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Priority areas and integrated actions for the conservation of Amazonian turtle populations historically over-exploited by humans

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ABSTRACT

The definition of priority areas for conservation and integrated management actions are essential for the effective maintenance and recovery of natural populations, especially for species overexploited by humans. Amazonian chelonians are a food resource historically used by people, resulting in the decline of species populations and worsening the risk of local extinctions. In this paper, we establish priority areas and define integrated conservation actions for populations of three Amazonian chelonians most threatened by human consumption in Brazil (*Podocnemis expansa*, *P. unifilis* and *P. sextuberculata*). To do so, we used 15 prioritization criteria (ecological, logistical and socioeconomic) estimated with 30 years monitoring data in 15 areas by the Amazon Chelonian Program (in portugues Projeto Quelonios da Amazonia, PQA). Each criterion presented four levels of priority with scores increasing according to the relevance for conservation of chelonian populations. The sum of the scores obtained in each area of the PQA allowed a ranking and four categories of importance for conservation to be defined. We also analyzed the similarity of scores among areas of the PQA and among the prioritization criteria to evaluate the application of integrated conservation action strategies. The areas of PQA were classified as Extremely Important for Conservation (Rebio Trombetas River, Middle Xingu River, Middle Araguaia River, Upper Guaporé River), Very Highly Important for Conservation (Middle Purus River, Middle Juruá River, Crixás-Açu River Mouth, Sub-middle Tapajós River); Highly Important for Conservation (Sub-Middle Araguaia River, Amazonas River Mouth, Middle Mortes River); and Important for Conservation (Middle Guaporé River, Lower Branco River, Flechal River, Afuá River). The prioritization and similarity analyses can support the development of a national integrated plan of conservation actions to reduce the overexploitation of Amazon chelonian populations, according to the ecological, logistical and socioeconomic needs of each PQA area.

Keywords: Conservation priority; Threatened Species; Chelonians; Amazon; Game species; Wild meat.

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SIGNIFICANCE STATEMENT

This work arose from the need to discuss priority areas for the conservation of chelonian species in the Amazon region, since historically these have been highly threatened due to their cultural use as a food resource for humans, in addition to the impacts resulting from deforestation, agricultural advances, hydroelectric dams and illegal trade, which led to the decline of many of their populations. This work seeks to contribute to decision-making and to be a point of debate on conservation actions for Amazonian chelonians.

INTRODUCTION

The establishment of priority areas for conservation is essential to guide efficient and effective actions for the maintenance and recovery of wild species, especially those threatened by direct exploitation by humans (Félix and Martins 1999; Wallace et al. 2010). Chelonians are historically exploited as a food and medicinal resource in several regions of the world (Luiselli et al. 2021; Rueda-Almonacid et al. 2007; Santos and Fiori 2020), with emphasis on those that concentrate a high diversity of species of the group and low socioeconomic development, such as Southeast Asia and the Amazon region (Alho, 1985; Rhodin et al. 2018; Turtle Conservation Coalition 2011). This anthropic pressure promotes an increased risk of extinction of chelonian species, motivated by population decline resulting from the destruction of natural habitats and direct capture for consumption (Lovich et al. 2018; Stanford et al. 2020).

Despite the critical increase in destruction of the Amazon forest caused by anthropic activities (Alfinito 1975; Mittermeier 1978; Smith 1975), direct exploitation still configures as the main threat to Amazon chelonians (Erade et al. 1998; Fagundes et al. 2018; Kemenes and Pezzuti 2007; Norris et al. 2018; Ojasti 1971; Schneider et al. 2011). This fact was diagnosed by the Brazilian threatened species assessment that classified most of these chelonians as least concern (LC) or as insufficient data (DD), except for three of them, recognized as near-threat (NT) and dependent on management: *Podocnemis expansa*, *P. unifilis* and *P. sextuberculata* (ICMBio 2018; Malvasio et al. 2019). The need for management is due to the population decline, which began since colonial times, in several regions where these species occur due to the intense capture of females and eggs for food or raw material for domestic utensils, in addition to the use of egg oil in the kitchen and in lighting (Alho 1985; Bates 1876; Eisemberg et al. 2019; Forero-Medina et al. 2021; Johns 1987; Mittermeier 1978). However, changes caused by humans in spawning areas, for example, by the construction of hydroelectric plants and highways, dredging of river bottoms, urban expansion and agropastoral enterprises, among other environmental changes, also negatively impact the spawning sites of these species (Alfinito 1975, Mittermeier 1978, Smith 1975, 1979, Rodrigues 2005). Additionally, climate change, mainly related to hydrological cycles, has the potential to further accentuate the decline of these species (Eisemberg et al. 2016). In response to this need, the Amazon Chelonian Program (in portugues Projeto Quelonios da Amazonia-PQA) was created (Coutinho 1968; Ryles and Pinto 1998).

The PQA arose from the union of several governmental projects that have sought to protect these Amazonian chelonians since 1970 (Coutinho 1968), which seeks to plan, standardise and structure the monitoring and implementation of conservationist actions on the important beaches for the reproduction and maintenance of these species. This program operates in a participatory way, with the inclusion of local communities and the Brazilian federal government, which monitors and develops actions to protect turtle nests and females, seeking economic alternatives for local populations involved (Lacava et al. 2020). Over the past 30 years, the PQA has monitored nesting areas in nine Brazilian states and managed more than 46 million nests of the species *P. expansa* (Amazon turtle), *P. unifilis* (tracajá) and *P. sextuberculata* (iaçá) (Cantarelli et al. 2014). However, even with histor-

ical conservation efforts, the threat of extinction to these species still persists, requiring new approaches to prioritise areas and project actions to optimise the financial and human resources for the management of the areas monitored by the PQA (Forrero-Medina et al. 2021).

