new maximum coverage analysis was conducted, using Tobler's speed instead of 3D distance as the impedance.

Table 2: Hierarchy for traversing each arc.

Arc	Arc direction	Priority
	Flat	1
Terrain	negative slope	2
	positive slope	3
	Flat	4
Road	negative slope	5
	positive slope	6
River	-	7
Uses	**Abbreviation**	**Route segment**
1	T	Forest land tracks
2	U	Streams
3	D	Wide streams
5	F	Interstate highways
6	E	State highways
7	V	Dirty roads

Vehicle routing problem (VRP)

For this network analysis, it was necessary to create new barriers to include the arcs of the roads and rivers that reach Puerto Maldonado. As these arcs had different attributes (Table 2), it was necessary to establish additional impedance values for their intersections (see Supplementary Material). The travel time for each arc was calculated by dividing its length by the respective speed. For the process of creating the barriers, the arcs of the delimited area were joined with both road and stream networks. Next, the arcs were grouped with similar attributes without using the multipart feature. The points where the arcs intersected were generated. The next step was to create an extension area of 5.3 m (this value was calculated by dividing the value of the diagonal by eight to prevent it from recurring from one area to another). Intersections were made with the generated areas and the junctions of the arcs. To search for the optimal route for a capacitated problem, the "Network Analyst" extension and the VRP module for vehicle routing were used (ESRI, 2018).

Two VRP analyses were performed where productivity was not partitioned into more than one vehicle to be transported independently of the terrain, i.e., productivity was defined as transporting 9,561 cans at a single time. The first analysis aimed to define the optimal sequence of visits among the placements determined by ArcMap and to minimize the total distance traveled to Puerto Maldonado; the actual distance (3D) was used for this analysis. The second analysis aimed to minimize the total time of the route, using the multimodal attribute, the table of delays, the result of the division of the placements by the productivity, the location of the port, and the traversal time of each arc.

RESULTS

A natural proportionate distribution of Brazil nut trees in Tahuamanu (Figure 4A) does not exist, and the number of Brazil nut trees varied from 207 to 1,221. The results of the first reallocation can be seen in Figure 4B. In this analysis, the 5,500 trees were divided into balanced quantities between the eight placement areas. However, since the initial count was not accurate, the ArcGIS software redistributed the trees so that an area had a smaller number of Brazil nut trees (684). The second location-allocation analysis aimed to distribute the Brazil nut trees in a balanced way, taking into account their productivity. To achieve this, the 1,196 cans produced by the trees were divided between the eight placement areas, resulting in a range of 355 to 751 trees per area (Figure 4C). In total, 4,526 productive trees were distributed, while 974 unproductive ones were left out. Both the initial placement areas and the location allocation were changed in both analyses.

The resulting route that reduces the 3D distance to Puerto Maldonado is shown in Figure 5A, where it can be observed that the analysis resulted in a route with a large number of crossings (59) and consequent delays. The delay time was 24:20′ and the time taken to cover all the arcs was 8:09′, for a total time of 32:29′ (Table 3). The total number of arcs covered was 5,723 (146,009 m). Within the placements, the entire route was largely realized within the forest land tracks, with a brief use of streams. The direction of the walk followed the numerical sequence from 1 to 8 (Figure 5B) with a path distance of 23,054 meters (Table 4).

The total time spent by the extractivists in the VRP analysis with the aim of minimizing time was 13:56′:3″. Unlike the previous analysis, the number of crossings was lower (18). In addition, a segment of the route was completed via wider streams. The time taken to cover the route without delays was 08:46′, which is superior to the time taken to minimize the distance. However, the total delay time was 05:10′ (Table 3).

The walking sequence in this area also followed 1 to 8 (Figure 5C), and the time spent on this route was Fig.05:28′ (Table 3). The total distance traveled within the placement areas was 30,776 m (Table 4). Among the placements, the longest distance was between 4 and 5, with a length of 11,467 m (Table 4). This was also the displacement that took the longest time of 71 minutes (Table 3). However, the displacement from 3 to 4, despite covering almost half the distance from 4 to 5, took almost the same time at 1:5′ (Table 3). This was due to the two roads presenting two barriers with similar delays in exchanging means of transport. The walking route passed through five of the six types of land use while failing to pass through the state highway (Figure 5D). The directions of the routes in the placement areas, identified between the minimization analyses of the 3D distance and time, were different (Figure 6B). It can be observed from Figure 6C that despite the difference in the path between the two VRP analyses, some of the crossings used by both analyses were similar and could be considered as possible harvest support points.

