Opportunities for conservation and livelihoods in Amazonian extractive reserves

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Contents

Abstract

Innovative management strategies are required to ensure the persistence of biodiversity and environmental services in intact tropical forest regions whilst developing the livelihoods of forest dwellers, particularly in light of increasing forest degradation and deforestation threats. Commercial extraction of non-timber forest products and payments for environmental services programmes aim to achieve these dual goals, often within extractive reserves, which provide the administrative and land-tenure framework for programme implementation. This thesis aimed to assess the potential of these two mechanisms to maintain forest integrity whilst contributing to rural economies, using a combination of ecological and social research methods – including line-transect censuses, an experimental harvest, weekly household surveys, GIS mapping, and community interviews. Substantial variation was observed in the livelihood strategies of traditional communities along the Juruá River of western Brazilian Amazonia. Agriculture, forest extractivism, and fishing were important to all households for subsistence, but there was significant variation in household engagement with income-generating activities. Much of this variation was attributed to local accessibility to permanently-unflooded land suitable for perennial agriculture. Heterogeneity was also observed in the spatial distribution, size structure, and harvest yields of trees in the genus *Copaifera*, which are valued for their medicinal oleoresin. Variation between species and forest types affected accessibility of this resource, determining the potential for commercial harvesting. Results also demonstrated that programmes that aim to protect environmental services by financially compensating rural people to avoid undesirable land-use practices may benefit from careful programme design in relation to participants' opportunity costs. Undifferentiated payments made by the *Bolsa Floresta* programme failed to account for the greater costs incurred by households that were more dependent on agrarian than extractive activities. The thesis concludes that the spatial configuration of forest types in the neighbourhood of Amazonian communities affects livelihood strategies and accessibility of forest resources, and is therefore a key determinant of the likely impact of conservation and development policy. The mechanisms examined both have their limitations, but in aggregate could form an effective management strategy for primary tropical forest extractive reserves.

Acknowledgements

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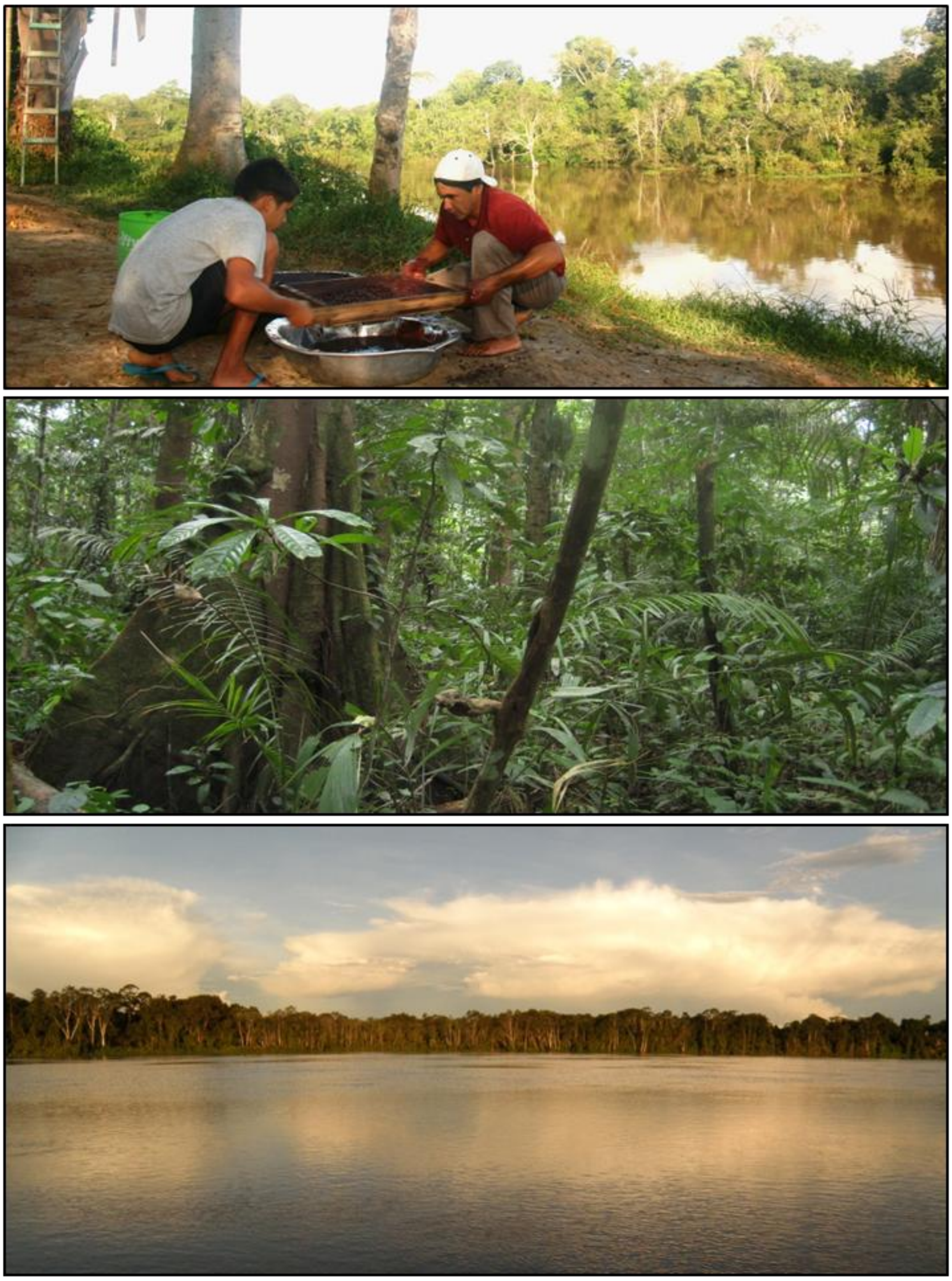
“The forest is one big thing; it has people, animals, and plants. There is no point saving the animals if the forest is burned down; there is no point saving the forest if the people and animals who live in it are killed or driven away. The groups trying to save the race of animals cannot win if the people trying to save the forest lose; the people trying to save the Indians cannot win if either of the others lose; the Indians cannot win without the support of these groups; but the groups cannot win without the help of the Indians, who know the forest and the animals and can tell what is happening to them. No one of us is strong enough to win alone; together, we can be strong enough to win.”

Paikan, Kayapó leader

(from Hecht and Cockburn 1989)

Chapter 1

Introduction



Photos: Making *açaí*; terra firme forest; the Juruá River

1.1 Tropical forests and Amazonia

Tropical forests contain a greater proportion of biodiversity than any other terrestrial biome, provide critical environmental services including carbon sequestration and hydrological regulation, and directly support the livelihoods of millions of rural people who rely on forest resources for food, shelter, medicine or income-generation (Chhatre and Agrawal 2009). Intact tropical forests are thus economically valuable at a global, national and local scale, even without consideration of non-monetary existence values. Amazonia is the world's largest tropical forest, covering 5.3 million km^2 (2003, 85% of the original area), of which 62% lie within Brazil (Soares-Filho et al. 2006; Malhi et al. 2008).

The integrity of Amazonian forests is threatened by a combination of anthropogenic influences including population growth, industrial logging and mining, agricultural development (especially cattle and soya), road construction (which opens access to areas of previously unaffected forest) and human-ignited fires (Laurence et al. 2001). These influences are greatest in eastern and southern Amazonia, particularly within the notorious 'arc of deforestation'. Deforestation rates have been highest in the states of Maranhão, Mato Grosso, Pará, Rôndonia and Tocantins, with up to 77% of the forest cover of individual states already lost (INPE 2011).

In contrast, forest cover in Acre and Amazonas – Brazil’s western Amazonian states – remains relatively intact. A paucity of roads and reliance on fluvial transport along meandering river systems has until now largely precluded encroachment by damaging cattle and agricultural industries. However, even remote parts of Amazonia are vulnerable to the threat of future deforestation. Large-scale infrastructural development can quickly alter accessibility and bring incentives for land-use change (Perz et al. 2008). For example, the *Avança Brasil* programme pledged US $40 billion of governmental investment to the construction of roads, pipelines, hydroelectric systems, power lines, river channelization and port facilities since 2000 (Fearnside 2002). The projected impacts of human-induced climate change are further evidence that the future of these forests is far from secure (Malhi et al. 2009).

Even in regions where absolute rates of deforestation are low or are observed to have been reduced, the impacts of forest fragmentation, edge-effects and selective logging can be more difficult to quantify. The extent of forest degraded by these human activities may be twice that calculated on the basis of deforestation alone (Asner et al.

2005). Other anthropogenic activities can be extremely damaging to forest integrity but are invisible to satellite imagery. Sub-canopy threats to ecosystem integrity affect both animal and plant populations and can result from hunting pressure, over-fishing or the unchecked exploitation of timber and non-timber forest products (Peres et al. 2006).

1.1.1 Amazonia’s protected area network

As part of a national policy to ensure that forested regions remain intact, Brazil’s federal and state government agencies have greatly expanded the country’s protected area network in the last two decades (Rylands and Brandon 2005). Although protected areas may be insufficient to ensure effective conservation of all ecosystem functions – Amazonian watersheds, for example, have headwaters which often extend beyond reserve boundaries – they do inhibit both deforestation and fire and are a critical component of regional conservation strategies (Nepstad et al. 2006; Soares-Filho et al. 2006). A total of 235 million ha of Brazilian Amazonia are currently designated as protected areas, including both inhabited (sustainable use reserves and indigenous territories) and uninhabited (strictly protected areas) reserves (ARPA 2009; Fig. 1.1). The number of reserves and their collective area has expanded rapidly during the last decade: 60.6% of all reserves and 67.4% of the total protected area has been designated since 2000 (Fig. 1.1). Inhabited reserves now account for 80.4% of reserve coverage, overwhelmingly exceeding the area accounted for by strictly-protected areas. The fate of Amazonian forests is therefore intricately associated with the lasting success of inhabited reserves as an integrated conservation-development concept.

1.1.2 Extractive reserves

Legally-occupied sustainable use reserves aim to combine the goal of biodiversity and environmental service conservation with that of socioeconomic development (Fearnside 1989). Within Brazil, the creation of this reserve network was initiated by the sociopolitical movement of rubber-tappers who fought to secure access to, and protection of, the forest that they relied upon for the harvest of rubber and Brazil nuts, in the face of growing pressure from cattle-ranchers (Allegretti 1990). The assassination of the rubber-tapper leader, Chico Mendes, in 1988 highlighted their struggle and attracted the attention of environmentalists who recognised a shared goal of forest conservation (Brown and Rosendo 2002). The first Brazilian *Reserva Extrativista* was designated in this same year, with more quickly following. The reserves aimed to allow rubber-tappers to continue their traditional livelihood practices whilst establishing a

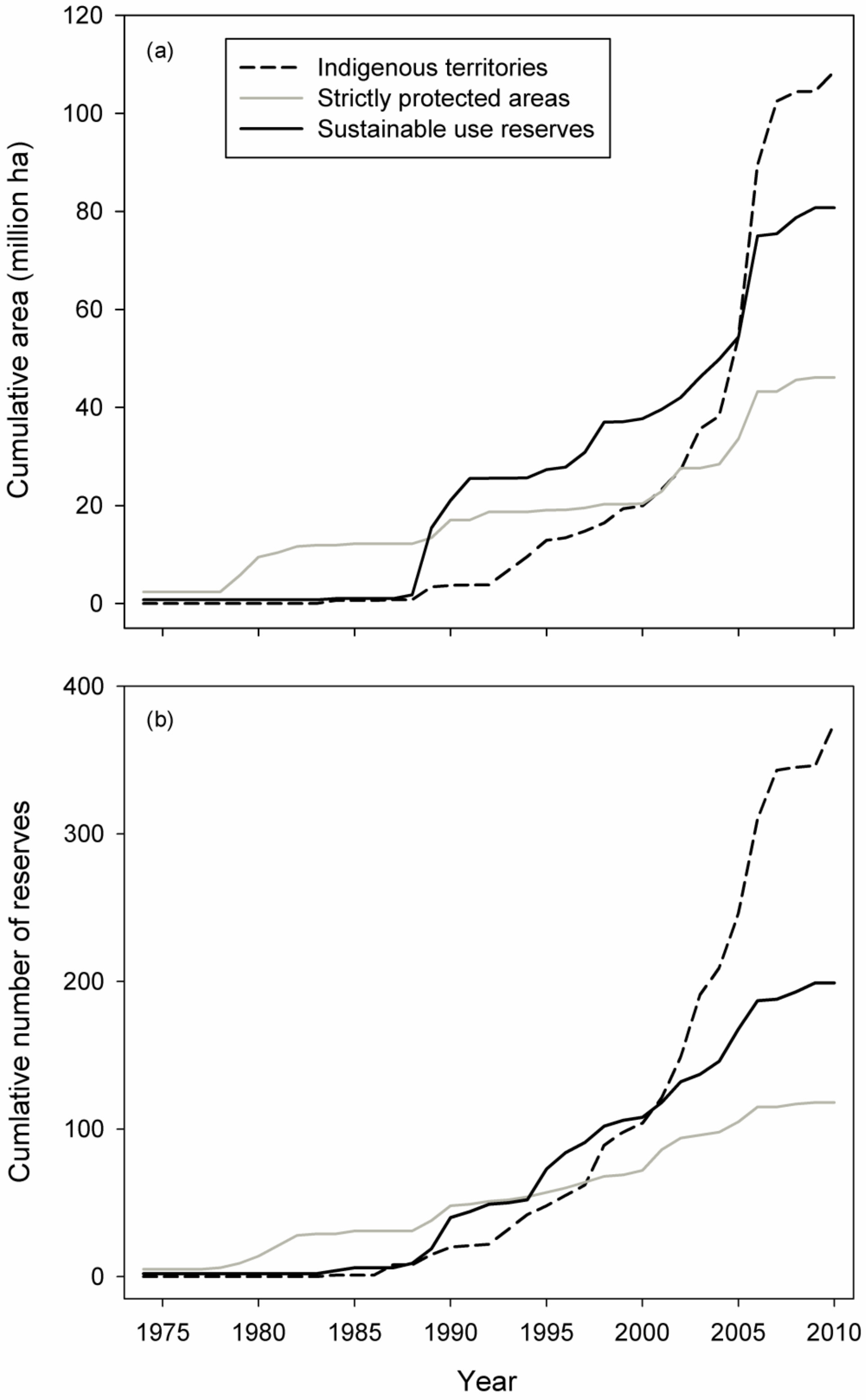


Figure 1.1. *The expansion of the protected area network in Brazilian Amazonia between 1974 and 2010. The cumulative creation of sustainable use reserves, indigenous territories and strictly protected areas is indicated by (a) the total area designated and (b) the number of reserves. Source: ARPA (2009).*

degree of economic self-sufficiency through a diversification of harvested products (Fearnside 1989). Sustainable use reserves currently account for 16.1% of Brazilian Amazonia, compared to 9.2% by strictly-protected areas and 21.7% by indigenous territories (ARPA 2009).

Brazilian sustainable use reserves include protected areas denominated as *Reserva Extrativista* (ResEx), *Reserva Desenvolvimento Sustentável* (RDS) and *Floresta Nacional* (FLONA), amongst others. Some reserves are administered by federal agencies (e.g. ResEx reserves are managed by the *Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis* (IBAMA)) whilst others are state-administered (e.g. RDS reserves are managed by the *Secretaria de Estado do Meio Ambiente e Desenvolvimento Sustentável* (SDS)). As a consequence of these administrative differences, subtle variation exists in the political framework, regulations, and management strategies associated with each reserve category, but all 199 such protected areas share the same underlying philosophy of combining conservation and development (Silva 2005).

In aggregate, sustainable use reserves are more commonly and globally referred to as ‘extractive reserves’. Although the term *Reserva Extrativista* translates to the same word and has significance as a particular designation of reserve within Brazil, ‘extractive reserve’ is used throughout this thesis to refer collectively to all legally-occupied protected areas except indigenous territories.

Legally-occupied protected areas are an effective barrier to deforestation, since local people represent a strong political means of deterring the frontier of forest loss (Schwartzman et al. 2000; Nepstad et al. 2006). However, extractive reserves were originally designed as social spaces, rather than biodiversity conservation units *per se*, and conservation success is not assured (Browder 1992). Extractivist populations may damage forest integrity through the ecologically-unsustainable harvesting of forest resources. A further risk is that protected areas may attract human settlements due to the investment and revenue opportunities from government and international donors; higher population growth rates within, or on the periphery of, extractive reserves can pose a threat to conservation aims (Wittemyer et al. 2008). There is therefore a need to better understand the capability of extractive reserves and other protected areas to conserve biodiversity throughout Amazonia (Moegenburg and Levey 2002).

