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# Return on investment of the ecological infrastructure in a new forest frontier in Brazilian Amazonia

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A B S T R A C T

Protected areas anchor the ecological infrastructure that societies need for long-term prosperity and provide benefits to local, national, and global stakeholders. However, these areas continue to go unfunded. In this paper, we have provided the first estimate of the return on investment for nine large protected areas that compose the core of the ecological infrastructure of the State of Amapá, which is located in a new forest frontier in Brazilian Amazonia. These nine protected areas will require US \$147.2 million over five years in order to be established and then US \$32.7 million in annual recurrent costs. If implemented, these nine protected areas have the potential to contribute at least US \$362.4 million per year in benefits (timber, non-timber forest products, nature-based tourism, fisheries, and carbon) to the local economy. The return on investment (ROI) of these protected areas will be 1.6% during the first five years and 10% thereafter; however, ROI could reach 45.8% or more if option and non-use values are also included as benefits. Although the costs of establishing the protected area system in Amapá are higher (US \$3.2–3.5 $ha^{-1}$ $y^{-1}$) than the costs reported in other tropical forest regions (US \$0.2–0.4 $ha^{-1}$ $y^{-1}$), the investments required are within the reach of both state and national governments. Our study shows that if fully implemented, protected areas can become engines for socio-economic upliftment, making the conservation-centered development model a feasible option for most of the world's new forest frontiers.


## 1. Introduction

Infrastructure refers to the physical elements of interrelated systems that provide goods and services essential to enable, sustain, or enhance societal living conditions (Fulmer, 2009). There are two types of infrastructure: socio-economic and ecological. Socio-economic infrastructure is composed of the physical assets required by both social sectors (such as financial, educational, health, cultural, defense, and judicial) and economic sectors (such as energy, water and sewage, food and agriculture, transportation, and communications). Economic and social infrastructures are also known as “hard” or “soft” infrastructures, respectively. The ecological (or green or natural) infrastructure is an interconnected network of natural and semi-natural areas that is planned and managed for its natural resource values and for the associated benefits it confers to human populations (Benedict and McMahon, 2006). Both types of infrastructure are required for human development, but investments in ecological infrastructure are much smaller than investments in socio-economic infrastructure (Ruggeri, 2009).

Ecological infrastructure underpins human well-being by directly supplying ecosystem services that cannot be imported and by providing services that, through interaction with the socio-economic infrastructure, become valuable to humans (Collados and Duane, 1999; Costanza et al., 2014). To be effective, ecological infrastructures should: (a) be large and connected enough to protect all species existing in a territory, (b) provide all goods and services that people need, and (c) increase society's resilience against the negative impacts of global climate changes (Garda et al., 2010; Maes et al., 2015; Sussams et al., 2015). If societies want long-term prosperity, they must design and establish their ecological infrastructures, integrating them at several spatial scales (Yu, 2012).

The core of any ecological infrastructure is composed of protected areas, which are clearly defined geographical spaces that are recognized, dedicated, and managed through legal or other effective means to achieve the long-term conservation of nature with associated ecosystem services and cultural values (Dudley, 2008). Currently, the global ecological infrastructure is built around 155,584 terrestrial protected areas covering around 12.5% of the world's land surface as well as 7318 marine protected areas covering 3% of the world's marine ecosystems (Watson et al., 2014). Most of the existing protected areas have not been fully implemented because financial resources for building the core of a global ecological infrastructure have always been

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significantly smaller than what is needed (Jenkins and Joppa, 2009). Although the act of designating an area as protected by governments can halt ecosystem loss for some time, a protected area can only achieve the desired goals if it receives enough funds to be well-managed (Bruner et al., 2001).

In the last few years, there has been a trend in which key national governments have reduced their commitment to supporting protected areas (Watson et al., 2014). The lack of support by governments has traditionally been demonstrated by cuts in the operational budgets of the agencies responsible for protected area management. However, currently, governments are also reducing the strictness of the conservation status of protected areas, opening them to more intense human activities, reducing their sizes via boundary changes, and removing legal protection (Mascia et al., 2014; Bernard et al., 2014).

Watson et al. (2014) suggested that more studies documenting the return on investment (ROI) of protected areas for local societies could help to renew the interest of local and national governments in this particular component of the world's ecological infrastructure. Although the use of return on investment is not new in conservation (see review by Boyd et al., 2015), it has primarily been used to identify conservation gaps during systematic conservation planning or to guide future resource allocations across regions (Murdoch et al., 2007, 2010), rather than to provide evidence that existing protected areas are indeed good investments for local societies (Task Force on Economic Benefits of Protected Areas of the World Commission on Protected Areas (WCPA) of IUCN, in collaboration with the Economics Service Unit of IUCN, 1998).

In this paper, we present the return on investment of nine protected areas that compose the core of the ecological infrastructure of the State of Amapá, Brazilian Amazonia (hereafter referred to simply as "Amapá"). We calculate the costs of implementing these protected areas as well as some direct benefits they can generate for the local human population. We selected Amapá as a case study because it is a new forest frontier, i.e., it harbors large stocks of natural ecosystems, has low deforestation rates, and has low population density (Bryant et al., 1997; Becker, 2009). New forest frontiers are relevant because they cover around 5.8 million km$^2$ in South America, Africa, and Asia (Bryant et al., 1997) and are the places where conflicts regarding the fate of the world's largest stocks of pristine ecosystems will possibly emerge in the near future if sustainable land-use policies are not implemented at an appropriate pace.

## 2. Materials and methods

### 2.1. Study area

Amapá is located in northern Brazil and is bordered by French Guyana and Suriname (Fig. 1). Amapá has an area of 14,281,458 ha (Drummond et al., 2008) and a population of 669,526 (Instituto Brasileiro de Geografia e Estatística, 2014). Most of the population is urban, with 74.6% of the population living in the capital of Macapá and in Santana. Amapá's gross domestic product (GDP) for 2013 was US $5.5 billion, representing 0.2% of Brazil's GDP (Instituto Brasileiro de Geografia e Estatística, 2014). The state's public budget is around US $1.6 billion per year (Governo do Estado do Amapá, 2015); of this budget, around 68% comes from transferences from the federal government. Most of the economy is based on services and government spending, with a small portion coming from forestry, mining, hydroenergy and agriculture (Instituto Brasileiro de Geografia e Estatística, 2014).