Usually, prioritization analyses for chelonian conservation apply macroecological metrics of diversity (taxon richness and endemism, phylogenetic uniqueness) or irreplaceability of species to define more important areas for the group (Buhlmann et al. 2009; Ennen et al. 2020; Ennen et al. 2021; Fagundes et al. 2018; Mittermeier et al. 2015). On the other hand, the population information of chelonians in PQA, widely distributed and monitored for a long time, allows establishing priorities for intraspecific and interspecific actions, expanding the potential of conservation strategies (Mace 2004; Rodrigues et al. 2006). In addition, it is possible to incorporate the variation of socioeconomic and logistical factors of each region studied to identify which areas are priority areas for conservation of these chelonians and which actions are a priority to increase the efficiency and effectiveness of the management carried out (Lacava et al. 2020). Therefore, this study analyzes these three factors monitored by PQA to propose and apply criteria for prioritizing the areas of occurrence of *Podocnemis expansa*, *P. unifilis* and *P. sextuberculata* populations, aiming to guide conservation efforts. We also evaluated the level of similarity of the criteria between the areas to propose integrated strategies for the development of conservation actions provided in the PQA (Cantarelli et al. 2014; Lacava et al. 2020).

To this end, we assume that ecological factors allow us to diagnose the population trends of the different species in each area studied by monitoring the number of nests and females to estimate the vulnerability of populations to extinction, so that areas with greater coexistence of species and with a greater tendency to population decline (less stability over time) are priorities for new conservation efforts (Eisemberg et al. 2019). As for the socio-economic factors, we consider that the populations under greater anthropic pressure must be a priority for conservation efforts (Norris and Michalski 2013), evaluated by: land use intensity (such as the level of restriction on use by protected areas and the level of anthropic influence), human population density, the level of organization and participation of local communities in the management of turtles and other associated animals, the possibility of economic alternatives for subsistence and the potential for tourism in the region. Finally, we assumed the logistical factors as they represent the difficulties and facilities for the management of PQA and the development of conservationist actions, considering: the inspection structure by governmental agencies, the partnerships with research institutions and civil society, the involvement of the local community and the estimated financial cost of nest management.

MATERIAL AND METHODS

The Amazon Chelonian Program (PQA) is developed in 15 chelonian breeding sites in the Brazilian Amazon, covering eight states (Amazonas-AM, Amapá-AP, Goiás-GO, Mato Grosso-MT, Pará-PA, Rondônia-RO, Roraima-RR e Tocantins-TO) (Figure 1), where their populations are monitored for over 30 years (Lacava et al. 2020). During the workshop of the II Forum "Strategy for Conservation and Management of Brazilian Reptiles and Amphibians", after extensive debate by continental chelonian specialists, the three target species were defined for prioritization of the areas of PQA (*P. expansa*, *P. unifilis* and *P. sextuberculata*), due to the strong pressure of exploitation for human consumption (Souza 2005). Then, the annual data on the reproductive management of chelonians and the socioeconomic information obtained through local questionnaires made it possible to establish 15 prioritization criteria for areas of the PQA, divided into three factors: ecological, socioeconomic and logistical (Table 1), according to the good practices of multicriteria analysis (Esmail and Geneletti 2018). This methodology resulted in a technical management report with information specific to the Amazon Chelonian Chelonian Project (PQA), restricted to the administrative field (Souza 2005).

The ecological factor is composed of two criteria that assess the conservation status of populations of *P. expansa*, *P. unifilis* and *P. sextuberculata*: (1) the co-occurrence of species and (2) the trend in number of females and nests per breeding area over the years (Table 1). Socioeconomic and logistical factors are described by 13 criteria on the characteristics of local human communities and the ability of federal environmental agencies to affect the conservation of each breeding site (Table 1). Also, according to the actions predefined by the team coordinating the PQA (`https://www.ibama.gov.br/fauna-silvestre/quelonios-pqa/programa-quelonios-da-amazonia-pqa`), we carried out a relationship between the prioritisation criteria and their respective priority conservation actions, which might contribute to improved conservation policy (Table 1).

Three levels of priority were assigned to each criterion with decreasing scores, corresponding to decreasing importance for conservation (Table 2). The scores within and between criteria were pre-defined by the chelonian specialist researchers consulted, who indicated greater importance for ecological factors, followed by logistical and socioeconomic factors. Next, the information from the monitoring of the PQA areas

was used to classify them in terms of ecological, logistical and socioeconomic aspects. The sum of the score values per area resulted in the respective PQA scores, which present higher priority for conservation as their value increases. Then, four decreasing categories of importance for conservation of Amazonian chelonians were defined by sorting and dividing the PQA scores into quartiles (Schröter et al. 2017): Extremely Important for Conservation, Very Highly Important for Conservation, Highly Important for Conservation and Important for Conservation.

Finally, two hierarchical clustering analyses were performed with the obtained PQA scores (Kassambara 2017), applying the Euclidean distance and the UPGMA method (unweighted pair group method with arithmetic mean) in the vegan package of the R statistical program (Dixon 2003). The first analysis sought to identify the areas of the PQA that share greater similarity regarding the prioritization criteria, allowing the recognition of the strengths and weaknesses of the program in each area of the PQA and relate the areas that share more similar conservation challenges and opportunities. The second analysis aimed to recognize the relationship between the prioritization criteria to evaluate those that present greater synergy between the areas of the PQA. These two analyses of similarity together provide subsidies for proposing integrated strategies between more similar areas to implement the conservation actions of the PQA (Table 1). These results are presented in a heatmap graph to represent the relationship between the importance of the prioritization criteria and the areas of the PQA, implemented by the superheat package (Barter and Yu 2018).