1.2 Traditional Amazonian livelihoods

Brazilian Amazonia's rural human population includes indigenous people, farming colonists who settled in the 1970s and 1980s, and immigrant Brazilians who travelled to the Amazonian interior during the rubber booms of the late-19th and mid-20th centuries (Dean 1987). Such immigrants are considered 'traditional Amazonians' and far outnumber the indigenous population, being variously referred to as *ribeirinhos* (river-dwellers), *seringueiros* (rubber-tappers) and *caboclos* (of mixed Brazilian Indian and European ancestry). During the height of the rubber trade, many traditional Amazonians lived as poorly-rewarded workers in a notoriously inequitable debt peonage system whereby harvested rubber would be traded for supplies with the landlord (*patrão*) of an area of forest (*seringal*) at prices that ensured a persistent debt of the worker to the employer (Hecht and Cockburn 1989). Competition from Asian plantation rubber eventually caused the collapse of the Brazilian rubber export market and the consequent disintegration of the debt-peonage system (Dean 1987). Traditional Amazonians remained in the region, adopting an agro-extractivist livelihood strategy that includes a combination of subsistence swidden agriculture, fishing, hunting, and extraction of forest products, with cash revenue generated from the sale of one or more of these resources.

Over the last decade, many areas have seen a decreasing emphasis on traditional extraction of rubber and Brazil nuts by these communities, with greater engagement with agriculture and cattle-ranching (Ruiz-Perez et al. 2005; Salisbury and Schmink 2007; Vadjunec and Rocheleau 2009). Even small-scale agriculture usually involves the clearance of swidden fields, often with detrimental long-term effects to primary forest cover. The economic prospects of traditional Amazonian communities may be enhanced in the short term (Hecht 1993), but ephemeral gains in livelihood quality associated with land conversion elsewhere in Amazonia have often rapidly been followed by collapses in both natural capital and living standards (Rodrigues et al. 2009). Increasing reliance on swidden agriculture does not necessarily lead to sustained improvement of livelihoods, and an alternative economic approach may be more effective from both a development and conservation perspective.

The spatial overlap of vast areas of tropical forest of immense biological value with millions of people living in poverty means that development of an optimal management strategy for this region is a complex process. Priorities and objectives vary widely on a gradient from stakeholders principally interested in environmental protection to those more concerned about poverty alleviation, with many attempting to balance the two via integrated conservation and development initiatives. An array of land-use mechanisms has been heralded as holding promise for reconciling the needs of conservation and livelihoods, including selective timber extraction, small-scale sustainable agriculture, and eco-tourism. Two further mechanisms have received particularly close attention, both in Amazonia and in tropical forests globally. The first of these, discussed in the academic literature for two decades, is the commercial harvesting of non-timber forest products (NTFPs). The second, having gained more recent prominence, is the implementation of market-based payments for environmental services (PES) programmes. The philosophy and background of these two mechanisms is discussed below.

1.3 Commercial harvesting of non-timber forest products

Non-timber forest products are harvested by millions of rural forest-dwellers worldwide as part of a subsistence livelihood strategy to provide food, shelter and medicine (Koziell and Saunders 1996). NTFPs have been defined as “all biological materials other than timber, which are extracted from forests for human use” (de Beer and Mcdermott 1989). Attention is usually focussed upon plant-based resources such as fruit, oils, resins, leaves, and barks although, since NTFPs are defined by what they are not, the term has also been considered by many authors to include animal resources such as hunted game and fish (Belcher 2003).

In addition to local consumption by the extractor, many NTFPs are also sold to generate cash revenue for extractors – either on an individual basis in local markets or through extractor co-operatives as part of a more formal trading agreement. Many tropical NTFPs including rattan (Sastry 2001), palm hearts (Galetti and Fernandez 1998) and Brazil nuts (Mori 1992), have a long history of commercialisation but emerging markets for forest resources have heightened the interest of both academics and development practitioners in the potential economic value of other NTFPs (Belcher et al. 2005). Seminal preliminary assessments suggested that the harvest of NTFPs may be an economically-competitive alternative to the extraction of timber within tropical forest areas (Myers 1988; Peters et al. 1989). Although valuation studies of this kind have been widely critiqued as over-simplifications (e.g. Salafsky et al. 1993), they have played a crucial role in raising consciousness of the potential contribution of commercial extractivism to tropical forest economies. Proponents of commercial NTFP extraction have drawn attention to the benign ecological impact relative to agricultural alternatives, and to the contribution that extractive revenues can make to rural economies (Nepstad 1992).

Other authors have more cautiously warned that the NTFP paradigm may not be a panacea, emphasising the nuances of extractive systems with uncertain markets. Unequal distribution of harvesting pressure and the highly-perishable nature of many NTFPs create a strong likelihood of local over-exploitation of resources in the vicinity of rural communities and of urban markets, respectively (Belcher and Schreckenberg 2007). Increasing demand for some resources may additionally promote the development of biodiversity-poor monocultures which ultimately replace extraction from wild populations. For example, the Brazilian rubber industry was outcompeted by Asian plantation rubber (Dean 1987), and the Amazonian palm fruit *açai* (*Euterpe oleracea*) has been intensively managed to increase supply in many areas (Weinstein and Moegenburg 2004). Even where ecological pressures can be minimised, markets for NTFPs are often poorly developed. Consumer demand is subject to changing trends and fashions, and the income earned is often insufficient to lift people out of poverty (Padoch 1992).

Given the large diversity of taxa, habitats, harvest methods, and markets involved, it is perhaps unsurprising that appraisals of extractive systems often reach conflicting conclusions regarding the ecological or economic sustainability of NTFP harvesting. In many cases, some of the problems identified above are not insurmountable, and emerging markets and improved sociopolitical organisation have increasingly allowed the development of commercially-viable extractive initiatives (Marshall et al. 2006). Larger-scale extraction of a greater diversity of products has boosted the cash economy of rural Amazonians. Within Brazilian Amazonia, recent increases in government subsidies and NGO investment to support extractive initiatives have coincided with expanding markets for tropical forest products (Sills and Saha 2010). Various NTFPs including cosmetic (e.g. *andiroba* oil (*Carapa guianensis*)), edible (e.g. Brazil nuts (*Bertholletia excelsa*), and medicinal (e.g. *copaíba* oleoresin (*Copaifera* spp.)) products are sold in domestic and international markets (Shanley and Medina 2005).

1.3.1 *Copaifera* spp. oleoresin

Oils and resins are particularly well suited to commercialisation due to their relatively high value per unit weight, which reduces their transport costs. Their non-perishable nature also means that they can be extracted in remote rural locations and transported greater distances to their eventual national or international market, and have a shelf-life of months or years in contrast to days or weeks of many other NTFPs such as fruits (Shanley et al. 2002).

Medicinal *Copaifera* oleoresin (known locally as *óleo de copaíba*) is a ubiquitously known and economically-valuable NTFP extracted from the basal trunk of trees of this genus across Brazilian Amazonia (Plowden 2004). The oleoresin is a secondary metabolite which probably plays a role in the defence strategy of the tree against pathogens or herbivores (Plowden 2004). It is widely harvested, traded and used by rural Amazonians and is valued for its demonstrated anti-inflammatory and analgesic properties (Veiga Junior and Pinto 2002). Rapidly-expanding domestic and international markets for *Copaifera* oleoresin have emerged in the last decade and the product can be bought globally in both urban markets and online.

Copaifera trees were historically harvested using an axe to open a cavity in the side of the tree from which the oleoresin was extracted, or by simply draining the oleoresin whilst felling the tree for timber (Plowden 2004). Even the former practice was likely to lethally damage the tree, however, and this harvest method is now prohibited in most protected areas. Contemporary harvesting uses a borer to drill a small hole (19 mm in diameter) into the tree trunk from which oleoresin may be drained through plastic tubing (Leite et al. 2001). If the hole is then sealed, the oleoresin stores may be replenished and the tree may be re-drilled after a period of months or years (Newton et al. 2011).

As a consequence of its non-perishable nature, expanding markets, and potential for ecological sustainability, *Copaifera* oleoresin represents a good candidate resource for commercial extractivism. Academics, government agencies, and NGOs across Amazonia are interested in the physical and chemical properties and harvest potential of this oleoresin, and the ecology of source populations (Santos et al. 2001). There is little history of *Copaifera* oleoresin harvesting within our study site, but local agencies are actively promoting this extractive activity. For these reasons, we selected this NTFP as a case-study resource for this thesis.

1.4 Payments for environmental services

The development of payments for environmental services (PES) programmes is a second, more recently emerging, mechanism by which to address conservation concerns whilst bringing development benefits to rural people. PES programmes seek to translate the value of natural capital into market values (Engel et al. 2008). This is achieved by transferring funds from those that benefit from environmental services (ES) – who may be downstream users, national governments or, in the case of many carbon services, the global community – to those whose land-use practices are responsible for maintaining those ES (Wunder 2005). Programmes vary enormously in their spatial extent, payment structure, and values, but are united by the ‘business-like’ transactions that define their approach to achieving conservation goals (Wunder et al. 2008). The PES paradigm is not foremost intended to be a poverty-alleviation mechanism but the inherent geographic congruence of welfare needs and threatened ES creates great potential for identifying development goals as a secondary aspiration (Wunder 2008). PES programmes have been implemented across a range of biomes but with particular emphasis on tropical forest areas following Costa Rica’s pioneering PES programme (Pagiola 2008).

1.4.1 The PES programme *Bolsa Floresta*

A large-scale PES programme, the *Bolsa Floresta*, has been implemented across extractive reserves in the Brazilian state of Amazonas since 2007 (Viana 2008). Enrolled participants are reserve residents who agree not to clear any primary forest, in return for cash payments and developmental support. In terms of scale, the *Bolsa Floresta* is one of the largest PES programmes introduced in a tropical forest region, with over 7,000 families enrolled and an ambitious planned expansion. We use this programme as a case-study in our examination of how PES may act as a complementary or alternative conservation mechanism in tropical forest areas.

1.5 Thesis background

1.5.1 Objectives

This thesis examines issues of sustainable resource use and socioeconomic development within the context of Amazonian extractive reserves. Specifically, this study quantifies patterns of livelihood strategies of rural Amazonians and explores the potential for NTFP commercialisation and PES programmes to play a role in tropical forest conservation and the development of rural livelihoods. The thesis uses two case-studies – *Copaifera* oleoresin as an NTFP and the *Bolsa Floresta* PES programme – as examples of contemporary conservation and development mechanisms. By exploring the current contribution of agrarian and extractive activities to rural livelihoods, it is possible to assess the likely contribution of both NTFP extraction and PES payments to household incomes.

1.5.2 Interdisciplinary science

Conservation academia has increasingly recognised the benefit to be gained from interdisciplinary research that draws upon both the natural and social sciences (Campbell 2005; Kainer et al. 2006). Ecological and social problems in the tropics are frequently linked not only by their geographic congruence but also by their underlying drivers, and so the division of conservation and socioeconomic development is neither necessarily desirable nor productive. The central subjects of this thesis – extractive reserves, commercial NTFP harvesting, and PES programmes – have all been discussed within the context of achieving both conservation and development goals. A holistic understanding of the issues addressed by this study therefore demands an interdisciplinary approach, and I thus draw upon both ecological and social science research methods.

1.5.3 Study site

1.5.3.1 Amazonas

This study examines resource use within intact tropical forest areas, with a focus on the Brazilian state of Amazonas. Occupying 1.57 million km^2, Amazonas is the largest Brazilian state and retains 96.2% of its original forest cover (INPE 2011). Almost half of the state (76,907,408 ha; 49.0%) is designated as protected areas, with the proportion of inhabited reserves (41.8%) vastly exceeding that of strictly protected areas (7.2%) (ARPA 2009; Fig. 1.2). Amazonas has consequently been a centre of attention for conservation and research programmes aiming to understand and protect livelihoods, environmental services, and biodiversity within extensive intact primary forest areas and extractive reserves.

Amazonas has a total population of 3.5 million people, but 51.5% of these live in the state capital, Manaus, and a further 27.6% live in municipal towns (IBGE 2011). Rural population density is thus just 0.5 per km^2 and the rural population of ~728,000 people

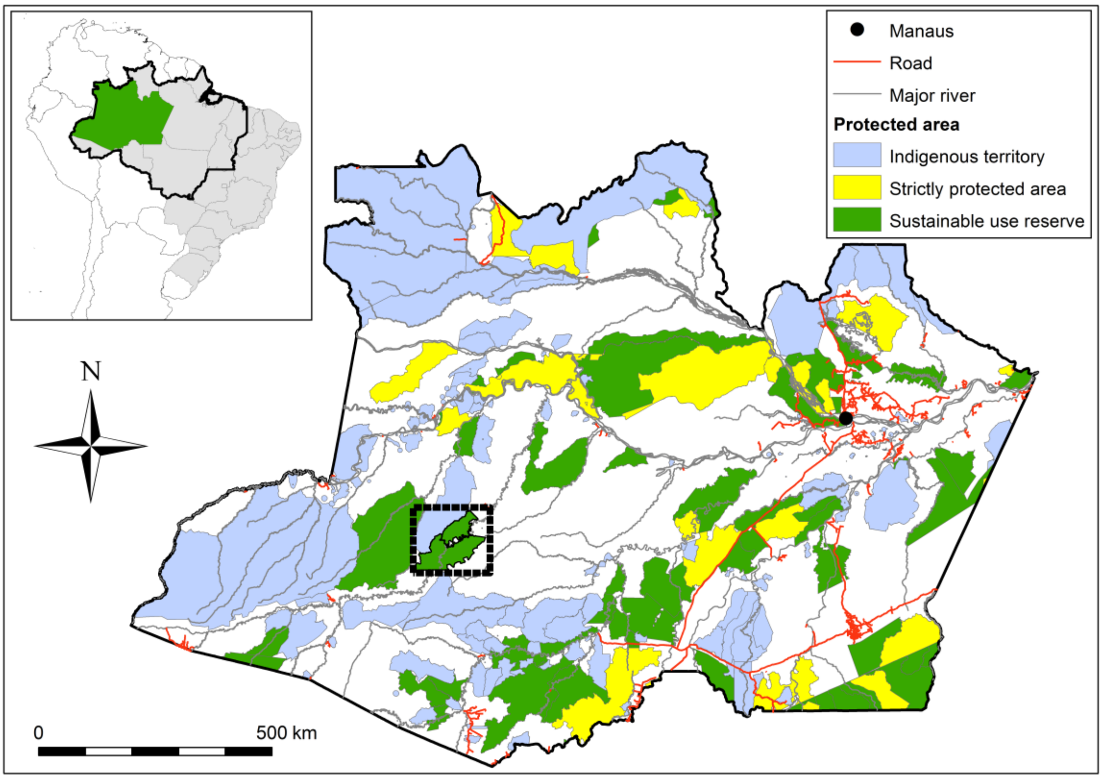


Figure 1.2. *The protected area network of the state of Amazonas, Brazil. The dashed rectangle indicates the study reserves, shown in Fig. 1.3. The inset indicates the location of Amazonas (green) within the Brazilian* Amazônia Legal *(bold) in Brazil (grey).*

live mainly in river-side communities, since Amazonas contains few major roads and mobility is dominated by fluvial transport.

1.5.3.2 Seasonal floods and *várzea* forest

Much of western Amazonia, including Amazonas, is subject to a large seasonal flood pulse as a consequence of high rainfall in the Andean catchment (Pinedo-Vasquez et al. 2011). Water levels rise by up to 12 metres in the months following peak rainfall, flooding wide bands of forest on either side of the main river channels. This seasonally-flooded *várzea* forest contrasts with the permanently dry *terra firme* forest found at higher elevations further from the main river channels and on the smaller tributaries that drain local catchments. The fauna and flora of várzea forests have evolved unique strategies to cope with this seasonal inundation, resulting in ecologically-distinct communities and behaviours (Haugaasen and Peres 2007). Rural people living within or near várzea forest have similarly adapted to its idiosyncrasies, often adjusting their livelihood strategies seasonally to take advantage of opportunities to access alternative resources presented by rising and falling floodwaters (Pinedo-Vasquez et al. 2011).

1.5.3.3 Médio Juruá study site

Most of the data in this thesis were collected within and around two contiguous extractive reserves bisected by the Juruá River, a large white-water tributary of the Amazon (Solimões) River in the state of Amazonas, Brazil. The federally-managed Médio Juruá Extractive Reserve (hereafter, *ResEx Médio Juruá*) occupies 253,227 hectares, whilst the larger, state-managed Uacari Sustainable Development Reserve (hereafter, *RDS Uacari*) is 632,949 hectares in area (Fig. 1.3).

A 10 – 20 km wide band of várzea forest spanning the main river channel is subjected to a prolonged flood-pulse every year between January and June, whilst terra firme forests on higher elevation are never inundated. The elevation is 65 – 170 m above sea level and the terrain is flat or undulating. The area has a wet, tropical climate; daily rainfall recorded at the Bauana Ecological Field Station (S 5°26' 19.032" W 67°17' 11.688") indicated that 3,659 mm and 4,649 mm of rain fell annually in 2008 and 2009, respectively. All forest within the study site was intact, primary forest which had experienced virtually no logging activity except for some historical selective removal of the largest adult trees of commercial timber species (including *Copaifera* spp.) from várzea forest between 1970 and 1995 (Scelza 2008). Timber extraction ended with the creation of the reserves.