Ninety-three percent of Amapá's territory is still covered by natural ecosystems. Dense upland forests of the Guiana Shield cover 75% of the territory (Instituto de Pesquisas Científicas e Tecnológicas do Estado do Amapá, 2008). Along the coast, Amapá harbors seasonally flooded grasslands (11%), upland savannas (7%), seasonally flooded forests (5%), and the Americas' most pristine mangroves (2%) (Instituto de Pesquisas Científicas e Tecnológicas do Estado do Amapá, 2008). Since 1995, the government of Amapá has implemented an ambitious socioeconomic development agenda based on the sustainable use of its natural resources (Drummond et al., 2008). As a result, Amapá is the most protected state in Brazil, with 73% of its area covered by protected areas or indigenous lands. Together, these two types of areas compose the Amapá Biodiversity Corridor, an initiative launched in September 2003 during the World Park Congress in Durban, South Africa. The Amapá Biodiversity Corridor aims to integrate the management of protected areas and indigenous lands by creating synergies between them, reducing management costs, and leveraging resources from multiple partners.

Nine large public protected areas anchor the Amapá Biodiversity Corridor (Fig. 1). The national government manages seven of them and the state government manages two (Table 1). Three protected areas are strict nature reserves (IUCN's Category I), two are national parks (Category II), and four are protected areas with sustainable use of natural resources (Category VI). Five protected areas were declared during the 80s and two during the 90s. The two largest protected areas, encompassing 42.4% of the state, were not declared until 2002 (Montanhas do Tumucumaque National Park) and 2006 (Amapá State Forest).

### 2.2. Protected area costs

We classified the protected area costs into two categories: establishment costs and recurrent management costs. Establishment costs are start-up investments and include: (a) physical infrastructure (e.g., trails, visitor centers, and offices), (b) equipment (e.g., cars, boats, and communication), and (c) planning and demarcation (e.g., management plans, land tenure surveys, and boundary demarcation). Recurrent management costs are annual and include: (a) staff salaries, (b) operational costs (e.g., fuel, electricity, services, and meetings), (c) maintenance of infrastructure and equipment, and (d) priority projects (e.g., research, tourism, and environmental education) as defined by the management plan.

To estimate the costs of protected areas, four pieces of information are required: (a) an assessment of the current state of implementation of each protected area; (b) an estimate of the number of staff required for each protected area; (c) a list of minimum infrastructure and services required for each protected area; and (d) a table with standard reference costs for products and services that are required to implement the protected areas.

To assess the current state of implementation of each protected area, we interviewed the areas' managers. We used an open-ended questionnaire. We asked questions about: the number of staff, available assets, current expenses, existing funds and revenues, past and existing investments, status of the management plan and boundary demarcation, existence and status of essential infrastructure (such as visitor centers, management and surveillance offices, existence and extension of trails, and research laboratories), major needs, and potential number of visitors.

We used 1:3333 ha as the minimum acceptable density of field staff. We selected this value because it was the median density of guards in the 15 most effective parks studied by Bruner et al. (2001). Protected areas also need management staff to provide technical and administrative support for the field staff and to manage relationships with external stakeholders. To calculate the number of management staff required by each protected area, we used the following assumptions: (a) if the protected area requires 70 or less field staff, then it would require seven management staff; (b) if the protected area requires 70 or more field staff, then the required management staff should be 10% of this number.

The amount of equipment and number of offices were estimated based on the staff numbers required for each protected area. Other infrastructure needs (e.g., trails and visitor centers), planning and demarcation costs (management plan and boundary demarcation),


**Fig. 1.** Nine Protected Areas that compose the core of the ecological infrastructure of the State of Amapá: (1) Lago Piratuba Biological Reserve; (2) Maracá-Jipioca Ecological Station; (3) Jari Ecological Station; (4) Cabo Orange National Park; (5) Montanhas do Tumucumaque National Park; (6) Amapá National Forest; (7) Rio Cajari Extractive Reserve; (8) Rio Iratapuru Sustainable Development Reserve; and (9) Amapá State Forest.

and recurrent costs (priority management programs) were estimated based on data in the approved management plans or through consultation with the protected area manager.

We conducted market price research in Macapá, the capital of Amapá, to organize a reference table with the products and services that are needed for the implementation of the protected areas. In a few cases, we also used reference values previously collected by the Brazilian Fund for Biodiversity (FUNBIO) and the Brazilian Ministry of the Environment (Ministério do Meio Ambiente, 2007). All reference costs were gathered in a single spreadsheet and evaluated together with the protected area managers during a two-day workshop held from 27 to 28 October, 2011 in Macapá. We updated the cost reference values from 2011 to 2014 by incorporating the national official inflation rate (General IPCA) calculated by the Brazilian Institute of Geography and Statistics (IBGE).