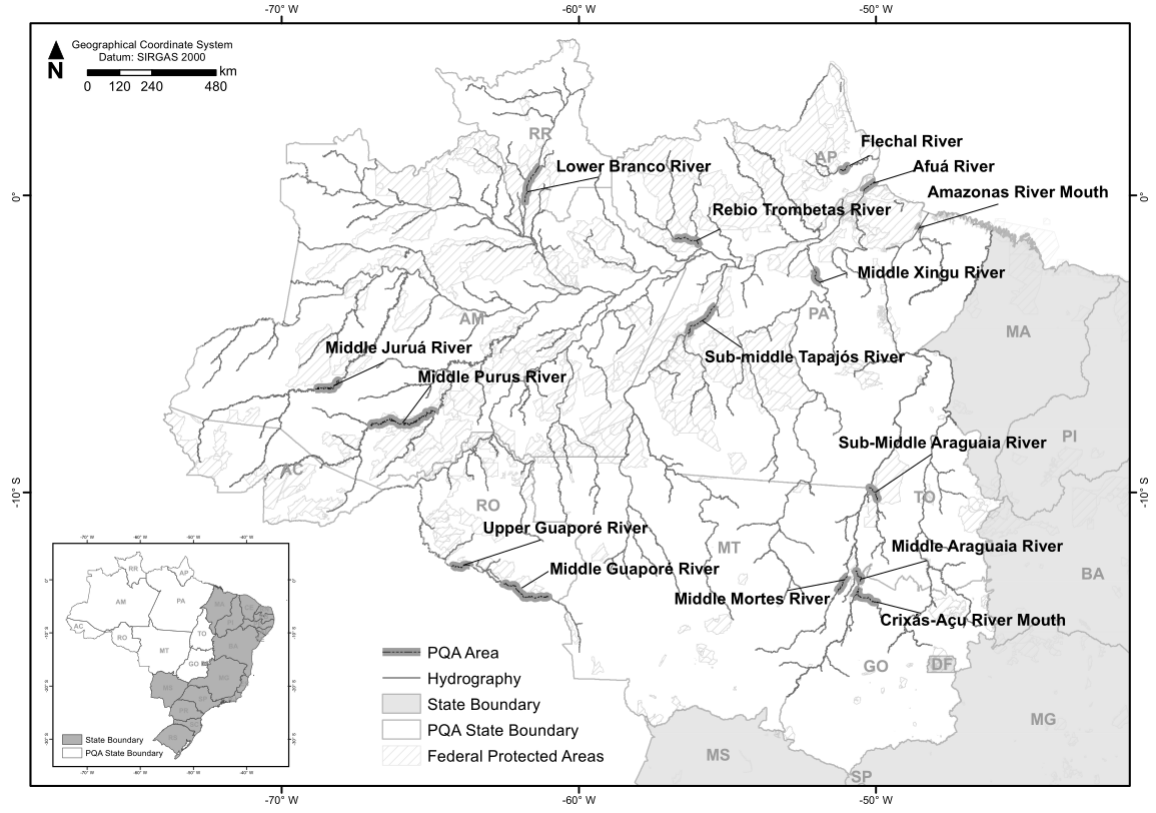

Figure 1. Location of historical work areas of Amazonian Chelonian Program – PQA

Table 1. Factors and criteria determining Amazonian Chelonian Program (PQA) priority areas and the corresponding PQA conservation actions.

FACTORS	CRITERIA	CRITERIA DESCRIPTIONS	PQA ACTIONS	PQA ACTIONS DESCRIPTIONS
ECOLOGICAL	Female population	Population trends based on field experiences and results of analysis of the number of females or offspring over the years.	In Situ management	Practices aimed at safeguarding the natural incubation process of the eggs laid by female chelonians, or the transfer of nests to places with characteristics similar to natural areas.
	Managed species	Number of species ovipositing in area.		
LOGISTIC	Inspection	Supervision and/or control in area – competent institutions or community itself.	Integrated surveillance	Joint participation among federal, state, and municipal inspectors focused on information and control of the use of environmental resources.
	Research area	Existence of research in area by universities and/or executors.	Research	Development of basic and applied studies aimed at consolidating management and sustainable use projects and programs.
	Management by other institutions	Management programs in area by other organizations (NGOs, traditional communities, among others).	Interinstitutional articulation	Integration of efforts among the various environmental entities to define competencies and plan actions for the conservation and sustainable use of the target species.
	Shared management	Shared management potential.		
	Nests transfer and/or beach reinforcement	Nests moved.	Ex Situ management	Development of breeding technologies for commercial or species conservation purposes.
	Breeding cost	Estimated cost of offspring (calculated by total cost of campaign times the number of offspring born).		
SOCIOECONOMIC	Area in conservation unit	Proximity of managed areas to Conservation Units; proximity of managed areas indigenous areas.	Integrated surveillance	Joint participation among federal, state, and municipal inspectors focused on information and control of the use of environmental resources.
	Anthropic intervention	Degree of anthropic interference in area.		
	Average population density	Average population density of area.	Permanent environmental education	It permeates all PQA's work actions. It seeks to establish paradigm shifts in human behavior in relationships with environmental resources, especially chelonians, by raising awareness and reflection on the importance of conservation, sustainable use, and respect for nature's assets.
	Level of organization of the communities	Level of community organization.		

	Community management	Level of training in environmental education focused on wildlife management/promoters.		
	Income-generating alternative	Main income source.	Sustainable technology management	Integration of efforts aimed at the sustainable use and conservation of fauna and flora resources, adding value to generate employment and income.
	Tourism	Sustainable tourism alternatives.		

Table 2. Factors, criteria and scores that determine the three levels of prioritization of areas of the Amazon chelonians program (PQA), defined by a specialist in the taxonomic group.