The ResEx Médio Juruá and RDS Uacari were decreed in 1997 and 2005, respectively, and are currently inhabited by some 4,000 legal residents distributed across approximately 60 settlements of between 1 and 89 households (mean ± SD = 10.3 ± 13.2, median = 7, *N* = 50). Most communities are located along the main river channel, while others are settled on the banks of tributaries and oxbow lakes on either side of the Juruá River. Reserve residents variously engage in agricultural, extractive, and fishing activities for both subsistence and cash income (SDS 2010).

These reserves are two of the most ‘traditionally-functioning’ reserves in Amazonas (H.S.A. Carlos (SDS), personal communication). Although administered by different government agencies, the two reserves are geographically contiguous, and their shared ecological, socioeconomic, and income opportunities unify them to a much greater

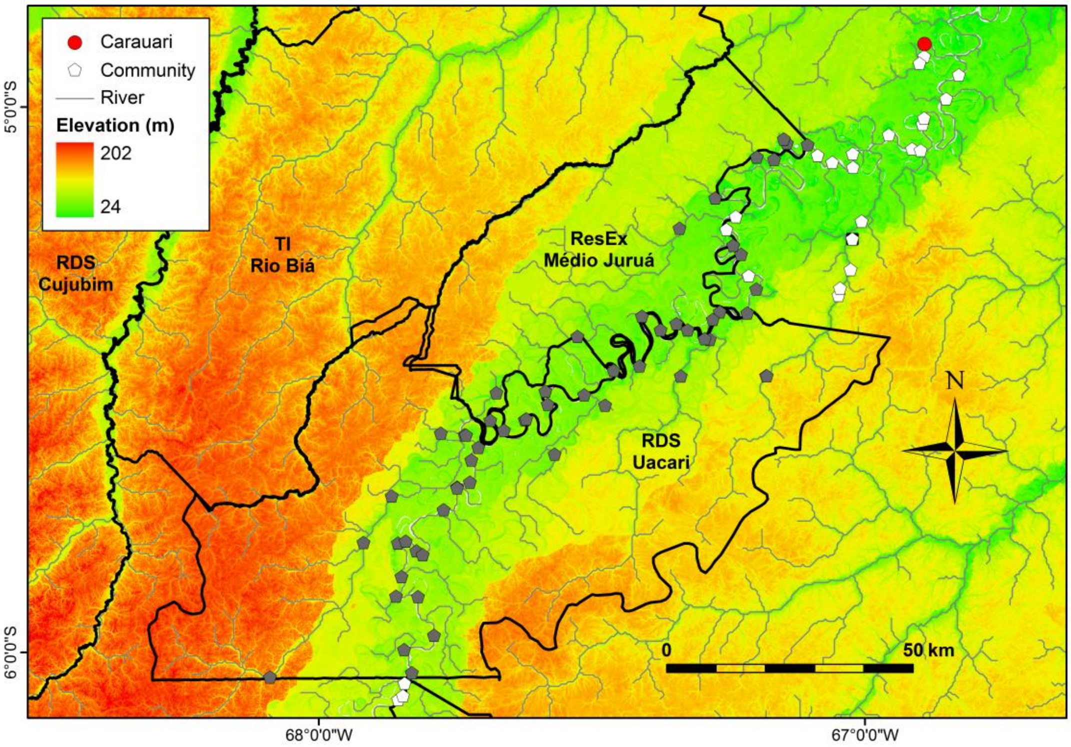


Figure 1.3. *The study landscape, incorporating the Médio Juruá Extractive Reserve and the Uacari Sustainable Development Reserve in the state of Amazonas, Brazil. All communities within the Juruá watershed are shown: grey communities are administratively within the reserves; white communities are outside. The municipal town, Carauari, and adjacent protected areas are indicated. Elevation colours approximate to the two main forest types: green areas are várzea forest; yellow and red areas are terra firme forest.*

extent than their administrative structure separates them. We therefore treated them largely as a single system, without disregarding their differences when pertinent.

1.5.4 Research context

This study was conducted within the context of a 4-year DEFRA Darwin Initiative research project (Ref. 16-001). Exploring ideas related to the “community-based sustainable management of forest resources in Amazonian extractive reserves”, this 3-year multi-stranded project aimed to design guidelines to manage game vertebrates and other non-timber resource populations in large multiple-use tropical forest reserves. In collaboration with Brazilian federal and state government agencies, the project worked to develop effective community-based wildlife management programmes that were grounded in the socioeconomic reality of Amazonian extractive reserves. Data collection protocols and logistical operations employed by this project were a key contribution to this thesis.

1.6 Thesis structure

The five principal chapters (chapters 2 - 6) are written in the form of peer-reviewed papers. At the time of submission, one chapter was published (chapter 4: Newton et al. 2011), and two chapters were in press (chapter 2: Newton et al. in press *a*; chapter 6: Newton et al. in press *b*). Chapter 2 describes the heterogeneity in livelihood strategies adopted by rural Amazonians living in extractive reserves, relating these patterns to demographic, geographic, and socioeconomic determinants. In illustrating the principal patterns and drivers of contemporary resource use by reserve residents, this chapter will define the context for the remainder of the thesis. In chapters 3 to 5 I use the case-study of *Copaifera* oleoresin to explore the multiple disciplines that contribute to a holistic understanding of commercial NTFP harvesting. Seeking first to define the spatial distribution of this resource at a basin-wide, landscape, and local scale, I aim to demonstrate in chapter 3 how a cross-scale approach can be useful in understanding variation in resource density and spatial distribution. Chapter 4 describes the results of a quantitative experimental harvest of four species of *Copaifera* and assesses how morphological and environmental drivers may influence harvest yields of an NTFP. In an interdisciplinary synthesis, Chapter 5 combines results from the spatial and harvest studies with novel socioeconomic and market data. Using spatial accessibility models, I generate estimates of the potential volumetric and monetary values of oleoresin that could be harvested from the study area. Chapter 6 examines the concept of PES as an alternative, market-based mechanism by which some of the problems of tropical forest loss may be addressed. I assess whether the payment structure of the *Bolsa Floresta* programme may be limiting its ability to achieve its conservation goals. Finally, Chapter 7 draws together some of the implications and conclusions of the thesis, and suggests directions for future work.

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Chapter 2

Determinants of livelihood strategy variation in two extractive reserves in Amazonian flooded and unflooded forest

Photos: Living, fishing, cultivating, and extracting in the Médio Juruá

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2.1 Abstract

Managers of extractive reserves need to understand the livelihood strategies adopted by rural Amazonians in order to implement projects that benefit the livelihoods of local residents whilst maintaining forest integrity. Whilst resident populations are often descended from immigrant rubber-tappers, dynamic economic and social conditions have led to a recent diversification of land use practices. Our two-year study in two large contiguous extractive reserves encompassing both unflooded (*terra firme*) and seasonally flooded (*várzea*) forest, shows the degree to which local livelihood strategies of different settlements are heterogeneous. Extractive offtake of forest products and fish catches and agricultural activities, together with income from sales, of 82 households in 10 communities were quantified in detail by means of weekly surveys. The survey data were combined with interviews to examine the demographic and wealth profile, and engagement in alternative activities, in 181 households across 27 communities. All households and communities were engaged in all three subsistence activity types, but there was large variation in engagement with income-generating activities. Households within a community showed considerable congruence in their income-generating activity profiles, but there was significant variation between communities. Yields from agriculture and fishing were more temporally stable than extraction of highly-seasonal forest products. Generalised linear mixed models showed that forest type was consistently important in explaining yields of both agrarian and extractive products. Communities with greater access to terra firme forest were inherently more agricultural, and strongly committed to manioc production. Communities with greater access to flooded forest, however, showed a greater dependence on fishing. We argue that conservation should be more attuned to the diversity and dynamism of livelihood strategies in protected areas; in particular, reserve managers and policy makers should account for the effect of local variation in physical geography when designing sustainable development projects.

2.2 Introduction

Developing rural livelihoods within protected areas is an important means of achieving conservation objectives in Amazonia (Campos and Nepstad 2006). As part of this strategy, sustainable-development and multiple-use reserves (hereafter, collectively referred to as extractive reserves) currently account for over 14% of Brazilian Amazonia, and are being created at a faster rate than traditional, strictly-protected areas

(ARPA 2009). Extractive reserves have been defined as forest areas inhabited by extractive populations granted long-term usufruct rights to forest resources which they collectively manage (Schwartzman 1989). As legally-occupied protected areas, extractive reserves aim to ensure the conservation of biodiversity and environmental services whilst providing opportunities for sustainable resource use (Allegretti 1990). The fate of Amazonian forests is therefore intricately associated with the lasting success of extractive reserves as an integrated conservation-development concept. In turn, the likelihood of such reserves achieving a balance between conservation aims and socioeconomic development is significantly influenced by the aggregate resource-use behavioural patterns of their residents (Takasaki et al. 2001).

Most non-tribal rural Amazonians were originally drawn to the region by the rubber-booms of the late 19th and mid-20th centuries, when their principal income-generating activities were the extraction and sale of natural rubber (latex of *Hevea* spp.), Brazil nuts (seeds of *Bertholletia excelsa*) and the palatable latex of sorva (*Couma* spp.) (Dean 1987). However, extractive populations living in intact tropical forest regions have also traditionally exploited a diverse array of the available natural resources for both subsistence and commerce. The extraction of such forest products, which include a wide variety of plant and animal resources, is hugely important in subsidising the household economies of millions of rural forest dwellers worldwide (Koziell and Saunders 1996).

Rural Amazonians have been forced to substantially shift their livelihood strategies as a consequence of dynamic social, economic and political pressures and opportunities. Foremost, the collapse of Brazilian rubber exports saw a diversification of economic portfolios amongst former rubber-tappers (Dean 1987). Subsequently, the creation of extractive reserves, the associated formation of residents' associations, increasing levels of support from management agencies and non-government organisations (NGOs), and changing markets for non-timber forest products (NTFPs) have all broadly shaped the evolution of livelihood strategies in Amazonian forest reserves (Hall 2004).

In aggregate, there has been a trend away from traditional extractive exploitation (hereafter, *extractivism*) and towards cattle-ranching and agricultural development in several Amazonian extractive reserves (Ruiz-Perez et al. 2005; Salisbury and Schmink 2007; Vadjunec and Rocheleau 2009). Even in largely forested areas of rural Amazonia, small-scale agriculture usually involves successive rotation between cleared forest plots, thereby resulting in shifting land-use, often involving detrimental long-term impacts on forest cover. The economic prospects of reserve residents may be enhanced in the short term (Hecht 1993), but ephemeral gains in livelihood quality associated with land conversion are often rapidly followed by collapses in both natural capital and living standards (Rodrigues et al. 2009).

Describing pronounced aggregate shifts in livelihood strategies can fail, however, to identify more subtle differences in the contemporary activity budgets adopted by Amazonian agro-extractivist populations. Divergences in livelihood strategy may also occur at the household or community level (Coomes and Burt 2001). Understanding the behavioural patterns of rural Amazonians, and the drivers of these patterns, is a critical step towards managing legally occupied protected areas to meet the long-term interests of both forest conservation and local livelihoods. Various demographic, economic, geographic and historical factors are known to influence resource use decision-making in semi-sedentary horticultural societies in the humid tropics. For example, the availability of land suitable for cultivating perennial food-crops in *roçados* (swidden fields) has shaped the settlement patterns of rural Amazonians (Parry et al. 2010a; Takasaki et al. 2001). Engagement in commercial NTFP extractivism can be determined both by access to local markets (Ruiz-Perez et al. 2004) or by migrant and educational background (Stoian 2005). Access to education, healthcare, welfare subsidies and other forms of livelihood support may drive migration patterns of individuals, families or entire communities (Parry et al. 2010a). Deforestation rates often increase with smallholder wealth (Pacheco 2009).

Studying heterogeneity and dynamism in livelihood patterns is important (Salisbury and Schmink 2007) because agencies working with extractive reserves would benefit from a detailed understanding of how various factors drive or predict the economic activity patterns with which reserve residents engage (Nepstad et al. 2002). This understanding will indicate: i) whether reserves are likely to continue to serve as effective barriers to deforestation (Nepstad et al. 2006); ii) whether they may counter the broad Amazonian trend of rural depopulation (Parry et al. 2010b); and iii) whether or not management programmes and directives should be applied uniformly across different extractive reserves, ignoring within-reserve heterogeneity (Coomes and Barham 1997).Targeted implementation of management policy, commercial extractivism initiatives and payments for environmental services (PES) programmes will benefit from awareness of the context in which they are being developed. Research and promotion of extractive activities should thus be undertaken with consideration of the livelihoods affected by them.

Here we quantitatively assess the variation in livelihood strategies and modes of production by residents of two extractive reserves in western Brazilian Amazonia with respect to their engagement with both subsistence and income-generating activities. We examine the spatial and temporal heterogeneity in livelihood strategies at the levels of both households and entire communities, and seek to understand the factors driving this variation. If household or community characteristics can explain spatial or temporal variation in livelihood strategies, these characteristics may be used to target the implementation of development programmes and subsidies.

2.3 Methods

2.3.1 Study site

The study was conducted within and around two contiguous extractive reserves bisected by the Juruá River, a large white-water tributary of the Amazon (Solimões) River in the state of Amazonas, Brazil. The federally-managed Médio Juruá Extractive Reserve (hereafter, *ResEx Médio Juruá*) occupies 253,227 hectares, whilst the larger, state-managed Uacari Sustainable Development Reserve (hereafter, *RDS Uacari*) is 632,949 hectares in area (Fig. 2.1). The elevation is 75–175 m above sea level and the terrain is flat or undulating. A wide band of seasonally flooded (*várzea*) forests along the main river channel are inundated between January and June, whilst *terra firme* forests at higher elevation are never flooded. The area has a wet, tropical climate; rainfall recorded at the Bauana Ecological Field Station (S 5°26' 19.032" W 67°17' 11.688") during the study period indicated that 3,659 mm and 4,649 mm of rain fell annually in 2008 and 2009, respectively.

The ResEx Médio Juruá and the RDS Uacari, which were decreed in 1997 and 2005, respectively, are currently inhabited by some 4,000 legal residents, living in ~74 communities of 1 – 89 households each. Many communities are located on the main river channel, whilst others are found on the banks of tributaries and oxbow lakes on either side of the Juruá River. Residents of these extractive reserves are variously engaged in agricultural and extractive activities for both subsistence and cash income (SDS 2010).

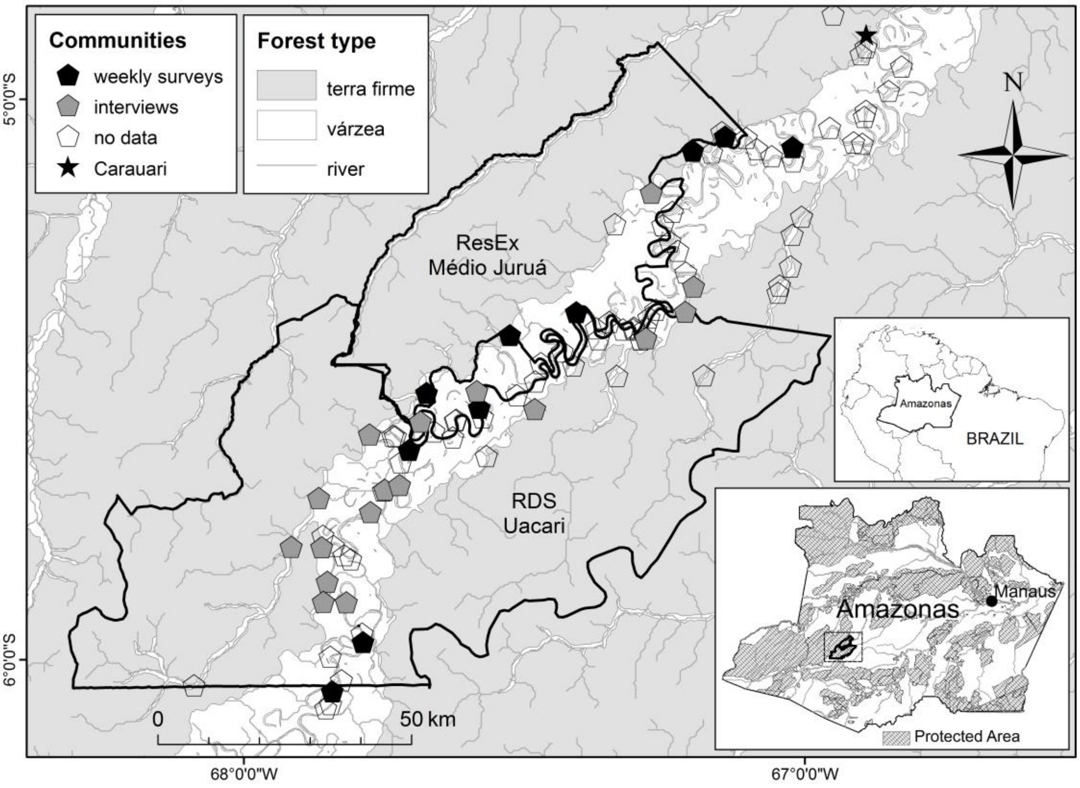

Figure 2.1. *Location of communities within, and immediately outside, the boundaries of the Uacari Sustainable Development Reserve and the Médio Juruá Extractive Reserve in the state of Amazonas, Brazil. Insets show the location of Amazonas within Brazil (above) and the study area within the full protected area network of Amazonas (below).*

2.3.2 Data collection

This research was undertaken as part of a large-scale, 3-year research project within this study site, of which all authors were team-members. We collected socioeconomic data from 181 households across eight communities in the ResEx Médio Juruá, 17 communities in the RDS Uacari, and two communities immediately adjacent to these two reserves, spanning a ~320-km section of the Juruá River. The research team maintained a constant physical presence in the reserves throughout, facilitating data collection, reinforcing data quality-control, and enhancing the reliability and level of detail of interviewees’ responses.