We used the IMC tool (Minimum Investments for Conservation) to integrate all information and generate both establishment and recurrent costs for each protected area. The IMC is a modified version of the cost approximation module of Micosys (see Vreugdenhil et al., 2003 for a detailed description of the cost factors and their associated assumptions), adapted to Microsoft Excel®. The IMC is the tool used by the Brazilian Government to calculate protected areas costs

**Table 1**
Basic information on the nine public protected areas that compose the core of the ecological infrastructure in the State of Amapá, Brazil.

| Protected areas | IUCN category | Size (ha) | Designation year | Governance type |
|---|---|---|---|---|
| Lago Piratuba Biological Reserve | Ia | 357,000 | 1980 | National |
| Maracá-Jipioca Ecological Station | Ia | 72,000 | 1981 | National |
| Jari Ecological Station | Ia | 227,126 | 1982 | National |
| Cabo Orange National Park | II | 619,000 | 1980 | National |
| Montanhas do Tumucumaque National Park | II | 3,867,000 | 2002 | National |
| Amapá National Forest | VI | 412,000 | 1989 | National |
| Rio Cajari Extractive Reserve | VI | 501,771 | 1990 | National |
| Rio Iratapuru Sustainable Development Reserve | VI | 806,184 | 1997 | Sub-national |
| Amapá State Forest | VI | 2,320,304 | 2006 | Sub-national |

(Ministério do Meio Ambiente, 2007). All costs were calculated in Brazilian reais (R$) and converted to American dollars (US$) by using an exchange rate of R$ 3.74: US $1 for the purpose of comparison with other studies.

We divided the implementation of a protected area into two phases: establishment and post-establishment. If all resources are made available, the establishment phase of a protected area in Brazil usually lasts five years (Muanis et al., 2009). Therefore, to calculate the amount of resources required to establish each protected area, we divided the total cost of establishment by five years. Because establishment costs do not cover staff and other maintenance expenses, a protected area manager would usually also need some portion of the estimated recurrent costs during the establishment phase. We assumed that a protected area would need 10% of the total recurrent cost in the first year, 25% in the second, 50% in the third, 75% in the fourth, and 100% from the fifth onward.

### 2.3. Monetary benefits of protected areas

We used the total economic value (TEV) framework to calculate the benefits generated by the nine protected areas (Task Force on Economic Benefits of Protected Areas of the World Commission on Protected Areas (WCPA) of IUCN, in collaboration with the Economics Service Unit of IUCN, 1998). The TEV framework presents categories of ecosystem benefits and measures these benefits in monetary terms. Ecosystem services may either provide direct use, indirect use, option use, or non-use. Direct use values are derived from the direct extraction of resources (e.g., timber, fisheries) or the direct interaction with the ecosystem (e.g., tourism). Indirect use values are derived from regulating services that support the economic activity (Seroa da Motta, 2002). Option values relate to potential future use of the ecosystem, while non-use values are associated with the conservation of the ecosystem for its own sake (Mayer and Job, 2014). We estimated values for four direct benefits (timber, non-timber forest products, fisheries, and nature-based tourism) and one indirect benefit (carbon).

The harvesting of timber is only legal in two protected areas: Amapá National Forest and Amapá State Forest. These two protected areas have had their management plans completed and approved by government authorities (Instituto Chico Mendes de Conservação da Biodiversidade, 2014; Instituto Estadual de Florestas do Amapá, 2014). The management plans define the size and location of the so-called forest management zones, which are the only areas where sustainable logging is allowed. Within the forest management zones, around 20% of the forests should be allocated to the protection of rivers and slopes and therefore cannot be logged. Forest management areas are not logged en masse, but rather will be harvested over 30 years to allow for forest regeneration (Instituto Estadual de Florestas do Amapá, 2014). Consequently, to calculate the area that can be harvested annually, we must divide 80% of the forest management zone by 30. Bandeira et al. (2012) estimated that upland forests in northern Brazil might produce 20 $m^3$ $y^{-1}$ of roundwood on average. Thus, to calculate the potential annual roundwood production of each one of the protected areas, we multiplied the area to be harvested annually by 20 $m^3$. According to Brazilian legislation, all roundwood harvested in protected areas should be processed in adjacent cities. The average processing yield is 41.5% (Bandeira et al., 2012). Thus, to calculate the potential revenues generated by selective commercial logging, we multiplied the processed yield by US $293.6, which is the average price per cubic meter of processed timber in northern Brazil (Pereira et al., 2010).

Non-timber forest products are any biological resources aside from the timber harvested from woodlands. Non-timber forest products play an important role in the rural economy, insuring and enhancing the quality of life for forest users (Sills et al., 2011). Some products are primarily consumed locally, while some find national and global markets. In general, non-timber forest products are primarily traded in the informal market, so their real impact on local economies is not easily assessed. Carvalho (2010) estimated that non-timber forest products contributed R$ 240 million to Amapá's economy in 2009. This value is equal to US $137.9 million, according to the US Treasury's exchange rate on 31 December, 2009 (US $1 = R$ 1.74). We divided this value by 11,394,675 ha, which is the area of Amapá covered by forests (Instituto Estadual de Pesquisas Científicas e Tecnológicas do Estado do Amapá, 2008). Thus, we estimated that each hectare of forest in Amapá has the potential to generate at least US $12.1 $ha^{-1}$ $y^{-1}$ in non-timber forest products. To estimate the potential economic value of the non-timber forest products for those protected areas where the extraction of non-timber forest products is allowed, we multiplied their areas by US $12.1 $ha^{-1}$ $y^{-1}$.

It has been demonstrated that nature-based tourism in protected areas provides a concrete economic benefit to local economies (Hunt et al., 2015). We estimated that protected areas in Amapá, where nature-based tourism is allowed, could receive at least 500 visitors a year if they had infrastructure. By collecting data from protected area managers and tourism agencies in Macapá, we estimated that each potential visitor would spend, on average, US $200 per day on transport, food, and lodging. Because most protected areas are located at least 3 to 4 h from Macapá (by car, boat, or both), we assumed that each visitor would stay in a protected area for at least three days.