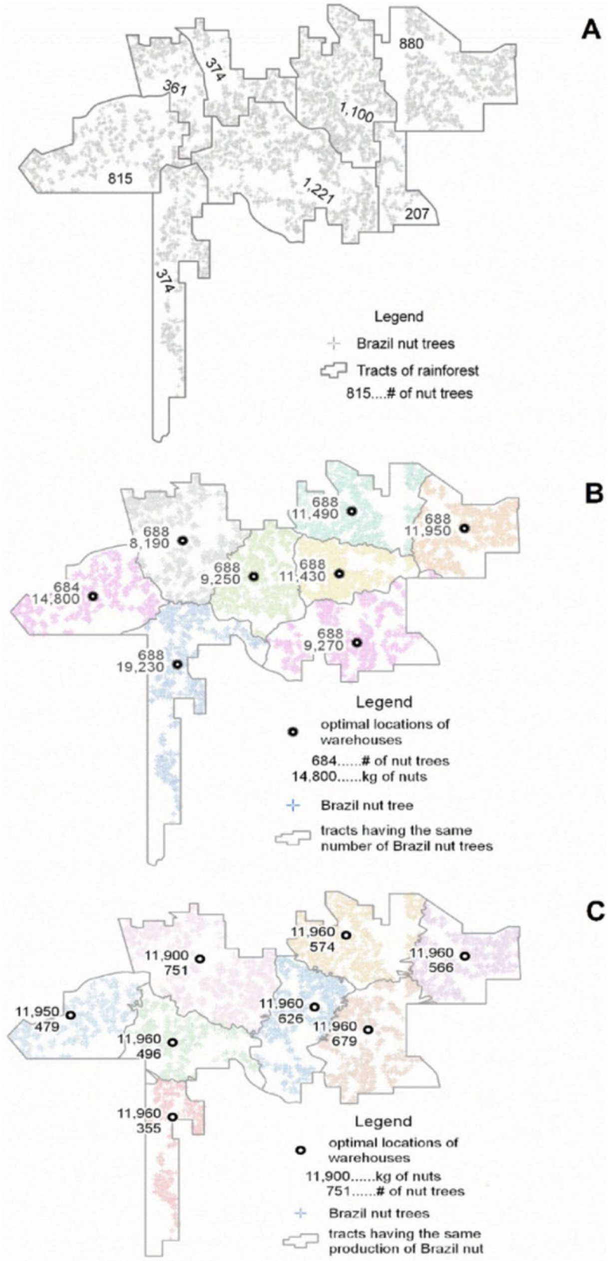

Figure 4: the spatial distribution of Brazil nut trees within the forest concessions (A); equal partitioning of forestland based on the number of nut trees (B); and equal partitioning of forestland considering nut productivity (C).

DISCUSSION

As this study represents an innovation in network analysis, it is worth highlighting the significance of database preparation. Any errors during network construction could impede the processing of the tool “Network Analyst,” necessitating the rework and reconstruction of the network in case of a fault. In addition, due to the large volume of data generated, the use of Python programming language was necessary because the ArcGIS software’s “Model

Builder" took a long processing time (days for certain analyses). However, with the use of Python, the processing time was significantly reduced to hours or even minutes, which represents a considerable improvement.

Network analysis enables a wide range of studies by creating a multimodal environment that generates several scenarios for combining field trips, transportation, and productivity. One potential analysis to explore further is the transport capacity of extractivists, given that each of them carries 10 to 15 cans per day, according to Nogueira (2011). Additionally, a balanced division of Brazil nut trees, along with the relocation of harvesting areas, can help minimize conflicts between extractivists and loggers in the Madre de Dios region.