2.3.2.1 Weekly household surveys

Weekly surveys were conducted in 127 households across 14 communities between March 2008 and July 2010. This sampling effort represented ~21% of all active households in these two reserves. One resident from each community, who had been previously trained, visited up to 10 randomly-selected households per community on a weekly basis and recorded all extractive and agricultural activities of each household. Each week, this trained resident questioned a senior household member about three categories of activity important for subsistence and cash-income: 1) cultivation of agricultural products; 2) extraction of wild plant forest resources; and 3) fishing. For each activity, the weekly household quantities of all resources collected or produced were recorded, together with their ultimate use (consumed locally or sold), values and markets for traded goods. In the interest of comparability, these questionnaires were based on those used in a biological monitoring programme including several protected areas within the state of Amazonas (Ferraz et al. 2008). The time interval of data collection varied between communities, and some weekly data were missing due to absences of monitoring personnel. We therefore analysed data from all households for which data were available for at least 40 weeks spread over at least a single period of 365 consecutive days, resulting in a subset of 82 households from 10 communities (mean ± SD number of weekly samples per household = 66.6 ± 10.3). Another 45 households sampled failed to capture a full year-round seasonality cycle, and were therefore excluded from the analyses. Data on game harvest were also collected by these surveys but, in these reserves, hunting accounted for a minor source of animal protein relative to fishing, and cash-income from hunting (which is in any case illegal) was negligible. Since the study’s aim was to compare the subsistence and income value of legal activities, all hunting data were thus excluded from our analyses.

2.3.2.2 One-off household and community interviews

Two modes of one-off interviews were conducted within 181 households belonging to 27 communities between June and December 2009. These interviews generated predictor variables that were used to model livelihood strategies, and offered an opportunity to gather data to further explain the patterns observed. Firstly, household interviews were undertaken with one or more senior members of each household to document the household’s demographic profile, material assets and wealth. Interviewed households were also asked to indicate their highest-earning main activity type as the principal income-generating activity. Secondly, community interviews were conducted with a senior member of each community (usually the locally elected leader) to document the community’s overall demographic profile, physical geographic setting, infrastructure and material assets. Both forms of interview were structured, although additional information was recorded on an ad-hoc basis if offered. We distinguish weekly surveys (82 households in 10 communities) from one-off interviews (181 households in 27 communities) throughout the study. All communities and households surveyed weekly were also interviewed.

2.3.3 Data analysis

2.3.3.1 Data-cleaning

Weekly survey data occasionally lacked certain details (e.g. prices in R$; R$1 = US$0.60, March 2011) for some resources, so whenever necessary we used product-specific prices, averaged from all other households, to fill these gaps because product prices were temporally and spatially stable, and to allocate zero to all missing values would have unnecessarily biased the data.

Since fish catches were presumed to greatly exceed agricultural and forest extraction events in frequency, surveyed households were only asked details about the previous two days in terms of fishing yields, and the total weekly income derived from fishing. Where necessary, we multiplied the recorded data based on these two days by 3.5 to estimate weekly offtake.

Resources were grouped according to taxonomy and end-use functionality. Agricultural products were generally divided by species. Extractive resources were divided by species where the taxonomy dictated the use and/or price (e.g. seeds of *andiroba* trees [*Carapa guianensis* (Meliaceae)] were specifically used for oil extraction), but were grouped by the extracted plant-part when collectors were less taxonomically discriminatory (e.g. many tree species were collected for firewood, or for their bark). Catches of most fish were reported at the level of species but these were grouped by family using the classification system described by Santos et al. (2006).

Since each resource was recorded using different traditional units of quantity, we hereafter define the number of yield ‘events’ as the frequency with which each resource was recorded as being produced or extracted, irrespectively of the amount produced or harvested. All reported correlations use the Pearson coefficient, denoted by the symbol ‘r’ throughout.

2.3.3.2 Models

We used multi-level generalised linear mixed models to relate variation in household production and extraction of key resources derived from alternative activity categories to demographic and geographic variables at the household and community level. Multi-model inference based on the AIC information criterion was used to rank the importance of variables and produce model-averaged parameter estimates (Burnham and Anderson 2002). We built models using the package ‘lme4’ in R (R Development Core Team 2010), and used the package ‘glmulti’ to facilitate multi-model inference based on every possible first-order combination of predictor variables (Calcagno 2010). This package also calculated selection probabilities for each variable, from which we could infer their relative importance. We incorporated a null predictor into the model, with which to identify those predictors with a genuine effect on household production (Boughey et al. 2011).

Mean weekly production rates were calculated separately for each household for the most frequently-produced or harvested agricultural, extractive and fishing resources. Key household and community-level variables were identified and incorporated as predictors, with households nested within a community, which was included as a random variable.

Household-level variables were: ‘family size’ (total number of people in the household membership); ‘residence period’ (the number of years the family had been in residence in its current community); ‘welfare income’ (the mean weekly payment received by the household in the form of government and nongovernment support grants); and ‘labour income’ (the mean weekly household income derived from casual labour and state employment).

Community-level variables were: ‘community size’ (the number of households within any given community); ‘community age’ (the number of years the community had occupied that location); ‘forest type’ (measured as the proportion of all land (78.5 km^2) within a 5-km radius from the community centre comprised of várzea forest rather than terra firme forest or a permanent water-body); and ‘distance to town’ (the low-water fluvial distance (km) from the community to the municipal urban centre, Carauari; Fig. 2.1). The landscape metric describing the forest type was generated in ArcGIS 9.3 using a 5-km buffer zone around each community, overlain onto a shapefile of vegetation types obtained from the Projeto RADAMBRASIL (1977) survey. This may be the best available proxy for distinguishing forest types within the RDS Uacari, compared to Shuttle Radar Topography Mission (SRTM) digital elevation data or alternative vegetation classifications (SDS 2010). Since forest type was measured as the proportion of várzea forest, it follows that a negative model coefficient for this variable indicates that an increased availability of terra firme forest (negatively correlated with várzea forest) has a positive influence on the modelled variable. The network analyst extension of ArcGIS was used to generate the 'distance to town' variable, based on the WWF hydrosheds river network data (Lehner et al. 2006). The buffer distance was set at 5-km for both 'forest type' and 'population density' (see below). Although linear distances can only be a proxy for tropical forest accessibility, which is heavily influenced by navigable watercourses and existing forest trails, survey data and local information suggested that a 5-km radius was an approximate mean boundary threshold of resource extraction.

2.4 Results

2.4.1 Weekly surveys of livelihood activities

The large number of cultivated and harvested products reported over the entire study were grouped based on congruence of their local names and their end-use functionality, including 21 agricultural products, 20 timber and non-timber forest extractive resources and 17 clades (families) of fish.

Many households also gained income from other sources, including employment by the state (as health agents, school boat drivers, research assistants and in schools; 52 households); employment by neighbours (usually as chainsaw operators or other manual work; 21 households); and from state benefits including *Bolsa Família* (a family welfare allowance from the federal government; 132 households), *Bolsa Floresta* (a payment for environmental services from a non-governmental organisation (NGO); 70 households), and state pensions for elderly or disabled people (25 households).

2.4.1.1 Frequency of resource yield

A total of 17,121 yield events were recorded across the 82 focal households. The frequency of events for the three most frequently-recorded resources in each activity category considered individually was strongly correlated with the quantity produced or extracted ($r > 0.5$, $p < 0.001$). The number of yield events was therefore a good proxy indicator for comparing the extent of production and extraction of different resources whose quantities were unavoidably measured using different currencies.

Each activity type was dominated by the frequent production or extraction of a small number of key resource commodities. Agricultural activity was focused primarily on the production of *farinha* (dry manioc flour) from the tubers of *Manihot esculenta*, a staple carbohydrate that accounted for 63% of all agricultural yield events (Table 2.1).

A total of only eight products, including manioc flour and a number of fruits, collectively accounted for 95% of all events with a further 12 infrequently-recorded products jointly summing to 5%. Similarly, forest extractivism was dominated by the collection of firewood (40% of all events), although *açaí* (fruit of the slender palm *Euterpe* spp.) and rubber (latex of *Hevea* spp.) were also frequently extracted (21% and 10% of events, respectively). Eleven resources accounted for 95% of events and a further nine accounted for the remaining 5% (Table 2.1). Seventeen families of fish were recorded in the catches of the study households, the most frequent family of which (Characidae: e.g. *Pygocentrus* spp., *Colossoma* spp., *Brycon* spp.) included piranhas, tambaquis and pacus, accounting for 44% of all catches. Catfishes (Pimelodidae) and cichlids (Cichlidae) were the second and third highest ranking amongst the eight fish families that accounted for 95% of all fishing events (Table 2.1).

2.4.1.2 Local consumption vs. sales

For each of the three activity types, consumption accounted for most yield events, indicating that commercial trade was of secondary importance to subsistence in the livelihood strategies of these rural Amazonians (Table 2.1). However, the relative extent of consumption and sale varied both between activity categories and resource types.

Only 12% of all 8,805 recorded fish catches were sold, compared to the 20% of 3,969 extracted forest resources. However, the proportion of agricultural products that were sold was much higher (42%), indicating that a greater proportion of cash income is derived from plant cultivars rather than from harvesting of wild resources. This trend was mirrored by the mean quantity of resources sold, with fish, forest products and agricultural resources respectively accounting for 8%, 37% and 55% of all resource units (17,121) recorded (Table 2.1).

All agricultural products, extractive resources and fish species were consumed locally by a minimum of one household at least once. However, many resources were

Table 2.1. *The principal agricultural, forest and fish resources produced and extracted by 82 households in the Médio Juruá region of Amazonas. Within each activity category, the resources that jointly accounted for 95% of all yield events are listed together with the proportion of all events accounted for by that resource and the volumetric proportion that was consumed locally or sold. The total number of events and total quantity pertaining to each resource is summarised in the final columns. Rows labelled 'Total' show the sum proportion of events and the mean proportion of the quantity consumed locally or sold. Resources for which ≥80% of yield volume was either consumed or sold are highlighted in grey. Fishing events are shown from only two surveyed days per week, on the basis of weekly household-scale surveys. 'inds' = individuals.*

Activity category	**Product (*local name*)**	**Species, genus or family**	**Locally consumed**		**Sold**		**Total**		
			Prop. events	**Prop. quantity**	**Prop. events**	**Prop. quantity**	**No. events**	**Quantity**	**Units**
Agriculture	Manioc	*Manihot esculenta*	0.36	0.31	0.27	0.69	2,734	5,164	50-kg sacks
	Banana	*Musa* spp.	0.08	0.20	0.06	0.80	631	3,931	bunches
	Lime	*Citrus aurantifolia*	0.00	0.01	0.04	0.99	186	55,978	inds
	Watermelon	*Citrullus lanatus*	0.03	0.89	0.00	0.11	147	4,197	inds
	Papaya	*Carica papaya*	0.01	0.03	0.03	0.97	146	3,969	inds
	Palm fruit - *pupunha*	*Bactris gasipaes*	0.02	0.52	0.01	0.48	134	671	bunches
	Yam	*Dioscorea* spp.	0.02	0.90	0.00	0.10	75	1,238	kgs
	Avacado	*Persea americana*	0.01	0.77	0.00	0.23	65	2,202	inds
	12 other resources	Various species	0.04	N/A	0.01	N/A	229	N/A	N/A
		Total	0.58	0.45	0.42	0.55	4,347		
Forest extractivism	Firewood	Various species	0.40	1.00	0.00	0.00	1,584	1,635	branches
	Palm fruit - *açaí*	*Euterpe* spp.	0.19	0.72	0.02	0.28	820	3,460	18-litre tins
	Rubber	*Heavea* spp.	0.02	0.20	0.08	0.80	407	7,783	litres
	Palm fruit - *tucumã*	*Astrocaryum aculeatum*	0.05	0.99	0.00	0.01	215	6,064	inds
	Honey	Various bee species	0.01	0.26	0.04	0.74	196	588	litres
	Seeds - *andiroba*	*Carapa guianensis*	0.01	0.18	0.03	0.82	160	1,966	18-litre tins
	Seeds - *murumuru*	*Astrocaryum murumuru*	0.00	0.06	0.02	0.94	109	1,288	18-litre tins
	Fruit - other	Various species	0.03	0.95	0.00	0.05	103	2,836	inds
	Timber - other	Various species	0.01	0.77	0.00	0.23	73	491	trees
	Timber - construction	Various species	0.02	0.99	0.00	0.01	62	91	metres
	Bark	Various species	0.01	0.86	0.00	0.14	58	343	metres
	9 other resources	Various species	0.04	N/A	0.01	N/A	182	N/A	N/A
		Total	0.80	0.63	0.20	0.37	3,969		
Fishing	*Tambaquí, pacu, piranha* etc	*Characidae*	0.41	0.96	0.03	0.04	3,936	64,558	inds
	Surubim, mandim, pirarara etc	*Pimelodidae*	0.12	0.68	0.07	0.32	1,710	10,362	inds
	Tucunaré, carauaçú etc	*Cichlidae*	0.08	0.98	0.00	0.02	674	4,309	inds
	Jaraquí, curimatã	*Prochilodontidae*	0.07	1.00	0.00	0.00	605	4,594	inds
	Piau	*Anostomidae*	0.07	0.97	0.00	0.03	598	6,147	inds
	Aruanã, piraracu	*Osteoglossidae*	0.05	0.75	0.01	0.25	507	1,853	inds
	Bodó	*Loricariidae*	0.03	1.00	0.00	0.00	270	4,587	inds
	Cascuda, branquinha	*Curimatidae*	0.01	1.00	0.00	0.00	125	4,231	inds
	9 other families	Various species	0.04	N/A	0.00	N/A	380	N/A	N/A
		Total	0.88	0.92	0.12	0.08	8,805		

consumed locally but never sold, and the ratio of local consumption to sales was highly variable. Resources predominantly (≥80%) produced or exploited for commercial purposes included cultivated fruits (bananas, limes and papayas), rubber (*Hevea* spp. latex) and oilseeds (*Carapa guianensis* and *Astrocaryum murumuru*), rather than fish. Conversely, a number of resources were primarily consumed locally, including two agricultural (watermelons and yams), five forest extractive (firewood, construction timber, the bark of various tree species, and fruits from *tucumã* palms (*Astrocaryum tucuma*) and other tree species), and six of the eight top-ranking fish families (Table 2.1).

2.4.2 Spatial variance in livelihood strategies

Quantifying livelihood strategies based on self-reporting by households and communities, local consumption was more prevalent than trade. Of 180 respondent households across 27 communities, all reported engaging in agricultural, forest extractivism and fishing activities for subsistence. However, only a fraction of these households and communities reported sales of these major resource types: 144 households in 27 communities sold agricultural products; 141 households in 24 communities sold timber and non-timber resources; and 98 households in 22 communities sold fish.

The ten focal communities within which we obtained detailed weekly survey data shared similar activity profiles in terms of the production and harvesting of resources for subsistence, but varied widely in the extent to which they generated income from these activities. There was little variation across communities in the relative partitioning of engagement between agricultural, extractive and fishing activities for consumption, as indicated both by the overall frequency of events in each category (Fig. 2.2) and by the monetary value accrued from each activity type (Fig. 2.2). In contrast, there was a large degree of heterogeneity in the frequency of activities for income-generation (Fig. 2.2) and the proportion of community-level income derived from each activity type (Fig. 2.2).