Three restricted use protected areas in Amapá (Cabo Orange National Park, Maracá-Jipioca Ecological Station, and Lago Piratuba Biological Reserve) maintain some of the most pristine mangroves in the Americas and are home to lakes and coastal wetlands (Drummond et al., 2008). They also provide a wealth of fishery resources (Silva and Dias, 2010; Silva et al., 2012). There is evidence that restricting fisheries within protected areas increases the abundance, body size, biomass, and reproductive output of exploited species, which benefits adjacent fisheries (Roberts et al., 2001). Fishermen from municipalities (Oiapoque, Calçoene, Tartarugalzinho, Cutias, and Amapá) organize their activities around these three protected areas and receive benefits directly from them. Recent studies indicate that fishermen in Amapá can earn around R$ 1576 a month during seven months of the year when they can catch all species and R$ 788 a month in government subsides when catching species of high value is not allowed (Oliveira and Ribeiro-Neto, 2013). Therefore, a fishermen can earn around R$ 14,972 a year or US $4,003. To estimate the total monetary value provided by the fisheries around the three protected areas, we multiplied US $4,003 by the number of fishermen officially registered in each one of the four municipalities, based on the work by Oliveira and Ribeiro-Neto (2013).

Brazilian Amazonia has the largest carbon stock in tropical vegetation (Fearnside, 2012). Therefore, protecting tropical forests contributes to reducing carbon emission, thereby mitigating the negative effects of climate change. Establishing protected areas is recognized as one of the most effective ways to prevent deforestation (Bruner et al., 2001, Soares-Filho et al., 2010). As a consequence, Brazilian Amazonia can generate tradable carbon credits by comparing the carbon stocks that they help to maintain with a hypothetical baseline based on the projection of deforestation and greenhouse-gas emissions under a scenario in which protected areas have not been declared and established. To calculate the carbon stock that is available for avoided deforestation projects, we calculated how much forest would be lost within protected areas in Amapá by 2050 under the "governance" scenario proposed by Soares-Filho et al. (2006). We selected the "governance" scenario because it is the most conservative one. This scenario assumes that Brazilian legislation will be implemented across the region according to the refinement and multiplication of best practices in forest governance (Soares-Filho et al., 2006). We also limited our analysis to the two protected areas that are managed by the Government of Amapá (Amapá State Forest and Rio Iratapuru Sustainable Development Reserve) because subnational governments in Brazil are more amenable to Reducing Emissions from Deforestation and Forest Degradation (REDD) projects than the national government is. We used the software ArcGIS to overlap the maps produced by Soares-Filho et al. (2006) with a map of the two protected areas and then calculated the extent of the predicted deforestation. In order to calculate the carbon stocks that will be lost by 2050, we multiplied the area of the predicted deforestation by 164.0 tC, which is the average estimate of carbon stock (above and below ground) contained in one ha of Amazonian forest (Nogueira et al., 2015). We multiplied the total carbon stock by US $4.2, which was the average market price for voluntary REDD projects in 2014 (Peters-Stanley and Gonzalez, 2014), to generate the total economic value of this benefit. Finally, we divided the total value of the carbon by 35 years to have a crude estimate of the potential annual revenues generated by each protected area.

### 2.4. Return on investment

We calculated the return on investment (ROI) of the entire group of protected areas by using the standard formula: ROI = [(benefits − costs) / (costs)] ∗ 100. We calculated the ROI for establishment and post-establishment phases.

## 3. Results

### 3.1. Costs of protected areas

A total of US $62.0 million over five years is required to establish the nine protected areas (Fig. 2). Most of the establishment costs will go to building infrastructure (US $36.7 million), followed by equipment acquisition (US $18.4 million), and planning and demarcation (US $6.9 million).

The nine protected areas in Amapá require 3051 staff members (Table 2). There is a large gap between existing and required staff numbers. Field staff should grow from 65 to 2769, while management staff should grow from 39 to 282 (Table 2). The projected annual recurrent cost for the nine public protected areas of Amapá is US $32.7 million (Fig. 3). Most of the annual expenses are for staff salaries (US $16.8 million), followed by operations (US $7.9 million), maintenance (US $4.6 million), and priority management projects (US $3.3 million). Annual costs per hectare range from US $3.1 to $10.0 and are inversely correlated with the size of the protected area (Spearman Rank Correlation, $rs = -0.99$, $n = 9$, $p < 0.0001$).

The total investment (establishment + recurrent costs) required during the first five years is US $147.3 million, with annual investments during this period ranging from US $15.7 million in the first year to US $45.2 million in the fifth year (Fig. 4). After the fifth year, protected areas will need US $32.7 million per year for recurrent costs.

### 3.2. Benefits of protected areas

Selective logging can generate US $268 million a year for Amapá's economy if both state and national forests are fully implemented (Table 3). The management plan of the Amapá State Forest selected 1,444,624 ha for sustainable logging (Instituto Estadual de Florestas-Amapá, 2014). Removing 20% of this area for protection of rivers and slopes means that 1,155,699 ha are available for logging. By dividing this area by 30 years, (the time required for forest regeneration after logging), the annual area to be harvested is 38,523 ha. This area can produce, on average, 770,851 $m^3$ of roundwood per year. If this roundwood is processed, we can expect an outcome of 319,903 $m^3$ of processed wood per year. This production can generate US $225.8 million a year. The management plan of the Amapá National Forest set aside 268,549 ha for sustainable logging (Instituto Chico Mendes de Conservação da Biodiversidade, 2014). Removing 20% of this area, we are left with 214,839 ha. By using cycles of 30 years, the annual area to be harvested is 7161 ha. This area can produce, on average, 143,942 $m^3$ of roundwood. If this roundwood is processed, we can expect 59,736 $m^3$ of processed wood, which can be sold for US $42.2 million.

Four protected areas allow the harvesting of non-timber forest product (Amapá National Forest, Rio Cajari Extractive Reserve, Rio Iratapuru Sustainable Development Reserve, and Amapá State Forest).