FACTORS	CRITERIA	PRIORITY LEVELS					
		PRIORITY I	**Score**	**PRIORITY II**	**Score**	**PRIORITY III**	**Score**
ECOLOGICAL	**Female population**	Female population decline in last 10 years	**300**	Stable population with a decreasing trend in females.	**200**	Female population increasing or stable with increasing trend	**100**
	Managed species	Two or more species of chelonians are managed	**100**	Two or more species of chelonians are managed	**60**	One species managed	**30**
LOGISTIC	**Inspection**	Low frequency of specific environmental inspection	**100**	Average frequency of specific environmental inspection	**50**	Area intensively inspected by ICMBio, IBAMA and State environmental agencies	**20**
	Research in area	Lack of research in area	**55**	With some research lines in area	**35**	Frequent existence of research in area	**15**
	Management by other institutions	No management carried out by other institutions	**55**	Implementation of few management initiatives by other institutions	**35**	Implementation of various management initiatives by other institutions	**15**
	Shared management	High potential for co-management (caiman)	**10**	Existence of few shared management initiatives (e.g., caiman and pirarucus)	**7**	Greater frequency of management initiatives shared with other animals	**3**
	Nests transfer and/or beach reinforcement	Area without need for nest transfer or beach elevation	**5**	Some areas may require beach elevation or nest transfer	**3**	Frequent need for beach elevation and egg transfers	**1**
	Breeding cost	Low cost per breeding R$0.30–R$2.50	**150**	Cost per breeding between R$1.00–R$4.00	**100**	Cost per breeding greater than R$5.00	**50**
SOCIOECONOMIC	**Area in conservation unit**	Area outside Conservation Unit	**35**	Presence in few Conservation Units	**20**	Area within or around Conservation Unit	**12**
	Anthropic intervention	Anthropic intervention in area, area with greater impact	**35**	Average impact in area	**20**	Area little impacted	**12**
	Average population density	High population density, average over 20,000 inhabitants	**20**	Average population density between 10 and 20 thousand inhabitants	**10**	Average population density of less than 10,000 inhabitants	**5**

Level of organization of the communities	Low level of community organization	**20**	Communities with level of organization classified as intermediate	**10**	Communities with a high level of organization	**5**
Income-generating alternative	Reduced income generation alternatives	**20**	Up to two income generation alternatives	**10**	More than two income-generating activities in area	**5**
Tourism	High tourist potential	**15**	Tourist potential of area classified as intermediate	**10**	Absence of tourism in area	**5**
Community management	Lack of management by other communities	**55**	Management by communities around the Program areas	**35**	Management by communities within the PQA area	**15**

RESULTS

The areas of the PQA presented prioritization scores that ranged from 755 to 389, due to the great variation of the three priority levels of the criteria among the PQA areas (Table 3). The ecological factor presented a mean score of 224 and standard deviation of 86 among the areas of PQA, with the highest value for Rebio Trombeta River (400) and lowest values for the Lower Branco River, Flechal River and Afua River Mouth areas (133). The logistic factor has an average score of 223 and a standard deviation of 63 among the areas analysed, with the highest scores (288) standing out in the Upper Guapore River, Middle Purus River and Middle Mortes River areas; and the lowest scores (108) for the Amazon River Mouth. Finally, the socioeconomic factor presented a mean score of 122.5 and standard deviation of 22.6 among the PQA areas, with higher value for Rebio Trombeta River (160) and lower values for the Upper Guapore River area (82). Ecological criteria tended to show greater relative importance for areas with higher PQA Scores, while the relative contribution of logistical criteria was more important for areas with lower PQA scores (Table 3). The criteria associated with the socio-economic factor presented low relative importance for the PQA scores of the areas.

Priority ranking and importance for conservation of Amazonian chelonian species

The quartile ranking of the PQA Scores resulted in four categories of conservation importance for PQA: Extremely Important for Conservation, Very Highly Important for Conservation; Highly Important for Conservation; and Important for Conservation (Table 4). The PQA conservation importance rankings showed no defined spatial pattern, with no relationship of the categories to geographic proximity, state boundaries or watersheds (Figure 2). This suggests that regional boundaries are less relevant in determining conservation priority than variation in ecological, logistical and socioeconomic criteria that are local and specific to each PQA area.

Category I – Extremely Important for Conservation.

The first four areas in the priority ranking were classified as Extremely Important for Conservation (Table 4). The areas Rebio Trombetas River and Middle Xingu River presented the highest PQA scores respectively, located in the northern part of Pará State (Figure 2). The other two areas are located south of the Amazon basin, Middle Araguaia River in the state of Goiás and Upper Guaporé River in the state of Rondônia (Figure 2).

All four Extremely Important for Conservation areas recorded higher importance for ecological factors, due to population declines or declining trends for at least two monitored species (Table 3). The areas Rebio Trombetas River and Middle Araguaia River showed similar relative importance of logistical and socioeconomic criteria, while the Middle Xingu River and Upper Guaporé River areas recorded higher relative importance for logistical factors compared to socioeconomic ones (Table 3).

Category II – Very high conservation importance

The areas of the PQA occupying the fifth to eighth positions of the priority ranking were classified as Very Highly Important for Conservation (Table 4). The Middle Purus River and Middle Juruá River areas occupy respectively the fifth and sixth positions in the PQA scores ranking, located in the southwestern part of the Amazonas State (Figure 2). The seventh position of the ranking belongs to Crixás-Açu River Mouth in the northwest of the state of Goiás. The eighth position of the ranking is occupied by the Tapajós River Sub-middle, in the central-western region of the state of Pará (Figure 2).

Among the Very Highly Important for Conservation areas, only the Crixás-Açu River Mouth presents declining population trends for *Podocnemis expansa*, and a greater relative importance for ecological criteria (Table 3). The other areas present records of population stability for the three monitored species, resulting in greater relative importance for logistical criteria compared to the other criteria (Table 3).

Category III – High importance for conservation

The areas of the PQA occupying the ninth to eleventh positions in the priority ranking were classified as Highly Important for Conservation (Table 4). The Sub-Middle Araguaia River area occupies the ninth position of the PQA scores ranking, located on the state border of the states of Goiás, Tocantins and Mato Grosso, southwestern part of the state of Amazonas (Figure 2). The tenth position of the ranking belongs to Amazonas River Mouth in the northeast of the state of Pará. The eleventh position of the ranking is occupied by the Middle Mortes River, located east-centrally in the state of Mato Grosso (Figure 2).

The Araguaia River Sub-Middle Mouth showed declining population trends for *Podocnemis expansa*,

and intermediate relative importance for logistical and socioeconomic factors (Table 3). The Amazonas River Mouth area recorded declining trends for the three species analyzed, presenting the highest relative importance for ecological criteria and lowest importance for socioeconomic and logistical factors, respectively (Table 3). Whereas the Middle Mortes River recorded a stable population of *Podocnemis expansa* and consequent low relative importance for ecological criteria compared to logistical criteria (Table 3).