Engagement with alternative income-generating activities showed a high degree of congruence between households belonging to the same community. All of the 82 weekly-surveyed households gained over half of their total annual income from a single activity type (mean ± SD proportion of total income from this activity = 0.85 ± 0.14) and so self-assessed ranking of activity importance proved to be a good proxy for

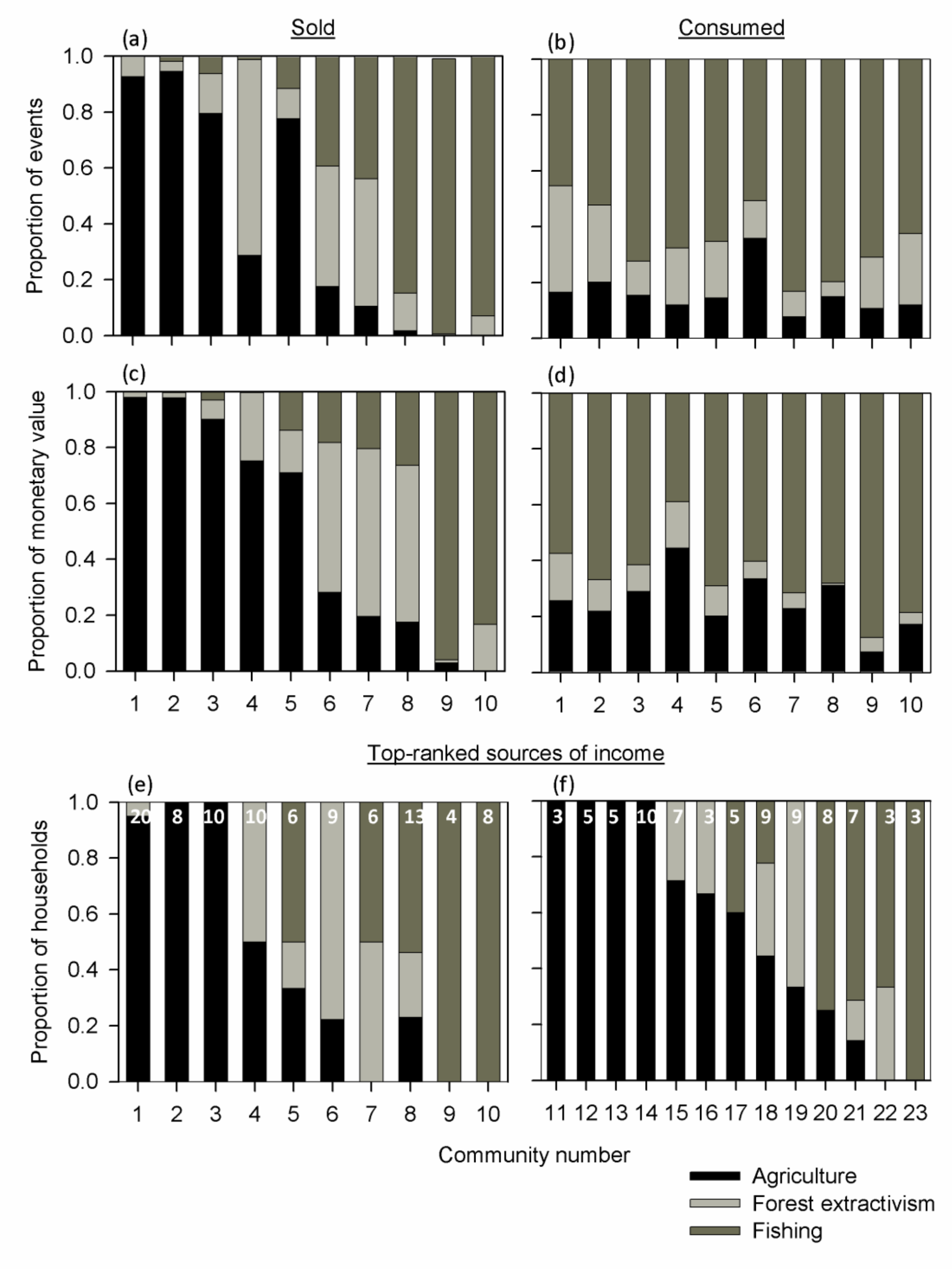

Figure 2.2. *Variation in livelihood strategies by rural Amazonians in the Médio Juruá region of Amazonas. On the basis of weekly surveys of 82 households: the relative frequency with which communities engaged in agrarian, extractive and fishing activities for (a) sale and (b) local consumption; the relative monetary value of resources produced or extracted for (c) sale and (d) local consumption. On the basis of one-off interviews of xx households: the relative frequency with which each activity was ranked as the principal income-generating activity by households within communities (e) surveyed on a weekly basis and (f) for which no comparable weekly survey data are available. The number of households surveyed and interviewed in each community are indicated at the top of the bars (e, f). In (a) and (b), fishing events are shown from only the two surveyed days per week.*

community activity profiles (strong congruence between Fig. 2.2c and e). In 65 of 82 cases, the highest-ranked activity from weekly survey data matched that of the household’s own assessment. The rankings reported by communities that were not surveyed on a weekly basis (Fig. 2.2) can therefore be interpreted as a fair approximation of community livelihood strategies on a wider spatial scale.

Households within a community were much more likely to converge in their principal income-generating activity than would be expected by chance (Fig. 2.2), indicating that household activity profiles be reflected at the community-wide level. Only three communities contained at least one household engaged primarily in each of the three activities. In nine out of 27 communities, all households ranked the same activity as being their most important income-generator and households in the other 15 communities reported just two of the three activities as their principal income source.

2.4.3 Temporal variation in resource use

The heaviest rainfall in the Juruá region was in November – April but water levels lagged this by ~14 weeks (Fig. 2.3). The várzea forest was therefore usually accessible on foot for the second half of each year, but was inundated by up to ~11 m of water between January and June.

Weekly surveys of resource use indicated significant variation in the relative consistency of monthly offtakes of the main resources in each of the three activity categories. The principal agrarian and fish resources were less variable over time than extractive plant products, with greater monthly variation in the proportion of the total annual harvest derived from the three most frequently-extracted plant resources than from the other two activity types (e.g. variance in monthly offtake of manioc = 0.001, rubber = 0.013, *açaí* = 0.012; Fig. 2.3). Firewood, the most frequently extracted class of plant products, was collected throughout the year, but *açaí* fruits were only available during the mid-wet to early-dry season (January – June), and rubber was tapped only between July and December. The proportion of the total harvest of the three most important fish families peaked during the dry season (May - August), though these were caught throughout the year.

2.4.4 Determinants of production and extraction of key resources

We have shown that livelihood strategies of reserve residents were dedicated to relatively few key resources, despite the overall high diversity of resources produced or

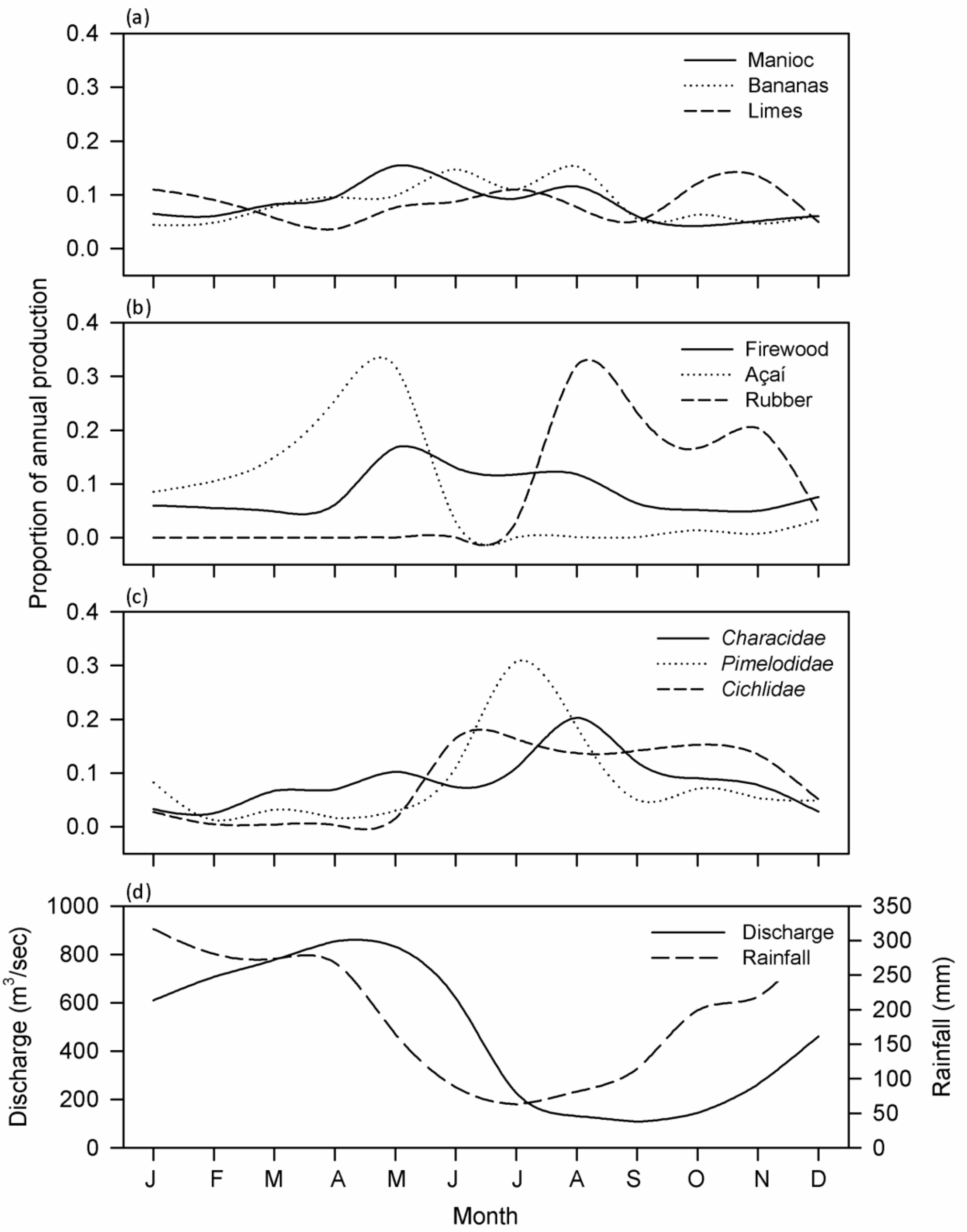

Figure 2.3. *Temporal variation in the yield rates of the three main resource types produced or extracted in the study reserves, as measured by the monthly proportion of (a) agricultural, (b) extractive, and (c) fish yields in relation to annual totals. Principal resources illustrated in each case are those that accounted for the greatest number of events in each activity category (see Table 2.1). The monthly variation (d) in mean rainfall is as measured at the Eirunepé meteorological station (2000-10) and mean discharge (m*^{3}*/sec) is of the Juruá River measured at Porto Gavião, Carauari (1972-94) (Source: Petrobras).*

extracted. The best single models for the production and extraction of these four resources had only intermediate or low Akaike weights (manioc: $\omega_i = 0.74$, firewood: $\omega_i = 0.69$, *açaí*: $\omega_i = 0.41$; characid fish: $\omega_i = 0.51$) suggesting uncertainty relative to alternative models and supporting the use of a model-averaging approach (Table 2.2). Production of manioc and extraction of all other resources were explained by two to five alternative models forming the 95% set of models (summed $\omega_i \geq 0.95$).

The best model for manioc production and firewood and characid fish extraction included the variable forest type, which appeared in at least half of all models in the 95% set for all these resources. Negative relationships between this variable and manioc production and firewood extraction indicate the importance of terra firme forest in predicting offtake of these resources, whilst a positive relationship with characid fish extraction suggests that larger spatial extents of várzea forest were associated with greater offtake of aquatic resources. The high sum of Akaike weights for the variable forest type for all three resources (Table 2.2) corroborates its importance for any model. The landscape structure in the general neighbourhood of settlements was therefore clearly a good indicator of relative effort allocated to agricultural, fishing, and other extractive activities. However, while the Akaike weight for forest type in the model set for *açaí* extraction was moderately high ($\omega_i = 0.27$), this compared unfavourably with the null predictor (upper 95% percentile $\omega_i = 0.36$), casting doubt on the importance of local forest composition for *açaí* harvest levels.

Family size was also included within all of the model sets, but only within the model set for *açaí* extraction did the sum of Akaike weights ($\omega_i = 0.57$) compare favourably against the null predictor. Higher labour input from larger families resulted in greater weekly volumes of these palm fruits.

2.4.5 Forest type

Forest type was used as a proxy for relative accessibility of different forest habitats by community members. The variable was a strong predictor of household offtake in three of the four top-ranking model sets. Mean household production of manioc and collection of firewood were negatively correlated with the extent of flooded forests within a 5-km radius of the community, whereas communities largely surrounded by flooded forest exhibited higher yields of characid fish.

Table 2.2. *Summary of multi-level mixed effects models of mean weekly production or extraction of (a) manioc flour, (b) firewood, (c)* açaí *fruit and (d) characid fish by 82 households in the Médio Juruá region of the Brazilian state of Amazonas. All models that make up 95% of the sum Akaike weight (*ω_i*) are shown. Variables included in each model are shaded grey. Model averaged Akaike weights for each variable are indicated in the first model of each set. In the logarithmic notation used for β and variance, 1.58E-01 indicates 1.58 x* 10^{-1}.

Resource	No. models in 95% set	Model no.		Household covariates				Community covariates				Null predictor	IC	Δ IC	ω_i
			Intercept	Family size	Residence period	Welfare income	Labour income	Community size	Community age	Forest type	Distance to town				
(a) Log no. sacks of manioc flour per week	3	1	1.00	0.21	0.00	0.00	0.00	0.01	0.00	0.94	0.00	0.37	48.22	0.00	0.74
		2	▨	▨						▨			50.92	2.70	0.19
		3	▨										54.27	6.06	0.04
		β	1.06E+00	3.42E-02	-6.86E-03	-1.34E-03	8.60E-04	1.10E-01	-3.75E-01	-2.60E-01	-1.43E-01				
		variance	1.58E-01	4.57E-08	1.73E-06	1.48E-11	5.82E-13	5.06E-04	7.61E-02	3.72E-02	1.24E-02				
(b) Log no. branches of firewood per week	6	1	1.00	0.14	0.01	0.00	0.00	0.03	0.04	0.87	0.01	0.67	274.10	0.00	0.69
		2	▨	▨						▨			277.80	3.70	0.11
		3	▨										278.07	3.96	0.10
		4	▨						▨	▨			280.36	6.26	0.03
		5	▨					▨		▨			281.43	7.32	0.02
		6	▨	▨									281.48	7.38	0.02
		β	8.12E+00	8.73E-02	7.56E-02	8.62E-03	-2.04E-02	6.06E-02	6.30E-01	-4.16E+00	4.51E-03				
		variance	7.39E-01	2.07E-07	5.53E-05	7.67E-09	3.88E-07	1.84E-03	1.79E-01	1.29E-01	7.83E-10				
(c) Log no. 18-litre tins of *açaí* fruit per week	4	1	1.00	0.57	0.00	0.00	0.00	0.00	0.01	0.27	0.00	0.36	21.15	0.00	0.41
		2	▨										21.72	0.57	0.31
		3	▨	▨						▨			23.19	2.04	0.15
		4	▨							▨			23.69	2.54	0.12
		β	2.07E-01	3.34E-02	5.19E-01	-1.60E-01	1.26E-03	1.74E-02	1.47E-03	-5.59E-02	-1.15E-03				
		variance	5.93E-03	8.47E-08	1.40E-01	2.46E-03	5.21E-12	6.88E-06	2.72E-10	8.90E-05	1.09E-12				
(d) Log no. characid fish per week	5	1	1.00	0.10	0.01	0.00	0.00	0.01	0.04	0.60	0.00	0.48	126.99	0.00	0.51
		2	▨										127.80	0.80	0.34
		3	▨	▨						▨			131.40	4.40	0.06
		4	▨	▨									132.26	5.27	0.04
		5	▨						▨	▨			133.10	6.11	0.02
		β	1.66E+00	2.02E-01	2.30E-01	-4.82E-01	3.75E-01	-1.90E-03	2.46E-01	1.43E+00	5.36E-02				
		variance	7.74E-03	7.17E-03	7.56E-03	1.68E-01	3.65E-02	4.84E-09	1.45E-02	2.44E-01	3.26E-05				

The number of 50-kg sacks of manioc flour produced by households surveyed each week was highly correlated with an alternative measure of manioc production, namely the number of manioc stems that those households reported to have planted most recently in swidden fields (r = 0.847, $N = 78$, $p < 0.001$). This indicates both that interviewees were able to accurately report their current manioc crop size and that there was a strong linear relationship between crop size and agricultural output. We therefore used crop size (the number of planted stems reported by all 181 interviewed households) as a proxy for manioc production, and tested the relationship between crop size and terra firme availability (the proportion of terra firme forest within this 5-km radius) for all households. Mean crop size per community was strongly correlated with the availability of terra firme (r = 0.782, $N = 27$, $p < 0.001$; Fig. 2.4), and thus predicted the extent of agrarian effort throughout the two reserves and not just those 10 communities surveyed on a weekly basis.