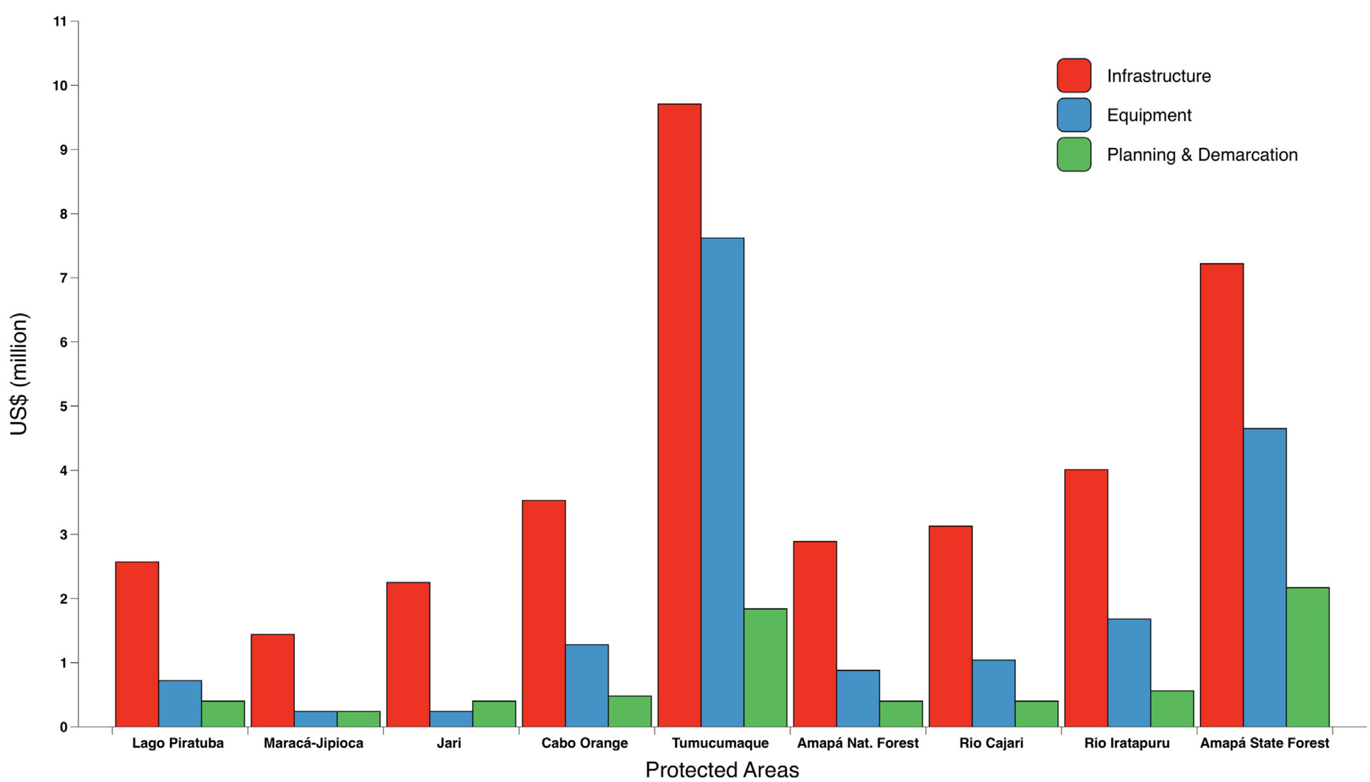


**Fig. 2.** Establishment costs (in million US$) for nine public protected areas that compose the core of the ecological infrastructure in the State of Amapá, Brazil.

**Table 2**
Current and required staff number for nine public protected areas that compose the core of the ecological infrastructure in the State of Amapá, Brazil.

| Protected areas | Current field staff | Required field staff | Current management staff | Required management staff |
|---|---|---|---|---|
| Lago Piratuba Biological Reserve | 11 | 107 | 4 | 11 |
| Maracá-Jipioca Ecological Station | 0 | 22 | 11 | 7 |
| Jari Ecological Station | 19 | 68 | 2 | 7 |
| Cabo Orange National Park | 15 | 186 | 3 | 19 |
| Montanhas do Tumucumaque National Park | 9 | 1160 | 3 | 116 |
| Amapá National Forest | 5 | 124 | 6 | 12 |
| Rio Cajari Extractive Reserve | 5 | 150 | 5 | 15 |
| Rio Iratapuru Sustainable Development Reserve | 1 | 242 | 2 | 24 |
| Amapá State Forest | 0 | 710 | 3 | 71 |
| Total | 65 | 2769 | 39 | 282 |

If we multiply the size of these protected areas by US $12.1 we can expect annual revenues of at least US $48.8 million (Table 3).

Nature-based tourism is allowed in six protected areas. National Parks (Cabo Orange and Montanhas do Tumucumaque) offer mostly environmental attractions, while the other four protected areas (Amapá National Forest, Rio Cajari Extractive Reserve, Rio Iratapuru Sustainable Development Reserve, and Amapá State Forest) offer both cultural and environmental attractions because traditional populations live within them. By assuming that each protected area would receive 500 visitors a year, these six protected areas could generate at least US $1.8 million a year in direct benefits if their tourism programs are fully implemented (Table 3).

There are at least 5474 registered fishermen who benefit from the fish stocks associated with the three protected areas along the coast of Amapá (Oliveira and Ribeiro-Neto, 2013). If each one of these fishermen generates an average of US $4,003 per year, then these three protected areas are providing at least US $21.9 million per year in direct benefits to the local economy (Table 3).

Deforestation prevention projects in the Amapá State Forest and Rio Iratapuru Sustainable Development Reserve could generate at least US $16.5 million per year in carbon credits for Amapá's economy, if these projects are developed and buyers decide to invest in them (Table 3). The Amapá State Forest is predicted to lose 843,049 ha of forest until 2050 under the governance scenario proposed by Soares-Filho et al. (2006). This area has an equivalent of 138,260,036 t of carbon. Assuming a price of US $4.2 per ton and assuming annual payments over 35 years, this protected area could generate US $16.5 million a year. The Sustainable Development Reserve Rio Iratapuru is predicted to lose 2371 ha of forest until 2050. This area has 388,844 t of carbon. By using the same assumptions as those used for the Amapá State Forest, Rio Iratapuru could generate US $46,661 per year in carbon credits (Table 3).