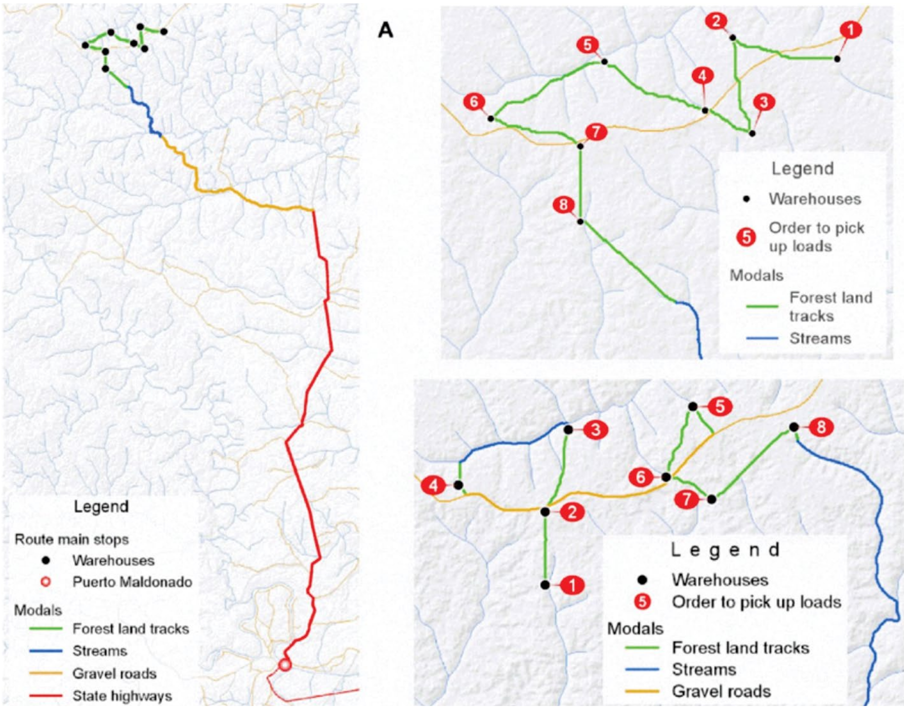

Figure 5: Shortest route for picking up nut loads and shipping them to Puerto Maldonado (A); optimal sequence for picking up nut loads in the concessions (B); and optimal sequence for picking up nut loads in the concessions with the aim of minimizing time (C).

Table 3: Summary of route segments for minimizing real distance and travel time.

Shortest real distance route										
	NA¹	**DR²**	**DH³**	**TA⁴**		**NC⁵**	**D⁶**		**Tt⁷**	
1-Tr	1.076	27.056	27.025	332	05:32	13	520	08:40	852	14:12
2-S	474	11.928	11.927	29	00:28	22	800	13:20	829	13:48
5-RF	2.963	76.257	76.211	91	01:31	1	5	00:05	96	01:36
7-EV	1.210	30.768	30.703	37	00:36	23	135	02:15	172	02:51
Total	5.723	146.009	145.866	489	08:09	59	1.460	24:20:00	1.949	32:29:00
Fastest route										
	NA¹	**DR²**	**DH³**	**Tsa⁴**		**NC⁵**	**D⁶**		**Tt⁷**	
1-Tr	689	17.163	17.138	213	03:32	0	0	00:00	213	03:32
2-S	1.963	48.394	48.390	116	01:56	8	200	03:20	316	05:16
3-WS	2.952	74.295	74.281	111	01:51	2	40	00:40	151	02:31
5-RF	179	41.412	4.140	5	00:04	2	10	00:10	15	00:14
7-EV	2.748	67.338	67.230	81	01:20	6	60	01:00	141	02:20
Total	8.531	248.602	211.179	526	08:46	18	310	05:10	836	13:56

Note: 1-TR=Forest land tracks; 2-S=Streams; 3-WS=Wide streams; 5-RF=Interstate highway; 7-EV=Dirty road; NA1=Number of arcs; DR2=Real distance (m); DH3=Horizontal distance (m); TA4=Travel time without delays; NC5=Number of turns; De=Delay6; and, Tt7=total traverse time.

Table 4: Traverse distance for visiting all placements.

	Id[1]	Load[2]	DPA[3]	DA[4]
Shortest route (1)				
1	271	1196	0	0
2	237	1196	3.678	3.678
3	848	1196	3.385	7.063
4	621	1196	1.842	8.905
5	55	1190	3.933	12.838
6	460	1195	4.466	17.303
7	495	1196	3.284	20.588
8	1036	1196	2.466	23.054
Fastest route (2)				
	Id[1]	**Load[2]**	**DPA[3]**	**DA[4]**
1	1036	1196	0	0
2	495	1196	2.501	2.501
3	55	1190	3.087	5.588
4	460	1195	5.343	10.931
5	237	1196	11.467	22.398
6	621	1196	2.745	25.143
7	848	1196	1.843	26.986
8	271	1196	3.791	30.776

Note: Id1=placement id; Load2=# of cans of nut load; DPA3=Distance from previous stop (m); and, DA4=Accumulated distance (m).