Category IV – Important for Conservation

The last four positions in the priority ranking were classified as Important for Conservation areas, with the following decreasing order of priority: Middle Guaporé River, Lower Branco River, Flechal River, Afuá River (Table 4). The Middle Guaporé River area is located in the State of Rondônia, while the Lower Branco River occupies the southern part of the State of Rorraima (Figure 2). The two least priority areas of the PQA, Flechal River, Afuá River, are located in the state of Amapá (Figure 2). The lower priority for these areas is justified by the stable populations of chelonians. Even with greater relative importance for logistical criteria, these are still lower than those found in other areas of the PQA.

Similarity relationship of PQA Priority Scores among breeding areas of Amazonian chelonians in PQA.

The similarities in the criteria' PQA Prioritization Scores grouped the analyzed areas into two large groups, divided into four smaller subgroups (Figure 3). The first large group indicates greater similarity among the seven most important areas for conservation of Amazonian chelonians, with emphasis on the subgroup formed by the areas Rebio Trombetas River, Middle Xingu River and Middle Araguaia River classified as Extremely Important for conservation (Figure 3). Still on the first large group, we identified a subgroup with more similar criteria that grouped the Upper Guaporé River, Middle Purus River, Middle Juruá River and Crixás-Açú River Mouth areas. The second large group indicates greater similarity of prioritization criteria among the eight areas of the PQA that are less important for conservation of Amazonian chelonians (Figure 3). This group is also divided into a larger sub-group (Sub-Middle Tapajós River, Sub-Middle Araguaia River, Amazonas River Mouth, Middle Mortes River, Middle Guaporé River and Lower Branco River) and another smaller one (Flechal River and Afuá River Mouth).

Similarity relationship of the PQA Priorization Scores among the priority criteria and their respective conservation actions

The similarity relations between the priority criteria present the synergistic characteristics in the definition of the most important areas of the PQA and allow integrated actions to be proposed to improve the efficiency and effectiveness of conservation efforts. In the end, five groups of well-defined criteria were recognized, with similarity capable of guiding the integration of the seven types of actions of the PQA among the areas analyzed (Figure 3).

The first two groups are formed by the criteria Female population and Managed species. Both criteria showed the greatest influence in the prioritization analysis of areas (Figure 3), due to the relevance of population trends and co-occurrence of species for allocation of conservation efforts. For these two groups, we suggest greater effort for in situ management actions, especially for those clusters of areas with greater importance for conservation. The third group is composed only by the criterion Nest transfer and beach elevation, which presents the lowest influence in the definition of priority among all criteria (Figure 3). Despite this low influence, the areas with the highest priority for this criterion need further strengthening of ex situ management actions.

The fourth group is formed by the criteria Management with Communities, Management by other institutions and Research in area. This group brings together important scores for prioritization of PQA areas, which influence the ranking and classification of breeding sites (Figure 3). The priority actions to improve the efficiency and effectiveness of chelonian conservation are associated with the strengthening of permanent environmental education, inter-institutional articulation and research activities in the region.

The fifth group is formed by the remaining logistical and socioeconomic criteria, which can be subdivided into two subgroups. The first sub-group presents a greater importance than the second, being composed of the criteria Breeding cost, Anthropic intervention, Income generation alternatives, and Area unconservation unit. The second subgroup is formed by the criteria Inspection, Average population density, Level of organization of communities, Shared management, and Tourism. Among the actions that influence the effectiveness of this group of criteria are *Ex Situ* management, Integrated surveillance, Sustainable technology management, Permanent environmental education, and Inter-institutional articulation.

Table 3. Summary of priority scores obtained in each area of Amazonian Chelonian Project (PQA) and the relative importance of each factor.

Prioritization criteria	Rebio Trombetas River (PA)	Middle Xingu River (PA)	Middle Araguaia River (GO)	Upper Guaporé River (RO)	Middle Purus River (AM)	Middle Juruá River (AM)	Crixás-Açu River Mouth (GO)	Sub-Middle Tapajós River (PA)	Sub-Middle Araguaia River (GO/ MT/ TO)	Amazonas River Mouth (AM)	Middle Mortes River (MT)	Middle Guaporé River (RO)	Lower Branco River (RR)	Flechal River (AP)	Afuá River Mouth(AP)
Female population	300	200	300	200	100	100	200	100	200	200	100	100	100	100	100
Managed species	100	100	60	60	100	100	30	100	30	100	30	60	30	30	30
Inspection	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Research in area	55	35	15	55	55	55	15	55	15	15	55	35	35	35	35
Management by other institutions	55	55	15	55	55	35	55	35	35	15	55	55	55	55	15
Shared management	10	7	3	7	7	7	7	7	3	3	7	7	7	7	7
Nests transfer and/or beach reinforcement	5	5	1	1	1	3	3	1	1	5	1	1	1	5	5
Breeding cost	50	150	100	150	150	150	100	150	100	50	150	150	150	50	50
Area in conservation unit	20	20	12	12	20	20	20	20	20	12	20	20	20	20	35
Anthropic intervention	35	12	35	20	12	12	20	20	35	35	12	20	20	12	12
Average population Density	15	10	10	10	10	10	10	15	5	15	5	10	10	5	10
level of organization of the communities	10	20	5	5	10	10	20	20	20	20	20	5	20	10	5
Income-generating alternative	20	5	5	5	20	10	10	5	10	10	5	5	5	5	5
Tourism	5	5	15	15	5	5	5	5	5	15	10	10	5	5	5
Community management	55	55	55	15	15	35	55	15	55	35	55	35	55	55	55
PQA Score	**755**	**699**	**651**	**630**	**580**	**572**	**570**	**568**	**554**	**550**	**545**	**533**	**533**	**414**	**389**
% Ecological	52.98	42.92	55.3	41.27	34.48	34.97	40.35	35.21	41.52	54.55	23.85	30.02	24.39	31.4	33.42
% Logistic	25.83	38.91	23.66	45.71	49.66	47.2	35.09	47.18	31.41	19.64	52.84	50.28	50.28	41.55	33.93
% Socioeconomic	21.19	18.17	21.04	13.02	15.86	17.83	24.56	17.61	27.08	25.82	23.3	19.7	25.33	27.05	32.65

Table 4. PQA Score, Ranking, Quantiles and Classification of Priority Areas of Amazonian Chelonian Project (PQA) according to their relevance for turtle conservation.