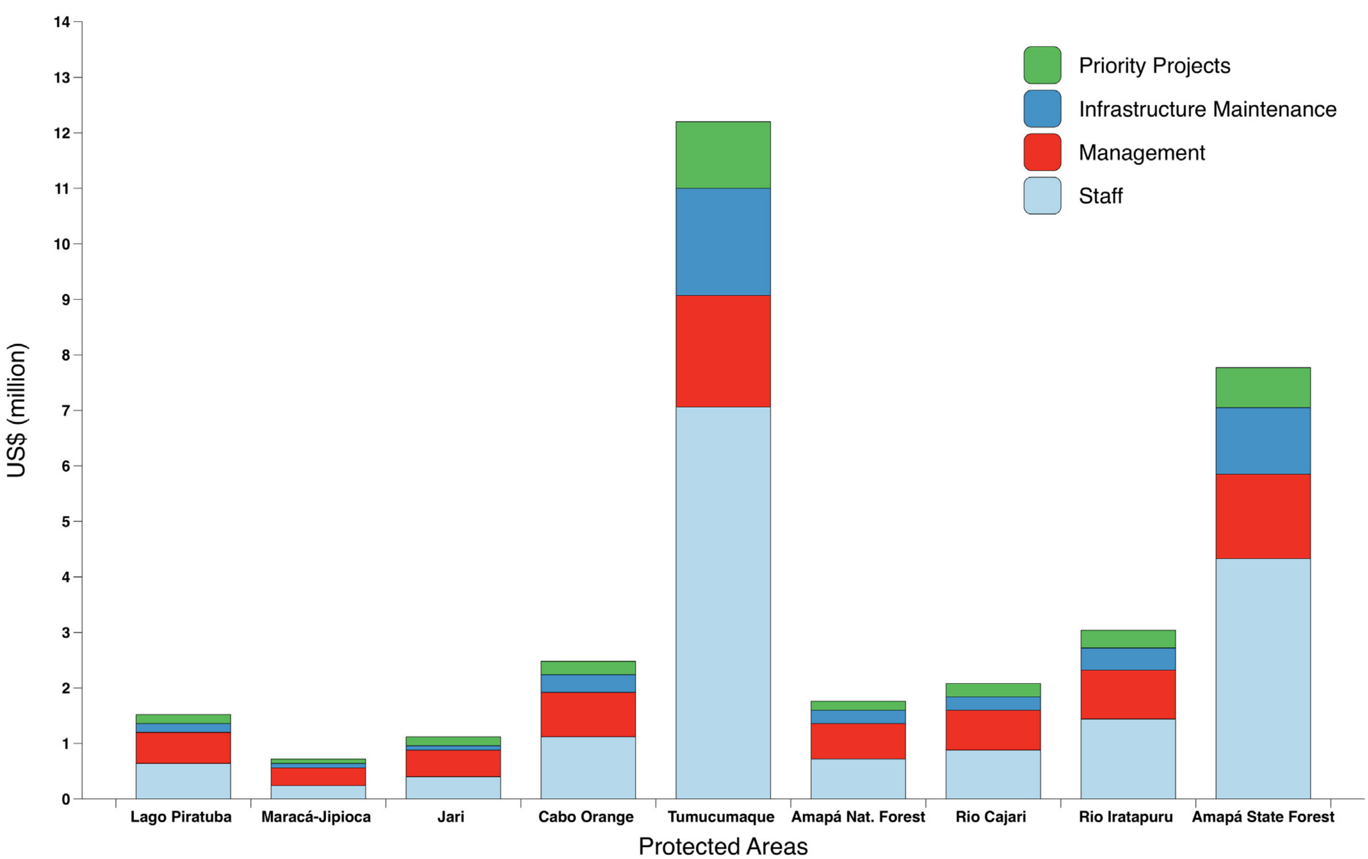


**Fig. 3.** Annual recurrent costs for nine public protected areas that compose the core of the ecological infrastructure in the State of Amapá, Brazil.