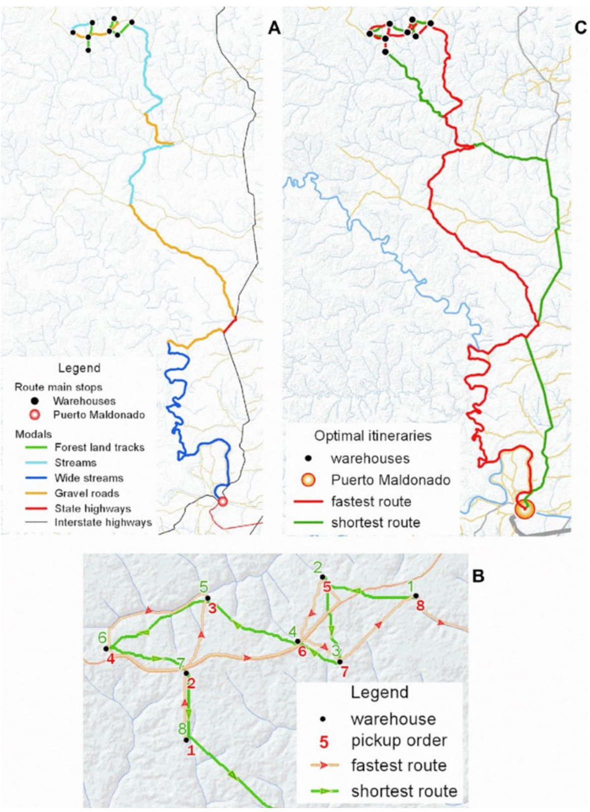

Figure 6: Fastest route for picking up Brazil nut loads and shipping them to Puerto Maldonado (A); Directions of travel between the two VRP analyses (B); and, Comparison of time and distance minimization routes (C).

The Brazil nut trees located in Madre de Dios are owned by the Ministry of Agriculture, which establishes a two-year contract with extractivists for their exploitation, as reported by Escobal, Aldana, and Agreda (2000). The volume of extraction is determined based on information provided by the extractivists. However, the property rights structures are not clearly defined, and overlapping settlements and boundary disputes may arise due to the lack of knowledge of the number of exploitable trees and the area, leading to conflicts with loggers (Willem et al., 2019).

A clearer definition of usage rights could potentially lead to higher income for extractivists. However, limiting access to forest resources presents sustainability challenges due to conflicting interests among extractivists, hunters, loggers, and miners, which can harm the ecosystem (Froese et al., 2022). Extractivists also perceive a substantial decline in nut yields over the past 25 to 30 years, which corroborates with recent findings highlighting losses due to forest degradation (Escobal; Aldana, 2003; Jansen et al., 2021). Network analysis can help optimize the distribution of scarce resources through models based on special types of linear programming (Ribeiro et al., 2017).

In addition to the study's objective of redistributing Brazil nut trees based on productivity and optimizing production routes, adequate management can help minimize the impact on the forest from both extraction and collection activities. Sustainable management practices can ensure the quality and sustainability of this resource, making it feasible for extractivists to exploit it indefinitely and increasing its commercial value. This type of production aims to promote both the conservation of the Amazon Forest and the well-being of the extractivists (Ribeiro, 2011).

Due to the remote location and natural accessibility challenges, as well as the lack of basic public services and high transportation costs, permanent occupations in Brazil nut tree areas are scarce (Escobal; Aldana, Agreda, 2000). The results of the network analysis with the VRP suggest that reducing the distance traveled and arrival time in Puerto Maldonado is feasible, potentially changing the conditions for occupations in the area. However, to support this new system, it would be necessary to establish garages and new ports.

The commercialization of NTFPs is influenced by the distance between the collection areas and distribution and commercialization centers (Fiedler; Silva, 2008). The collection points analyzed in this study could serve as support points for storage or drying of Brazil nuts. However, extraction methodologies are often carried out in precarious conditions, generating significant quantities of waste (Conforte, 2000; Kluczkovski et al., 2020). Prices of NTFPs also vary widely across countries (Torres, 2001; Chopra, 2020), which can be attributed to differences in distance between production areas and marketing centers, the quality of information available to extractivists about the market, and the organization of production. Given the vast size and diversity of communities and NTFPs in these regions, optimization of extraction processes and public actions should focus on constructing beneficial facilities within the communities, while requiring minimal investment in infrastructure to support commercialization (Marshall, 2005; Dyck, 2022).

CONCLUSIONS

The original approach proposed by Ribeiro et al. (2017) has been shown to be effective in optimizing Brazil nut harvest routes and redefining placement areas more reliably. The redefinition of Tahuamanu's eight placements resulted in greater uniformity and a balanced distribution of productivity. The study of the VRP has proven efficient in identifying better transportation routes for Brazil nuts. The results also highlighted the need to use intermediate support points for harvesting. This can be achieved by utilizing the location-allocation problem to maximize productivity, and from the intersection points of the two analyzed routes. However, the data processing time was long, requiring increased computational resources to apply this methodology to very large areas.

AUTHORSHIP CONTRIBUTION

Project Idea: MSL; CAASR; HGL

Database: CAASR; HGL

Processing: MSL; GEM;

Analysis: MSL; CAASR; GEM; HGL

Writing: MSL; APMT; GFD; HGL

Review: MSL; CAASR; APMT; GFD; VDNM; ARDS; HGL

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