PQA Monitored Areas	PQA Score	Priority Ranking	Quantile	PQA Importance for Conservation
Rebio Trombetas River (PA)	755	1st		
Middle Xingu River (PA)	699	2nd	4th quartile	Extremely Important
Middle Araguaia River (GO)	651	3rd	(755 – 605)	for Conservation
Upper Guaporé River (RO)	630	4th		
Middle Purus River (AM)	580	5th		
Middle Juruá River (AM)	572	6th	3rd quartile	Very Highly Important
Crixás-Açu River Mouth (GO)	570	7th	(604 – 568)	for Conservation
Sub-middle Tapajós River (PA)	568	8th		
Sub-Middle Araguaia River (GO/MT/TO)	445	9th	2nd quartile	Highly Important
Amazonas River Mouth (AM)	550	10	(567 – 539)	for Conservation
Middle Mortes River (MT)	545	11th		
Middle Guaporé River (RO)	533	12th		
Lower Branco River (RR)	533	13th	1st quartile	Important for
Flechal River (AP)	414	14th	(538 – 389)	Conservation
Afuá River (AP)	389	15th		

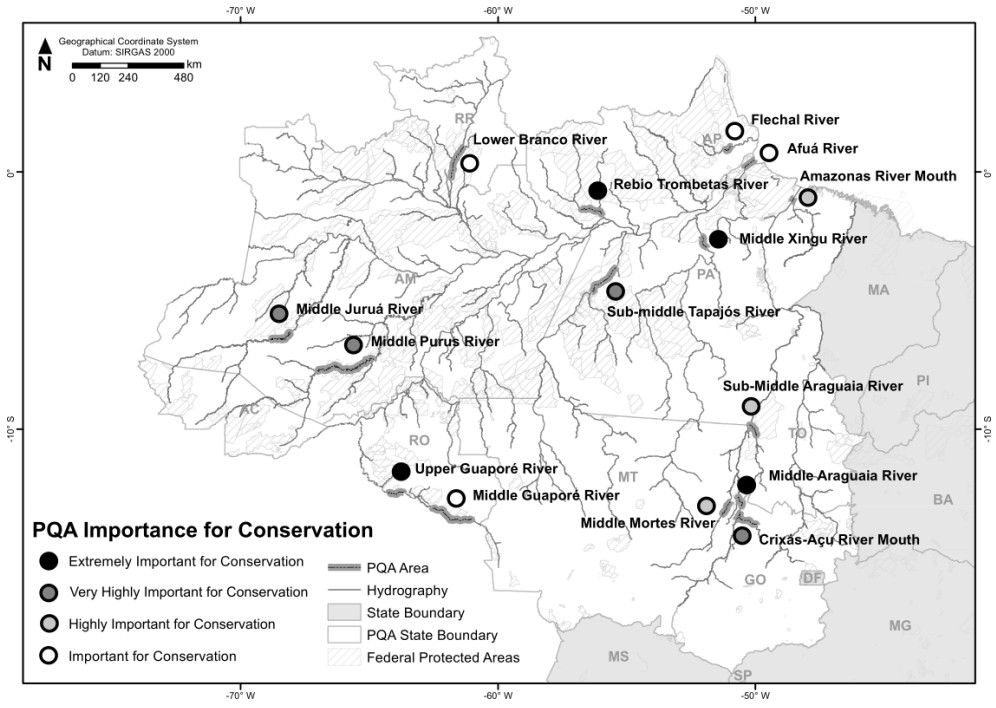

Figure 2. Map of PQA areas classified according to Importance for conservation.

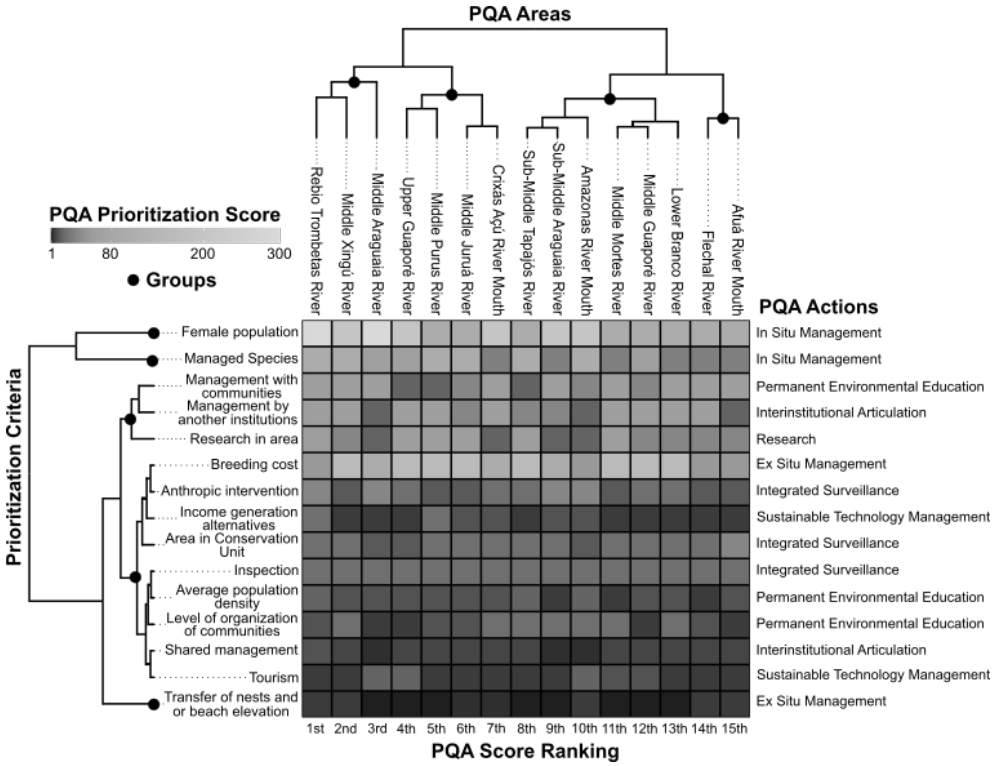

Figure 3. Heatmap of the relationship between and within the PQA prioritization criteria and areas, as per the PQA Score Ranking.