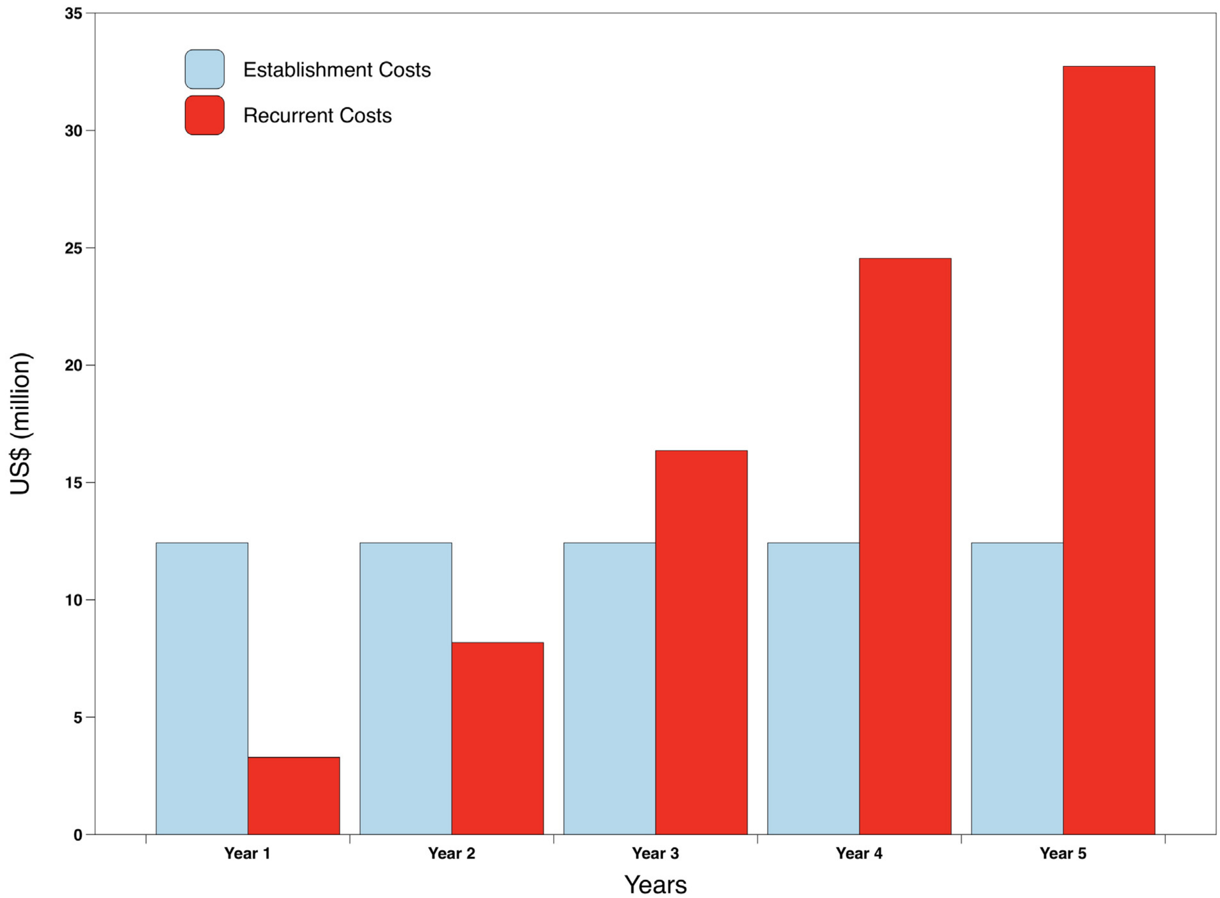


**Fig. 4.** Investment flow over the first five years (in million US$) estimated to cover establishment and recurrent costs of the nine public protected areas that compose the core of the ecological infrastructure in the State of Amapá, Brazil.

The nine protected areas have the potential to generate US $362.4 million per year in direct benefits to Amapá's economy. However, three benefits (selective logging, nature-based tourism, and carbon projects) would require plans and infrastructure in order to be fully realized. If we remove the values of these three benefits during the establishment phase, then the protected areas will generate US $76.1 million of direct benefits per year or US $380.5 million over five years.

### *3.3. Return on investment*

The establishment and recurrent costs of the nine protected areas are estimated at US $147.3 million initially and US $32.7 million per year in the years that follow. The benefits are estimated to be US $380.5 million during the establishment phase and US $362.4 million per year in the years that follow. The return on investment (ROI) for the nine protected areas during the establishment phase is 1.6% and will increase to 10% thereafter.

## 4. Discussion

We estimated that the costs for establishing the infrastructure needed to maintain 9.2 million ha is US $147.3 million over five years, followed by annual recurrent costs of US $32.7 million. This is equivalent to US $3.2 $h^{-1}$ $y^{-1}$ during the establishment phase and US $3.5 $h^{-1}$ $y^{-1}$ thereafter. Costs associated with staff salaries are the largest (51.5%) in the post-establishment phase. Currently, by combining field and

**Table 3**
Potential direct benefit (monetary values in million US$) generated by nine public protected areas that compose the core of the ecological infrastructure in the State of Amapá, Brazil.

| Protected areas | Selective logging | Non-timber forest products | Fisheries[a] | Nature-based tourism | Carbon |
|---|---|---|---|---|---|
| Lago Piratuba Biological Reserve | | | * | | |
| Maracá-Jipioca Ecological Station | | | * | | |
| Jari Ecological Station | | | | | |
| Cabo Orange National Park Cabo Orange | | | * | 0.3 | |
| Montanhas do Tumucumaque National Park | | | | 0.3 | |
| Amapá National Forest | 42.2 | 4.9 | | 0.3 | |
| Rio Cajari Extractive Reserve | | 6.0 | | 0.3 | 0.04 |
| Rio Iratapuru Sustainable Development Reserve | | 9.7 | | 0.3 | |
| Amapá State Forest | 225.8 | 28.0 | | 0.3 | 16.5 |
| System-wide | | | 27.3 | | |
| Total | 268.0 | 48.8 | 27.3 | 1.8 | 16.5 |

[a] Three coastal protected areas (indicated by *) harbor coastal wetlands, lakes and mangroves that support 5474 fishermen.

management staff, the nine protected areas in Amapá have a staff density of 1:88,292 ha. This number is well below the national average of 1:18,600 ha (Medeiros et al., 2011). If we consider only the field staff, the density is 1:141,267, which is also well below the global threshold of 1:3333 ha (found by Bruner et al. (2001) to be a good predictor of protected area effectiveness). Insufficient number of staff has always been a problem across protected area systems around the world (Balmford and Whitten, 2003), but it has increased in Brazil during the last few decades. The main reason is that even though Brazil was responsible for 74% of the new terrestrial protected areas created worldwide from 2003 to 2008 (Jenkins and Joppa, 2009), the number of employees hired by protected area agencies has not increased in proportion to the size of the areas (Medeiros et al., 2011).

Our estimates for establishment and recurrent costs for the nine protected areas in Amapá are around 7–17 times higher than some estimates for other forest regions in the world. This is surprising, since protected areas in Amapá do not require investments in land purchase (most of the state is composed of public lands) (Jorge, 2003). Blom (2004) calculated that a protected area network of 211 million ha in the Niger Delta-Congo Basin Forest Region would cost US $0.47 ha$^{-1}$ y$^{-1}$ over ten years to become established and then US $0.41 ha$^{-1}$ y$^{-1}$ in recurring costs. Balmford and Whitten (2003) suggested that recurrent costs for protected areas in wilderness regions of the world, such as Amazonia, would typically lie around 0.2 ha$^{-1}$ y$^{-1}$. Because estimates of conservation costs are context-dependent (Bruner et al., 2004; Green et al., 2012), their reliability increases as socio-economic conditions within and around the protected areas are considered. Although regional and global studies are important to justify the inclusion of costs in the design process of protected area systems, their use in guiding conservation investments and strategies at finer spatial scales should be considered carefully (Armsworth, 2014). We predicted that when more studies on actual conservation costs at subnational levels become available for tropical regions, the actual investments required to consolidate efficient protected areas are going to be several times higher than what has been predicted by existing global analyses.