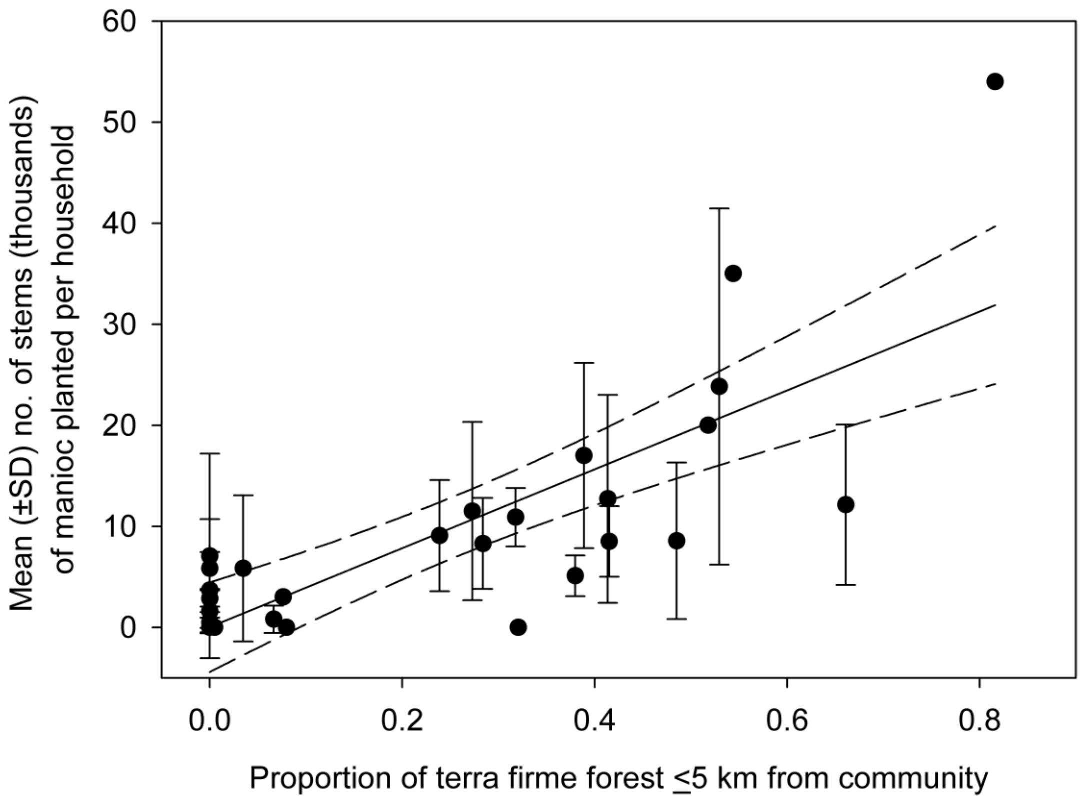

Figure 2.4. *The influence of the availability of terra firme forest within a 5-km radius of 27 communities on manioc production, based on the number of stems planted per household per community (mean ± SD). Solid and dashed lines indicate the overall linear regression and 95% confidence intervals, respectively.*

This dependence on terra firme land for agricultural production is further emphasised by the significant difference in forest landscape structure between nine communities reporting no sales of processed manioc and 17 communities that derived at least some income from manioc sales (proportion of várzea forest for non-trading communities = 0.86 ± 0.10; proportion of várzea forest for trading communities = 0.57 ± 0.21; t-test: $t = 4.639$, $p < 0.001$). Communities whose operational forest cover contained a high proportion of seasonally flooded forest tended to produce sufficient manioc for subsistence only.

2.5 Discussion

2.5.1 Overview

Common to all households were the imperatives of manioc cultivation as the staple carbohydrate, fishing as a principal source of protein and the harvest of timber and non-timber forest products for food, fuel, and the construction of houses and canoes. However, there was considerable variation between livelihood strategies of individual households within this study system, particularly with respect to the main income-generating activities with which they engaged. We now discuss how understanding the biophysical and demographic factors that influence this variation can be important to reserve managers and agencies wishing to implement development and subsidy programmes designed to modulate the behaviour of rural Amazonians.

2.5.2 Extractive reserves or agricultural enclaves within a forest landscape?

The extractive reserve concept originally sought to ensure land-tenure rights for traditional communities, though this subsequently broadened to additionally juxtapose biodiversity conservation objectives. Whilst manioc cultivation has traditionally been a means of producing *farinha* for subsistence in rural areas, it was implicit within the extractive reserve philosophy that Amazonians living within these reserves would engage primarily in extractive activities that exploited NTFPs such as rubber, Brazil nuts, *copaíba* oleoresin, and *andiroba* oil for income-generation (Fearnside 1989). Yet our results suggest that a large proportion of income in some households is derived from agricultural products, often with minimal engagement in commercial extractivism. This finding accords with the temporal shift away from forest extractivism and towards agricultural and ranching activities documented in other Amazonian agro-extractive systems (Ruiz-Perez et al. 2005; Salisbury and Schmink 2007; Vadjunec and Rocheleau

2009). Whilst this study focuses on only two of 199 extractive reserves currently decreed in Brazilian Amazonia, the Médio Juruá reserves are widely renowned as containing some of the most "traditional" communities of forest extractivists.

2.5.3 Subsistence and cash economies

Our figures suggest that the relative frequency of, and inferred monetary value derived from, the three main activity categories was much more similar for subsistence than for commercial trade. We therefore infer that most reserve residents have access to the full complement of resources required to maintain their livelihoods from a subsistence perspective, but that local resource availability largely determines which products are sufficiently abundant to enable surplus offtake to be sold.

2.5.4 Temporal variation

Most communities with immediate access to unflooded terrain planted small swidden fields of manioc in August, subsequently harvesting and processing the tubers to produce *farinha* throughout the year. Manioc cultivation thus provided these communities with a consistent source of year-round food and income.

In contrast, many of the most commercially-important NTFPs in this system were highly seasonal in their availability. Fruits and seeds, such as *açaí* fruits (*Euterpe* spp.) and the oilseeds of *Carapa guianensis*, are only a viable source of income during their fruiting season, and overall abundance may be subject to large supra-annual variation in fruit crop sizes (Bhat et al. 2003). *Hevea* spp. trees may produce rubber all year round but commercially-exploited congeners are restricted to floodplain forest, which is only accessible on foot between August and December. Some terra firme NTFPs such as lianas and understory palms are available all year, but these are generally harvested for local consumption (e.g. construction) rather than sale.

2.5.5 Convergence between households within a community

Our models suggest that shared geographic constraints within the community catchment area represent key factors in the close congruence between household livelihood strategies within a given community. If the viability and profitability of alternative activities is determined by common community-level variables such as forest type, distance to markets, fluvial location, or communal ownership of large boats, then we would expect to see nested choices of activity engagement amongst neighbours.

Additionally, the distinct social structure of these rural populations is such that communities often consist of one or more extended families bounded by kinship ties. Households within a particular community are thus more genetically related, as well as physically and socially connected. Family traditions, including their cultural or religious preferences and taboos, may therefore also contribute to intra-community congruence in lifestyles.

Regardless of the underlying drivers of the consistent tendency for households within communities to adopt similar livelihood strategies, this has implications for researchers and managers wishing to rapidly gauge the distribution of activity engagement across protected areas. Moreover, the ~80% similarity between detailed weekly survey data at the level of households and one-off self-assessments of principal income-generating activities at the level of communities suggests that targeted interviews yield good proxy responses to at least some questions about resource-use decision-making.

2.5.6 Agriculture

Engagement in agriculture was largely explained by the predominant forest type in the vicinity of each community. The number of manioc stems (which scales linearly with swidden field size) currently planted by a household was also a good predictor of agricultural productivity, confirming that the explanatory variable we identified through our models applied over a larger number of communities. Perennial crops like manioc require permanently unflooded land, since tubers typically require 12 months to attain a suitable harvest size. Households with limited access to terra firme land often cultivated manioc gardens within várzea habitat (on seasonally-exposed beaches and floodplains), but harvested them after only six months and before the flood pulse, thereby enabling production of just enough *farinha* to meet their own subsistence needs. This reliance on swidden fields created in areas of terra firme forest for manioc agriculture has implications for PES programmes such as *Bolsa Floresta*, which seek to maintain environmental services by restricting further forest clearance (Viana 2008).

2.5.7 Forest extractivism

The most frequently harvested class of forest product – firewood – was unsurprisingly collected throughout the year but this seldom amounted to a destructive means of timber harvesting since dead wood is usually collected off the ground, often from cleared swidden fields. The propensity for households in settlements with a relatively high proportion of neighbouring terra firme forest to collect more firewood was largely a result of higher demand; firewood was primarily collected to fuel the large ovens required for the *farinha*-making process, whereas butane gas was the most common fuel for domestic cooking. Changes in agrarian activities may thus directly affect the harvest of this resource.

Commercial dependence on forest extractivism was not homogenous across the reserve communities. Whilst we did not model the extraction of any of the most significant economically-exploited NTFPs (e.g. *andiroba* and *murumuru* seeds, and latex from rubber trees), the widespread occurrence of these resources in flooded forest and their absence from terra firme forest indicates greater engagement in commercial trade of NTFPs by communities with greater access to the former forest type.

These commercially-valuable NTFPs, similarly to manioc but in contrast to most fish, were relatively high-value per unit weight commodities and, critically, were non-perishable and could thus endure the inevitable delay between harvest and sale. These commodities also enjoyed relatively secure purchase quotas and markets, with annually-determined buying prices guaranteed by local residents' associations and cooperatives. Indeed, a prioritised goal of government agencies and NGOs involved in rural livelihood development in rural Amazonia has been the promotion of extractive industries as a means of augmenting household incomes (Belcher et al. 2005). In our study reserves, a community-run cooperative extracts *andiroba* oil from *Carapa guianensis* seeds, selling the oil wholesale to a large cosmetic company (Natura 2007). Smaller-scale projects have included establishing meliponiculture of native stingless bee hives in some communities, and training and equipping reserve residents to extract *Copaifera* oleoresin (Newton et al. 2011). Implementation of these projects has tended to assume a 'one-size-fits-all' approach, whereas our data clearly show that resource accessibility and current livelihood practises are not uniform, and may strongly influence the uptake and success of each of these initiatives. The development of extractive industries therefore demands consideration of the historical, socioeconomic, and especially the geographic context within which they are being introduced.

Further, the plethora of government subsidies associated with many NTFPs makes an accurate analysis of their true value to household economies very difficult, since many of the more economically-significant NTFPs benefit from both direct and indirect subsidies. A combination of direct government and NGO subsidies, for example, maintains the buying price of rubber at a level at which it remains profitable for reserve residents to continue to extract it. Less directly, the offtake volume of *andiroba* seeds required by the cooperative is allocated to all participating communities on an equitable quota system. The seeds are then collected from each community by the cooperative's own boat, effectively removing the usual diminishing returns of transport costs incurred by producers living farther from markets.

Yet studying extractive systems embroiled in subsidies and welfare payments is worthwhile, since this increasingly represents the way in which extractive reserves are operating. Such an approach may prove to be a sustainable way to overcome the problems of fluctuating markets, diminishing profits with increasing travel distances, and local overexploitation of natural resources that are frequently associated with extractive systems (Belcher and Schreckenberg 2007).

Finally, not all forms of forest extractivism are equally benign or desirable. Manufacturing canoes, for example, involves the removal of an entire tree and thus may not be as sustainable on the same scale as the collection of oilseeds or oleoresins. Although more assessments of the ecological impacts of NTFP harvesting have become available (e.g. Peres et al. 2003; Ticktin 2004; Vadjunec and Rocheleau 2009), resource- or site-specificity is often high and reserve managers need to consider the likely implications of actively encouraging or subsidising forest extractivism.

2.5.8 Fishing

Fishing yields depended on access to rivers, lakes, and seasonally inundated forest. The latter is particularly important at times of year when the main rivers and lakes are less productive and so forest type was again a key predictor of fishing yields. Although commercial fishing was prohibited within many of the reserves' oxbow lakes, this was the principal income-generating activity for some communities. This specialisation required cold-storage facilities for maintaining fish catches, and long-term arrangement with commercial fishing boats that would periodically bulk-buy captured stock. For the majority of communities, travel time to urban markets precluded frequent sale of perishable fish catches.

2.5.9 Drivers of variation

None of the demographic variables examined here were significant predictors of household resource offtake. However, communities enjoying greater access to terra firme forest tended to be larger, with implications for longer-term planning of reserve settlements. Communities are often transient and frequently relocate, particularly with respect to meandering river channels in highly dynamic fluvial systems like the Juruá (Abizaid 2005).

Forest landscape composition captured the physical geography of the area around settlements. Measured as relative proportions of terra firme and várzea forest, this variable was consistently the strongest predictor of mean weekly household offtake of key agrarian and extractive resources. Although the size of communities' catchment areas, from within which most of their resources are harvested, is likely to be a function of numerous factors including transport infrastructure, resource demand, and local spatial configuration of fluvial and forest systems, the partition of neighbouring forest into terra firme and várzea forest is clearly an important influence on the relative utilisation of different resource types. Therefore, whilst other factors may affect aggregate resource-use decisions on a wider spatial scale, we suggest that local variation in livelihood strategy may largely be determined by the distribution of forest types in reserves and landscapes elsewhere.

2.5.10 Conclusions

Understanding spatial and temporal patterns of resource use and availability within multiple-use tropical forest reserves is critical in helping managers to effect change within dynamic demographic and economic scenarios. Our data add to the body of evidence suggesting that, in terms of local patterns of subsistence and income, agriculture may be equally, if not more, important than extractivism of fish and forest products in many Amazonian reserves (e.g. Salisbury and Schmink 2007). However, we additionally demonstrate that the significant temporal and spatial variation in the livelihood strategies employed by rural Amazonians living in communities within these reserves may be largely driven by local geography and consequent resource accessibility. This finding complements those from similar agro-extractivist systems, where livelihood strategy is dictated by land tenure (e.g. Takasaki et al. 2001). Given the wide heterogeneity in economic profiles even within the same geographic area, we suggest that careful consideration should be paid to the non-uniform impacts that the implementation of development programmes (such as the promotion of new extractive activities), the enforcement of reserve regulations from reserve management plans, and the introduction of PES and welfare subsidies may have within multiple-use protected areas.

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Chapter 3

Variation across a range of scales in the density and spatial distribution of a neotropical non-timber forest resource

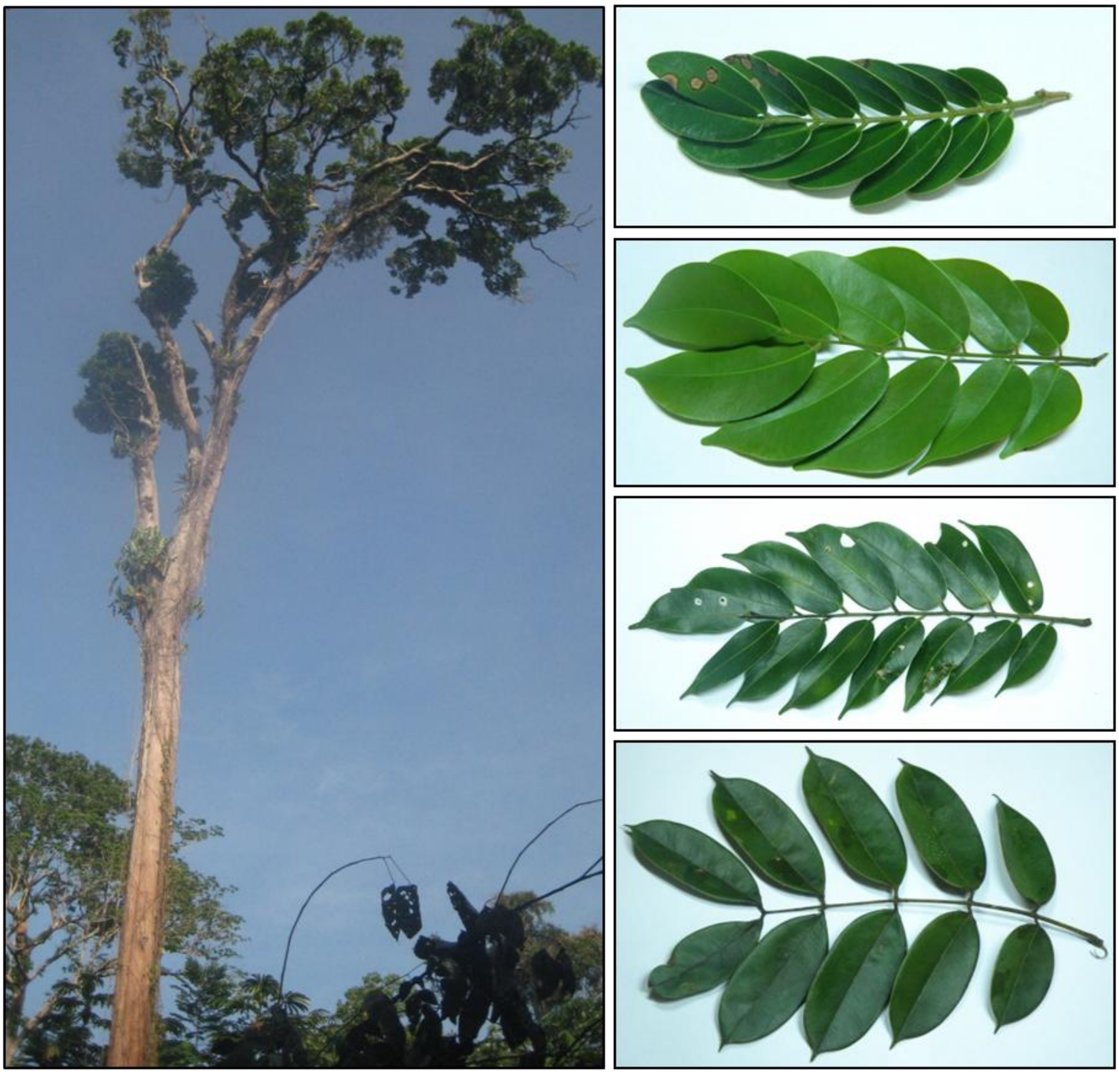

Photo: *Copaifera* species in the Médio Juruá region

3.1 Abstract

Successful management of tropical forest resources depends upon an understanding of their patterns of density and spatial distribution, since these affect the potential for harvesting. The variation in these patterns across different spatial scales has rarely been explored. We assessed the extent to which different spatial scales are useful in understanding resource distribution, using the example of an economically-significant tropical tree genus, *Copaifera*, which is valued in Brazilian Amazonia for its medicinal oleoresin. We mapped the spatial distribution of *Copaifera* trees at three nested spatial scales: basin-wide (across Brazilian Amazonia), landscape (across two contiguous extractive reserves) and local (within a 100-ha plot). Using data from our own study and an Amazon-wide forest inventory (Projeto RADAMBRASIL), we quantified the population distribution, density and size structure at the genus and species level at all three scales, relating these to two environmental variables – forest type and elevation. Spatial statistics were used to further characterise the resource at the landscape and local levels. The distribution, density and adult population structure differed between species and forest types at all three spatial scales. Overall tree densities ranged from 0.37 ha^{-1} (basin-wide scale) to 1.13 ha^{-1} (local scale) but varied between forest types, with várzea containing a *Copaifera* tree density just 43% of that in terra firme forest at the landscape scale. Spatial distribution analyses showed significant clumping of some species, especially *C. multijuga* which averaged 61 m between neighbouring trees. We compare our cross-scale density estimates and discuss the relative merits of studying the distribution of tropical non-timber forest products (NTFP) at more than one spatial scale. Our results have implications for the management and extraction of this important Amazonian forest resource.