DISCUSSION

One of the biggest challenges in conservation biology is defining what is a priority and how to establish action plans and funding lines, in the face of growing threats to biodiversity and scarce human and financial resources to contain them (Sheil 2001; Wilson et al. 2009). Priority areas are important environmental management tools because they guide conservation efforts to regions of highest biodiversity value, both inside and outside protected areas (Williams et al. 2002; WWF 2015). The priority areas are recognized by the Convention on Biological Diversity (CBD) as tools to support decision making that enhance the persistence of biodiversity at regional and global levels (IUCN 2020). Furthermore, their application increases the efficiency in the allocation of actions and resources according to objective criteria of urgency and opportunity for programs that reduce the threat to biodiversity (Félix and Martins 1999; Sheil 2001).

The identification and implementation of priority areas for conservation have already been proposed with different methodologies and spread around the world (Wilson et al., 2009). The most frequently used criteria for determining priorities are geostatistical models, diversity metrics (richness, endemism, irreplaceability) and estimates of environmental pressures promoted by man (Ennen et al. 2020; Ennen et al. 2021; Fagundes et al. 2018; Mittermeier et al. 2015), according to the objective of the study and the urgency to contain the risk of extinction (IUCN 2020). Our results identified four categories of priorities, based on criteria (ecological, logistical, and socioeconomic) obtained from actual information from 15 breeding sites over 30 years of monitoring of the Amazon Chelonian Program (Souza 2005). For this reason, we argue that the PQA priority areas identified in this study better reflect the local and regional field conservation demands of the populations of the three cinegetic species, as they indicate urgencies and opportunities that are more faithful to reality than the priorities defined by metrics or models that estimate this information.

Overexploitation for human consumption is among the leading causes of species extinction threats (Bellard et al. 2022; Brook et al. 2008), and long-term conservation and management programs are critical for the recovery of populations of these impacted species (Garlic 1985; Forero-Medina et al. 2021; Norris et al. 2018). The PQA is a long-term environmental management tool that acts in the recovery and protection of Amazon chelonian populations (Lacava et al., 2020), especially *Podocnemis expansa*, *P. unifilis*, *P. sextuberculata*. However, PQA has a deficit of hu-

man and financial resources to develop the necessary management actions (Forero-Medina et al. 2021), as do almost all conservation initiatives around the world (Sheil 2001; Wilson et al. 2009). We conducted this prioritization to increase the effectiveness and efficiency of the PQA resources allocated to the conservation of the three chelonian species most threatened by overexploitation in the Amazon.

Several other initiatives to define priority areas for chelonian conservation have been proposed with distinct objectives, such as identifying diversity hotspots and assessing the effectiveness of protected areas (Buhlmann et al. 2009; Ennen et al. 2020; Ennen et al. 2021; Fagundes et al. 2018; Mittermeier et al. 2015). This large number of studies is justified because it is the most endangered vertebrate group in the world, with almost half of the turtle species described under some degree of threat in global assessment (Rhodin et al. 2018; Stanford et al. 2020). In general, these studies evaluated the most important river basins for conservation of global chelonian biodiversity and identified the great relevance of the Amazon basin for the group (Buhlmann et al., 2009; Ennen et al. 2020; Ennen et al. 2021). However, few of them have analysed the variation of importance within the Amazon basin and identified higher species richness concentrated in the central-northern part of the basin (Fagundes et al., 2018; Buhlmann et al., 2009). We defined four categories of conservation importance within the Amazon basin that did not corroborate this spatial pattern, with all categories of importance for PQA areas distributed both north and south of the basin (Figure 2). This is a reflection of the different prioritization criteria and methodologies that result in distinct prioritizations and objectives among the papers. We argue that to support the planning of the PQA, our prioritization is more appropriate, as its results are problem-oriented for the program.

In addition to the ranking and priority classification of the PQA areas, the similarity relations of the PQA Prioritization Scores among the areas provide a comparative picture of the weaknesses and strengths of the conservationist program developed in the different breeding sites of the Amazon chelonians. Thus, the most similar groups and subgroups of areas in the PQA indicate alternatives for integrated planning of management actions directed by common demands, adding strengths and reducing shared weaknesses (Figure 3). However, the similarities identified also did not present a clear spatial pattern among the areas, with no direct relationship with geographic distances, watershed boundaries or state borders (Figure 2). This allows us to infer that an integrated national chelonian conservation plan should be more effective and efficient in the application of financial and human resources than several isolated plans (state or regional), minimizing costs and maximizing the sharing of benefits of the program. The ecological, logistical and socioeconomic idiosyncrasies of each area (Figure 2, Table 3), which may suggest specific conservation efforts for the local reality (Lacava et al. 2020), must be taken into account.

Only defining priority areas is unable to increase biodiversity conservation, being necessary the proposition of assertive actions to maximize strengths and minimize local weaknesses (Wilson et al. 2009). During the development of the PQA, strategic actions were planned to be performed in all areas of the program (Lacava et al. 2020), and which relate to the priority criteria of this study (Table 1). However, limited resources do not allow their full realization in all areas of the PQA, resulting in lower effectiveness in species conservation (Cantarelli et al. 2014; Eisemberg et al. 2019; Forero-Medina et al. 2021). Our results can add greater value to the conservation program by suggesting combined strategies for the execution of synergistic actions, to add efforts and reduce environmental management costs, through the similarity relationships of the PQA Score among the prioritization criteria along the breeding sites, in which the similarities of the criteria indicate a more coordinated pattern of conservation demands. This association suggests how to unite the implementers of isolated conservation actions, to gain more effectiveness by acting together on groups of criteria with more similar patterns of variation (Table 1 and Figure 3).