We estimated that the nine protected areas could generate at least US $349.6 million a year in benefits to Amapá's economy if they are fully implemented. As with any economic valuation exercise for ecosystem services, the level of confidence varies from service to service and depends on the quality of the available information (Costanza et al., 2014). We based our estimates for timber and nature-based tourism on the management plans of the protected areas; therefore, they are reliable. In contrast, the estimates for non-timber forest products and fisheries underestimated the actual values. For non-timber forest products, we calculate the potential of protected areas by using US $12.1 ha$^{-1}$ y$^{-1}$; however, recent studies in Amazonia have shown higher values ranging from US $18 to $35 ha$^{-1}$ y$^{-1}$ (Shone and Caviglia-Harris, 2006). Our estimates for fisheries considered only the average income earned by fishermen registered in the four municipalities adjacent to the coastal protected areas. We are aware that the value could be higher if we had information on income earned by unregistered fishermen, fishermen registered in other municipalities but operating around the three protected areas, and the commercial fleets from other Brazilian states or other countries that catch large stocks of fish along the coast of Amapá (Isaac et al., 1998). Regarding our carbon estimates, it is possible that by using a regional model, we overestimated the potential deforestation and, consequently, the amount of carbon stocks that qualify for REDD projects (Yanai et al., 2012). Despite these caveats and limitations, we are confident that our estimates represent at least the minimum value of the contributions the nine protected areas will make to Amapá's economy.

The return on investment of the protected areas in Amapá is 1.6% during the establishment phase and 10% thereafter. These numbers are modest and may be higher if option and non-use benefits are taken into account. Seroa da Motta (2002) suggested that Amazonian forests have at least US $21 ha$^{-1}$ y$^{-1}$ in option value and US $108 ha$^{-1}$ y$^{-1}$ in non-use value. If we use these values, the nine protected areas of Amapá could be worth at least US $193 million per year in option value and US $991.7 million per year in non-use value. If we add these values to the US $349.6 million per year generated after the establishment phase, the nine protected areas in Amapá are worth US $1.5 billion per year in ecosystem services, generating an ROI of 46%. Furthermore, if, instead of using our calculations, we use the updated total ecosystem service value of one hectare of tropical forest (US $5382 ha$^{-1}$ y$^{-1}$) proposed by Costanza et al. (2014), the ecosystem services provided by the network composed of the nine protected areas in Amapá are worth a little over US $5.3 billion per year with an ROI of 162%. In summary, ROI is relatively low (1.6% to 10%) if only a few of the direct and indirect benefits to local economies are taken into account, but very high (ranging from 46 to 162%) if option and non-use values are also included in the benefit calculations.

Although the investments required to fully implement the nine protected areas are higher than what is expected from global and regional models, they are within the reach of both state and national governments. Seven of the nine protected areas in Amapá are managed by the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBIO), the national agency for protected areas. Altogether, these seven areas represent 8% of the protected area system managed by the national government. ICMBIO's annual budget was US $242 million in 2014. If ICMBIO invests 8% of its current budget in Amapá every year over the next five years, then US $97 million would become available for the establishment of the protected areas. The remaining US $51.3 million should come from the public budget of the Amapá. In 2014, Amapá's budget was US $1.5 billion (Governo do Estado do Amapá, 2015). Most of this budget (68.1%) comes from transferences from the national government that are usually restricted and can only be used for education and health services. The budget is complemented by what Amapá collects from state taxes, which totaled US $361.8 million. Of this amount, US $65.6 million was transferred to the governments of the municipalities, leaving the state with US $296.2 million in flexible resources for investments (Governo do Estado do Amapá, 2015). Assuming that Amapá's flexible funds are stable, then the government need to invest around 3.5% of its total net tax revenues generated over five years to get its protected area system fully established. Annual recurrent costs can be covered by a combination of restrict funds provided by both federal and state governments plus flexible funds generated by the sustainable use of protected areas. In general, the ROI generated by the protected areas in Amapá are large enough to justify the investments from national and state governments in their establishment and maintenance.

Until now, Amapá has been able to avoid a large decline in forest cover, the land-use trend usually observed in forest regions undergoing fast economic development (Mather, 1992; Rudel et al., 2005). This is a result of the work of a new generation of local political leaders in the last few decades who were able to mobilize support towards a conservation-centered development model (Garda et al., 2010). By putting 73% of the Amapá's territory under different types of protected areas and indigenous lands as a preventive measure, both national and the state governments created the right conditions for (a) halting future deforestation and land grabbing, (b) ensuring land use rights for traditional and indigenous populations, and (c) regulating extractive industries such as timber by driving them to adopt strict environmental regulations. Unfortunately, these gains have not been translated in enough resources to implement all protected areas in this state at the speed required. The usual explanation is that governments lack flexible funds to strategic investments. However, we demonstrated that the establishment and recurrent costs of the protected areas are relatively modest and are within the reach of the current national and state public budgets. Also, we demonstrated that protected areas can produce substantial economic benefits for the local economy if fully implemented. Because conservation is a historical and political process (Gorenflo and Brandon, 2006), the long-term sustainability of conservation activities in Amapá and other new forest frontiers will also require a substantial increase in living standards, mostly for the poorest sectors of the local populations. If the direct connection between conservation and human development is demonstrated, then a virtuous cycle is established, because greater living standards and education levels will also increase political activism about environmental issues (White and Hunter, 2009). Our study shows that if fully implemented, protected areas can become engines for socio-economic upliftment, making the conservation-centered development model a feasible option for most of the world's new forest frontiers.

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