3.2 Introduction

Historically, there has been considerable interest in the spatial distribution of plants across a range of scales (Erickson 1945; Forman 1964) together with the environmental and demographic factors determining these patterns (Hutchings 1997). The sustainable management of plant resources also depends critically upon an understanding of the spatial distribution and population structure of the harvested species (Boll et al. 2005). This is particularly true of economically important tropical forest resources, which are vulnerable to over-exploitation if appropriate harvest levels are not determined by detailed knowledge of their patterns of distribution and recruitment (Reynolds and Peres

2005). As demand for such resources grows, an understanding of how the spatial distribution of a resource varies may allow managers and extractors to estimate the potential harvest of a resource over space and time.

The scope for understanding patterns of resource distribution is largely determined by the scale at which such patterns are examined, with different spatial scales offering alternative resolutions (Krebs 2009). Spatial heterogeneity in tropical tree distribution has been demonstrated at multiple scales from vast areas covering an entire region (e.g. Tuomisto et al. 2003), to intermediate scales covering landscapes (e.g. Phillips et al. 2003) to small, localized scales (e.g. Hubbell et al. 2001). When economically-important resources are considered, regional scale studies can offer an overview of both the potential for sustainable extraction and the impacts of exploitation (e.g. Peres et al. 2003), whilst landscape scale studies can usefully inform individual resource managers and extractors (e.g. Wadt et al. 2005). Local level studies are invaluable as a basis for detailed analyses of population structure and dynamics (e.g. Klimas et al. 2007) as well as for developing sustainable harvest models incorporating density dependence (e.g. Freckleton et al. 2003).

The distribution of plant species may be influenced by environmental conditions including light, edaphic factors, topography, climate, latitude, and hydrological conditions. However, environmental variables exert varying degrees of influence at different spatial scales (Willis and Whittaker 2002). Species’ ranges may be determined by climatic parameters or geographic boundaries (e.g. Wittmann et al. 2006), whilst landscape-level distribution may be influenced by edaphic or hydrological constraints (e.g. Haugaasen and Peres 2006). In contrast, local distribution patterns may be dictated by small-scale gradients in topography and natural disturbance such as tree-fall gaps (e.g. Valencia et al. 2004), through spatial patterns of recruitment and mortality (Hutchings 1997). The extent to which there is divergence in the environmental variables that best explain patterns of resource heterogeneity at different spatial scales is of interest to researchers and agencies wishing to predict and manage resource populations.

The oleoresin harvested from trees of the genus *Copaifera* is a commercially-important non-timber forest product (NTFP) found throughout the neotropics (Plowden 2004). Extractors drill a hole into the trunk from which oleoresin is drained; if the hole is then plugged, oleoresin deposits may be replenished over time (Newton et al. 2011). The oleoresin is valued for its therapeutic properties, which include those of an anti-inflammatory and analgesic (Veiga Junior and Pinto 2002). Widely harvested and used across Brazilian Amazonia, sales of *Copaifera* oleoresin generated R$4.1 million (≈ USD 2.6 million) in revenue in Brazil in 2009 (IBGE 2011). As a slow-growing hardwood tree, *Copaifera* also historically provided valuable termite-resistant timber in many regions, although extraction for this purpose is now prohibited within most protected areas. The spatial distribution of the genus is not well documented but is thought to be heterogeneous on both a basin-wide (Martins-da-Silva et al. 2008) and landscape scale (Plowden 2003; Rigamonte-Azevedo et al. 2006).

We investigated patterns of *Copaifera* species distribution, richness and abundance at three nested spatial scales: i) basin-wide (across the ~5 million km^2 Brazilian Amazonia); ii) landscape (across a ~900,000 ha area within two contiguous extractive reserves); and iii) local (within a single 100-ha *terra firme* forest plot). The study aimed to: 1) describe the spatial distribution of *Copaifera* at these three scales; and 2) explore how this distribution varied with respect to two key environmental variables: a) forest type; and b) elevation. We ask whether there is congruence between patterns of resource distribution at different spatial scales, and discuss the relative merits of a cross-scale approach in understanding and managing this and other key tropical forest resources.

3.3 Methods

3.3.1 Basin-wide scale

Data were compiled from 2,343 one-hectare (20 m x 500 m) tree plots inventoried in Brazilian Amazonia between 1968 and 1975 as part of the national *Radar na Amazônia* survey programme (Projeto RADAMBRASIL 1982; Fig. 3.1). Within each plot, all trees larger than 100 cm circumference at breast height (CBH), or ≥31.8 cm diameter at breast height (DBH), were measured and identified to genus or species by a plant taxonomist. *Copaifera* is a good model genus for large-scale surveys involving multiple parataxonomists since it is widely used and its distinctive trunk is easily recognizable, thereby reducing the likelihood of both false negatives (failing to record a tree) and false positives (mistakenly identifying a tree of a different genus as a *Copaifera*). For each plot, the number of *Copaifera* trees of each species, the latitude and longitude of the plot location, and a binary measure of forest type (unflooded or seasonally flooded) was recorded.

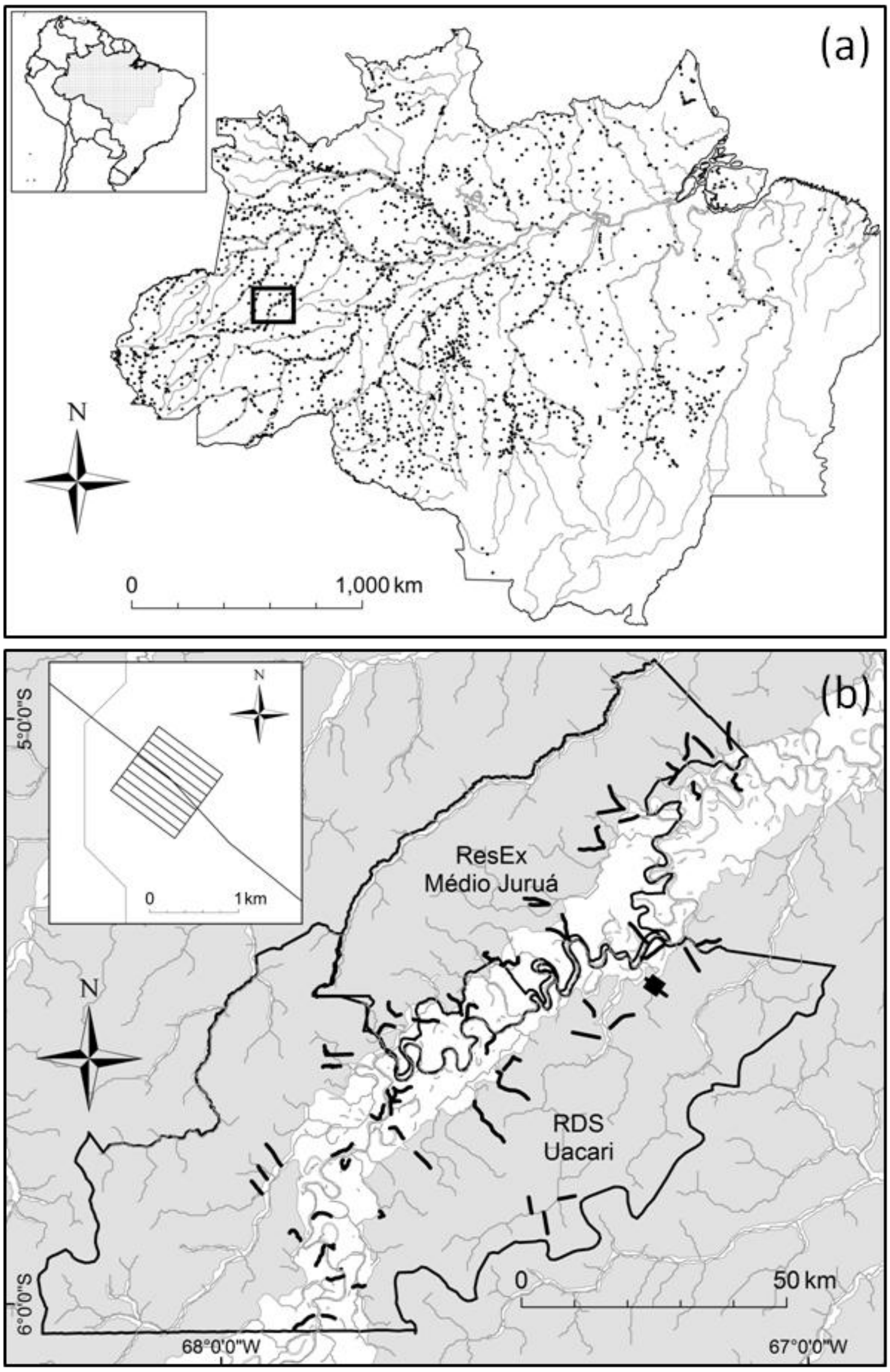

Figure 3.1. *Location of study populations of* Copaifera *spp. at three spatial scales. (a) Dots indicate a total of 2,343 1-ha plots across Brazilian Amazonia (indicated in the shaded inset within South America). The rectangle indicates the area shown in: (b) 63 linear plots (black lines) within and immediately outside the boundaries of the Uacari Sustainable Development Reserve and the Médio Juruá Extractive Reserve in the state of Amazonas. Grey and white areas are terra firme and várzea forest, respectively. The black square indicates the location of a 100-ha plot in terra firme forest, bisected by one of the linear plots (see inset). Rivers are shown in grey in both maps.*

We additionally reviewed the literature for studies that provided data on *Copaifera* densities across lowland Amazonia. These were summarized and tabulated for comparison with the results of this study.

3.3.2 Landscape scale

3.3.2.1 Study Site

The study was conducted within and around two contiguous extractive reserves bisected by the Juruá River, a large white-water tributary of the Amazon (Solimões) River in the state of Amazonas, Brazil. The federally-managed Médio Juruá Extractive Reserve (hereafter, *ResEx Médio Juruá*) occupies 253,227 hectares, whilst the larger, state-managed Uacari Sustainable Development Reserve (hereafter, *RDS Uacari*) is 632,949 hectares (Fig. 3.1). A 10 – 20 km wide band of seasonally inundated (*várzea*) forest spanning the main river channel is subjected to a prolonged flood-pulse every year between January and June, whilst *terra firme* forests on higher elevation have never flooded, at least since the Pleistocene. The elevation is 65 – 170 m above sea level and the terrain is flat or undulating. The area has a wet, tropical climate; daily rainfall records at the Bauana Ecological Field Station (S 5°26' 19.032" W 67°17' 11.688") indicated that 3,659 mm and 4,649 mm of rain fell annually in 2008 and 2009, respectively. All forest within the study site was intact, primary forest that had experienced very little logging activity except for some historical selective removal of key timber species (including *Copaifera* spp.) from várzea forest between 1970 and 1995 (Scelza 2008).

3.3.2.2 Study species

The recent taxonomic review by Martins-da-Silva et al. (2008) recognised nine species of *Copaifera* across Brazilian Amazonia. *Copaifera* species encountered within the study site were identified using the key provided by this monograph before being compared against voucher specimens previously identified by R. Martins-da-Silva in the herbarium of the Botany Department of the Instituto Nacional de Pesquisas da Amazônia (INPA), Manaus. Numbered voucher specimens of each species identified during this study have been deposited at the INPA herbarium.

3.3.2.3 Linear plots

We placed 63 transects of between 2,000 m and 5,000 m in length (mean ± SD = 4,213 ± 953 m) in both terra firme (37 transects) and várzea forest (26 transects) (Fig. 3.1). Each transect was measured using a HipChain®, marked every 50 m with flagging tape and mapped with a high-resolution handheld GPS receiver. Each transect was slowly (~1 km/h) censused on foot (during the dry-season in várzea forest) by a minimum of two experienced observers. All large *Copaifera* trees ≥25 cm DBH encountered within 10 m on either side of the transect were recorded, and their position along the transect recorded to the nearest 50 m. Each tree was identified to species and measured at 1.3 m height, to the nearest 0.1 cm using a standard DBH tape. Each transect was therefore effectively a *linear plot* (hereafter) of 20 m by *l* m, where *l* was the length of the transect, within which all *Copaifera* trees larger than the minimum size threshold were recorded. Line-transect analyses using the DISTANCE 6.0 software (Thomas et al. 2009) on a sub-set of 29 transects for which all trees were recorded, with no maximum perpendicular distance from the transect, showed that the effective strip half-width was 11.2 m. This reaffirmed our detectability confidence that we conducted complete counts of large *Copaifera* trees within our conservative 20-m strip width.

3.3.3 Local scale

We demarcated a 100-ha square plot in terra firme forest approximately 2 km from the Bauana Ecological Field Station in the RDS Uacari reserve (northern plot corner: S 5° 26' 51.288", W 67° 15' 55.800"; Fig. 3.1). This plot contained 11 parallel transects of 1-km length, spaced 100 m apart and connected at both ends by two perpendicular transects of 1-km length. Each transect was measured with a HipChain® and marked with flagging tape every 20 m.

The population of *Copaifera* ≥25 cm DBH was mapped and number-tagged within this plot. Initially, each of the 1-km transects was walked by two observers; subsequently, three observers walked midway between and parallel to the transect lines, recording all adult trees sighted. We recorded the same data as in the linear plots, but additionally each tree was mapped with an *x,y* coordinate to the nearest meter. This was determined by measuring the perpendicular distance from the tree to the nearest transect using a 50-m tape and Suunto® compass, and recording the position along that transect.

3.3.4 Data analysis

The genus and species level distribution (presence/absence), density and adult population structure (based on DBH size classes) were quantified for *Copaifera* trees at all three spatial scales.

3.3.4.1 Basin-wide scale

At the basin-wide scale, minimum convex polygons (incorporating 100% of points) were created using the Home Range Tools extension to ArcGIS 9.3 for each of the five species for which individuals were recorded in at least three plots (Rodgers et al. 2007). *Copaifera* density (stems ha^{-1}) was plotted in ArcGIS at the same scale.

There were discrepancies between the species nomenclature used by Projeto RADAMBRASIL, which was conducted in the 1970s, and those recognized by the most recent taxonomic review of the genus in Brazilian Amazonia (Martins-da-Silva et al. 2008). Here, we report the original species' names recorded by the survey, which were consistent across all plots, but additionally present minimum convex polygons produced from our own digitisation of the species distribution map presented by Martins-da-Silva et al. (2008) based on the gazetteer of collecting localities of herbarium specimens surveyed by that study.

3.3.4.2 Landscape scale

The *Copaifera* population ≥25 cm DBH had been mapped within the linear plots, but extreme edge effects precluded the use of most spatial statistics. Instead, Fortin and Dale's (2005) method was used to assess evidence of pairwise (W_m) and serial (h_m) clumping of trees, treating each linear plot as a one-dimensional line transect.