In situ management actions are planned to improve the conditions of natural environments, favoring the recovery of the ecological balance of populations in the areas of the PQA (Lacava et al. 2020). These actions act directly on the reduction of population decline and management of the three species monitored in the field (Cantarelli et al. 2014), and can be developed to improve two priority criteria, especially, because they form two clusters little similar the other criteria and with higher PQA Score (Figure 3). This importance of ecological aspects has already been highlighted in other studies that pointed out the indispensable nature of in situ management efforts of Amazon chelonians overexploited by humans (Alho 1985; Schneider et al. 2011; Forero-Medina et al. 2021). This practice becomes even more relevant in the face of the vulnerability of potential for Amazonian chelonian reproductive sites and with only 43% of the spawning monitoring actions of the National Action Plan (PAN) for the Conservation of Amazonian Chelonians (Fagundes et al. 2021), a public policy complementary to the PQA (Lacava and Balestra 2019).

The activities of nest transfer and beach reinforcement formed an isolated group of *ex situ* management

activities with the lowest PQA score. This prioritization criterion showed low similarity with the other criteria analyzed, indicating a low logistical gain in performing this action in synergy with the other conservation actions along the areas of the PQA (Figure 3). This does not mean that there should not be standardization of protocols and systematization of information obtained in each evaluation area of PQA, it only shows that nest transfer is benefited with the increased coordination of the execution with other activities, even because the proper transfer of nests can be a practice associated to the survival of the offsprings and for population recovery of Amazon chelonians (Alho 1985; Páez et al. 2015).

Another potential gain in value for the Amazon chelonians program is the combination of planning research actions with environmental education activities and the strengthening of inter-institutional articulation (Table 1 and Figure 3), as these are actions indicated to improve criteria that formed the third group of highest similarity of PQA score among the areas (Research in area, Management with communities and Management by other institutions). These coordinated conservation efforts can expand the integration of data and information from different management and research institutions, strengthening scientific knowledge about the species and its application in environmental education. Research actions are considered of great importance to cover knowledge gaps about the species and their populations (Cantarelli et al. 2014; Eisemberg et al. 2019), with emphasis on the vulnerable regions of the lower Araguaia River and the Solimões, Madeira, and Tapajós Rivers (Fagundes et al. 2021). The integration of management with communities and other partner institutions is fundamental to overcome the logistical and economic lack of public power to strengthen the PQA (Cantarelli et al. 2014), but depends on greater awareness of chelonian conservation and its threats provided by environmental education of partners (Ataídes and Malvasio 2019; Norris et al. 2018; Schneider et al. 2011).

Finally, the other prioritization criteria present more similar patterns of variation among the areas, forming a group related to logistical and socioeconomic factors (Figure 3). This group suggests that the integrated planning of repressive actions of anthropic pressures on chelonian populations with enforcement mechanisms and inter-institutional articulation, and of preventive actions of environmental education, *ex situ* management and support for economic development alternatives and of local human communities (Table 1 and Figure 3). These actions seek sustainable solutions for the consumption of chelonians, considering their economic and cultural importance (Norris and Michalski 2013, Santos and Fiori 2020), establishing ways and limits for the exploitation of populations with punishments those who do not comply with permitted management standards (Pantoja-Lima et al. 2014; Pezzuti et al. 2018).

All areas of importance for chelonian conservation are present within or around some conservation unit, with the exception of Afuá River. This suggests that the monitored areas tend to be more protected than other priority areas identified by other studies (Fagundes et al. 2018). A large network of protected areas is fundamental for the maintenance of biodiversity, as it manages anthropic pressures on species (Bonn and Gaston 2005), especially for freshwater chelonians that have important populations outside the limits of protected areas (Fagundes et al. 2016).

The Amazon Turtle Programme has great value for conservation of over-exploited Amazon turtles and for sharing socioeconomic benefits to communities with low human development indices (Cantarelli et al. 2014; Eisemberg et al. 2019; Forero-Medina et al. 2021). Long-term monitoring data and wide geographic distribution are critical for the sustainable use of long-lived reptiles, such as chelonians, which tend to exhibit late sexual maturity, low fecundity and high juvenile mortality, requiring high adult survival for population stability (Schneider et al. 2011). In this sense, the PQA is an important public policy for sustainable development for the Amazon region, considering that chelonians have historical importance in the diet of the population (Schneider et al. 2011), which needs a greater contribution of human and financial resources to expand the management of chelonians (Eisemberg et al. 2019; Forero-Medina et al. 2021). Until this happens, our study has established priorities to support a more integrated allocation of these resources between the reproductive sites monitored and conservation actions, seeking to make the management more efficient and effective for the recovery of populations of Amazonian chelonians.

CONCLUSION

It is remarkable that Amazonian chelonians are a group of vertebrates whose ability to maintain their populations is seriously threatened. This research project has focused on actions in Brazil aimed at protecting and conserving freshwater chelonians (Amazonian species), especially three Amazonian species. The Amazonian Chelonian Project has shown some promise in terms of achieving its goals. However, important loopholes remain, such as the prioritization of sites for the protection and conservation of species.

Due to the enormous natural extension of the area of occurrence of our species of interest, it is necessary to promote scientific research aimed at producing knowledge on the distribution and use of nesting environments, among other ecological and socio-

environmental variables related to the species. The research should not be limited to places where the PQA operates, but should be extended to different initiatives in the various regions where other programs or similar actions operate.

In order to define priorities for these places, both current ideas and those cited in this study must be assessed, and more practical aspects of public policies targeting the conservation of these animals must be considered. To do so, they should indicate the most important locations for the implementation and improvement of conservation strategies for chelonian species in Amazonia throughout the geographic context in which they occur.

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DATA AVAILABILITY

The data used to support conclusions of this study are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

CONTRIBUTION STATEMENT

Conceived of the presented idea: RAMB, AM.
Carried out the experiment: FBG, RAMB, GBF.
Carried out the data analysis: FBG, RAMB, GBF.
Wrote the first draft of the manuscript: FBG.
Review and final writing of the manuscript: FBG, RAMB, GBF, MSS, AM.
Supervision: RAMB, MSS, AM.

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