3.3.4.3 Local scale

Three spatial distribution metrics were calculated for exhaustively mapped *Copaifera* populations at the local scale using the R package 'spatstat' (Baddeley and Turner 2005): i) mean nearest-neighbour distances (NND) were calculated using Clark and Evans' (1954) method, based on the x,y locations of the trees encountered, applying Donnelly's (1978) modification to eliminate edge-effect bias (Krebs 1999); ii) the aggregation index (R) provided an initial indication of whether the population had a clumped, random or uniform distribution. The associated z-value was used to determine whether the observed pattern deviated significantly from an expected random pattern

(Krebs 1999); iii) since *R* does not reliably differentiate an aggregated distribution from an even distribution of regularly sized clumps (Klimas et al. 2007), we used a linearised Ripley's K function *L(r)* with edge correction as a further test of spatial randomness (Goreaud et al. 1999). All spatial statistics were applied to the entire assemblage of *Copaifera* spp. trees, as well as to each species independently.

3.3.4.4 Comparing scales

We divided the 100-ha plot into individual 1-ha subplots (100 m x 100 m) and each linear plot into 0.1-ha subplots (50 m x 20 m). We calculated the elevation (m above sea level) of each subplot from 90-m resolution Shuttle Radar Topography Mission (SRTM) data in ArcGIS 9.3 (Jarvis et al. 2008). Presence and absence of each species was also recorded for each subplot.

We assessed congruence between nested scales by comparing our density estimates within the Médio Juruá study region, using an equal minimum size threshold (≥31.8 cm DBH). Firstly, we selected all RADAMBRASIL 1-ha plots that fell within: i) the two reserves ($N = 12$); and ii) the Juruá watershed ($N = 55$). Secondly, we used the 100 1-ha subplots to assess intra-plot variation in tree density at the local scale, and compared this to the landscape and basin-wide scale data.

3.4 Results

3.4.1 *Copaifera* density, spatial distribution and adult size class structure

3.4.1.1 Basin-wide scale

A total of 864 *Copaifera* trees were recorded within the 2,343 1-ha plots, resulting in an overall mean *Copaifera* density of 0.37 trees ha^{-1}. However, density was not homogenous across the basin, with only 497 (21.2%) of the plots containing one or more *Copaifera* trees (mean density ± SD = 0.37 ± 0.89 trees ha^{-1}; mean density per occupied plot = 1.74 ± 1.15 trees ha^{-1}; Table 3.1). The region north of the Solimões River had relatively low densities of *Copaifera*, whereas a hotspot of elevated tree density was centred on the Madeira and Aripuanã Rivers in southern central Brazilian Amazonia (Fig. 3.2).

Five species of *Copaifera* were identified within these plots, though species richness per plot never exceeded two species per hectare. We mapped the distribution of individual *Copaifera* species across the basin and found a distinct spatial partitioning in species'

Table 3.1. *Comparison of population densities of* Copaifera *tree species from different studies conducted across lowland Amazonia.*

Reference	**Country**	**State**	**Location**	**Species**	**Forest type**	**Area covered**	**Number found**	**Mean density (ind ha^{-1})**	**SD** [a]	**Min size (≥ *x* cm DBH)** [b]
Alencar 1982 [c]	Brazil	Amazonas	Reserva Ducke	*C. multijuga*	terra firme	~ 200 ha	82	~ 0.41		25.0
Ramirez and Arroyo 1990	Venezuela		Los Lanos	*C. pubiflora*		277 ha		1.04		not stated
Phillips et al. 1994	Peru		Madre de Dios	*C. reticulata*	various	7 plot of 1-ha	1	0.14	0.38	10.0
ter Steege and Zondervan 2000	Various		Guiana Shield	*Copaifera* spp.		23 plots of 100-ha	328	0.14	0.38	not stated
Plowden 2001	Brazil	Pará	TI Alto Rio Guamá	*Copaifera* spp.		7 ha	6	0.86		10.0
Rigamonte-Azevedo 2004	Brazil	Acre	3 municípios	*Copaifera* spp.	terra firme	3 plots totalling 37 ha	28	0.74	0.61	rep. adults
Barbosa 2007	Brazil	Amazonas	RDS Tupé	*C. multijuga*	open forest	13 ha	22	1.69		10.0
Medeiros and Vieira 2008 [c]	Brazil	Amazonas	Reserva Ducke	*C. mulitjuga*	terra firme	~ 2,600 ha	43	≥ 0.02		30.0
Chambers et al. 2009	Brazil	Amazonas	Reserva Ducke	*C. multijuga*	terra firme	5 ha	4	0.80		10.0
This study	Brazil		All Amazonian states	*Copaifera* spp.	various	2,343 plots of 1 ha	864	0.37	0.89	31.8
		Amazonas	ResEx Médio Juruá	*Copaifera* spp.		63 plots totalling 530.6 ha	341	0.63	0.52	25.0
			& RDS Uacari	*C. multijuga*	terra firme	37 plots totalling 311.2 ha	66	0.22	0.28	25.0
				C. piresii	terra firme	37 plots totalling 311.2 ha	47	0.14	0.25	25.0
				C. guyanensis	terra firme	37 plots totalling 311.2 ha	150	0.47	0.32	25.0
				C. paupera	terra firme	37 plots totalling 311.2 ha	2	0.01	0.02	25.0
				C. guyanensis	várzea	26 plots totalling 219.4 ha	13	0.05	0.11	25.0
				C. paupera	várzea	26 plots totalling 219.4 ha	63	0.31	0.28	25.0
			RDS Uacari	*Copaifera* spp.	terra firme	100 ha	113	1.13		25.0
				C. multijuga	terra firme	100 ha	51	0.51		25.0
				C. piresii	terra firme	100 ha	24	0.24		25.0
				C. guyanensis	terra firme	100 ha	38	0.38		25.0

[a] Standard deviation calculated for studies that reported densities for >1 plot

[b] DBH = diameter at breast height

[c] Not exhaustive searches

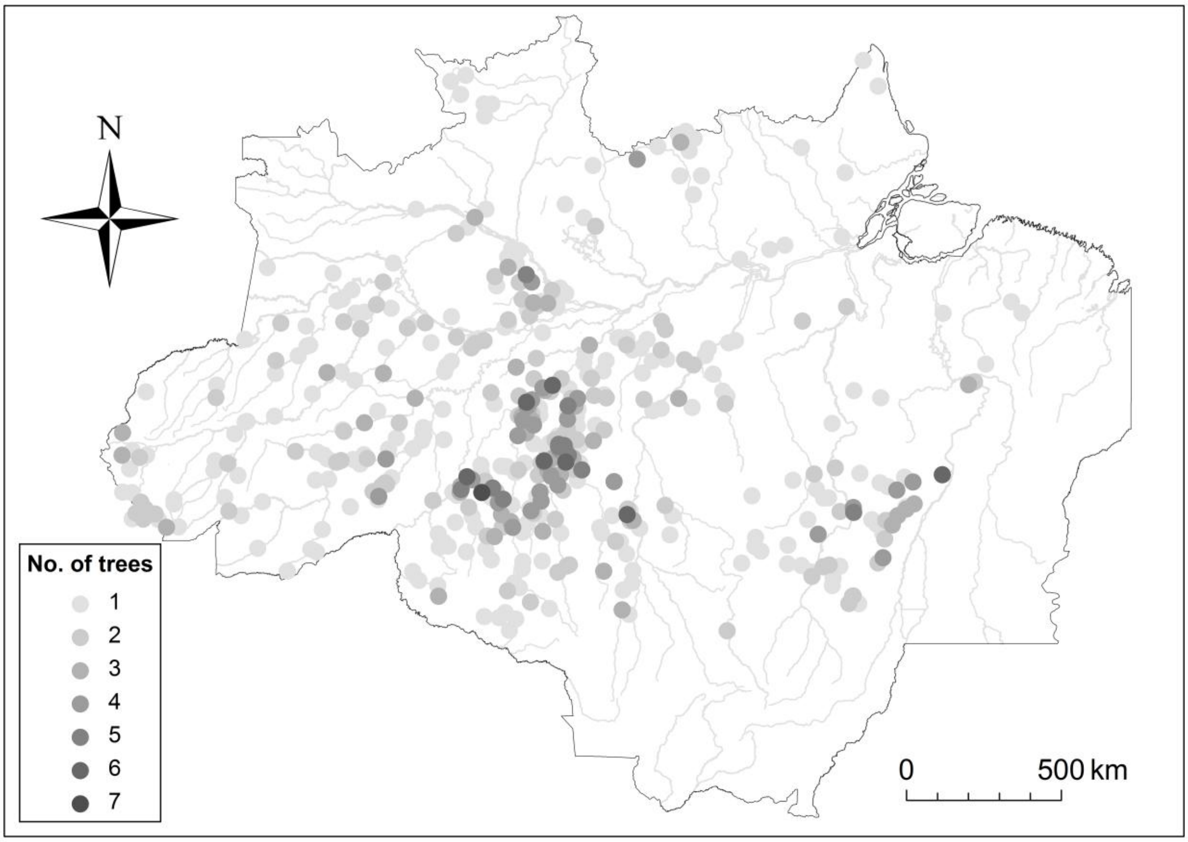

Figure 3.2. *Variation in* Copaifera *density across Brazilian Amazonia, based on 2,343 1-ha plots surveyed by Projeto RADAMBRASIL between 1968 and 1975. Plots in which* Copaifera *trees were not recorded are not shown.*

distributions. Minimum convex polygons showed that *C. reticulata* had the most extensive distribution, covering the majority of the basin, whereas *C. multijuga*, *C. langsdorffii*, *C. glycycarpa* and *C. duckei* had more restricted geographic ranges (Fig. 3.3). More abundant species had significantly more extensive distributions (RADAM: r = 0.932, $N = 5$, $P = 0.021$; Martins-da-Silva: r = 0.874, $N = 9$, $p = 0.002$). The region of greatest species overlap coincided with the area of highest *Copaifera* density (Fig. 3.2). There was a high degree of congruence in distribution between the taxonomy used by Projeto RADAMBRASIL and that described by Martins-da-Silva et al. (2008) (Fig. 3.3).

Copaifera density was approximately equal in the two main forest types, with a mean of 0.37 ± 0.87 trees ha^{-1} (N = 2,052 plots) in terra firme forest and 0.37 ± 0.99 trees ha^{-1} (N = 291 plots) in várzea forest. However, there was considerable species turnover with respect to forest type, with all species occurring in terra firme forest but only two

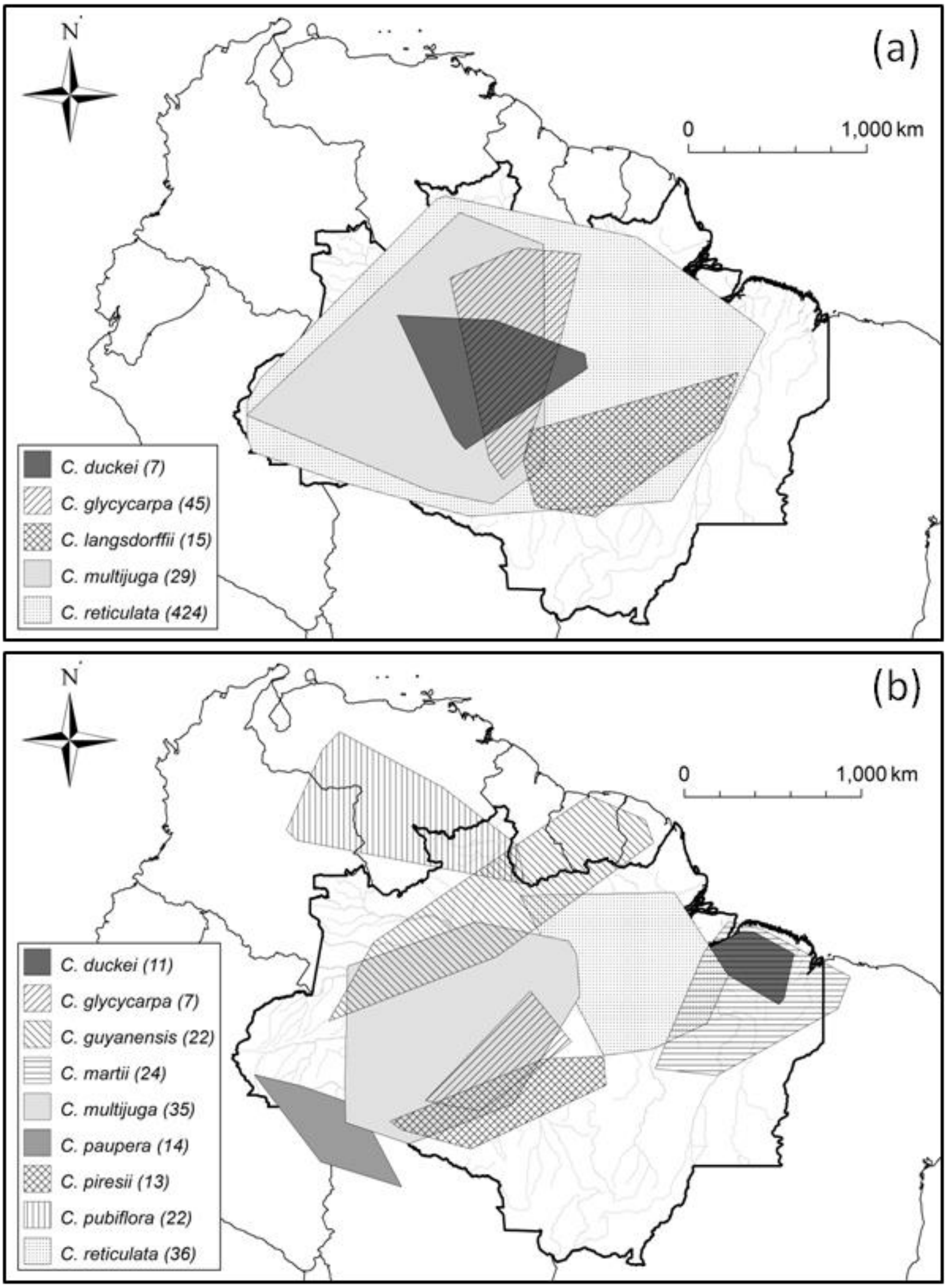

Figure 3.3. *Minimum convex polygons (MCP) representing the approximate geographic distributions of* Copaifera *species in Amazonia. Polygons incorporate all data points based on (a) the presence of each species within all 2,343 1-ha plots surveyed by Projeto RADAMBRASIL in Brazilian Amazonia (bold outline) between 1968 and 1975, and (b) the gazeteer of collecting localities of herbarium specimens examined by Martins-da-Silva* et al. *(2008) in the most recent taxonomic revision of the genus* Copaifera*. Numbers in parentheses indicate the number of data points used to create the MCP in each case.*

species, *C. reticulata* and *C. glycycarpa*, regularly encountered in várzea forest (11.3% and 15.7% of conspecifics, respectively).

There were significant differences between the mean size (DBH) of some of the seven species (ANOVA (ln DBH): $F_{\text{Brown-Forsythe}} = 4.329$, df = 6, $p = 0.001$; Table 3.2). In aggregate, *Copaifera* trees within várzea forest (median DBH = 50.93 cm, $N = 107$) were larger than their congeners in terra firme forest (median DBH = 46.15 cm, $N = 757$) (Mann-Whitney U = 34910, $z = –2.318$, $p = 0.020$; Fig. 3.4).

3.4.1.2 Landscape scale

A total of 341 *Copaifera* trees ≥25 cm DBH were encountered in a total of 530.6 ha of forest censused, resulting in an overall density of 0.64 trees ha$^{–1}$. However, density was not homogenous across the landscape (mean density ± SD = 0.63 ± 0.52 trees ha$^{–1}$, $N = 63$ linear plots; Table 3.1), and four of the 63 linear plots did not contain a single *Copaifera* tree.

Four species of *Copaifera* were identified within the Médio Juruá study area: a total of 163 *C. guyanensis*, 66 *C. multijuga*, 65 *C. paupera* and 47 *C. piresii* were recorded. Species distributions were not uniform between forest types: *C. multijuga* and *C. piresii* were found only in terra firme, whilst all but two *C. paupera* trees were found in várzea. *C. guyanensis* was encountered in both forest types, though predominantly (92.0%) in terra firme. Species distributions (defined as presence or absence from each linear plot) and species richness (the number of species per plot) were not uniform across the study area (Table 3.3).

Copaifera density differed significantly between forest types, being more than twice as high in terra firme forest (mean = 0.83 ± 0.57 trees ha$^{–1}$, $N = 37$ linear plots) than in várzea forest (mean = 0.36 ± 0.26 trees ha$^{–1}$, $N = 26$ linear plots). *C. guyanensis* (the only species occurring in both forest types), was found at densities an order of magnitude higher in terra firme forest than in várzea forest (Table 3.1). *C. guyanensis* and *C. paupera* were the most abundant species in terra firme and várzea forest, respectively.

There were significant differences between the mean size (DBH) of some of the four *Copaifera* species. Within terra firme forest, *C. multijuga* were significantly larger than *C. piresii*. The two várzea forest species (*C. guyanensis* and *C. paupera*) were both significantly larger than the three terra firme forest species (*C. guyanensis*, *C. multijuga*

Table 3.2. *Size comparisons of adult* Copaifera *spp. trees within Amazonia. Populations were surveyed at three nested spatial scales: (a) the basin-wide scale (within a total of 2,343 1-ha plots across Brazilian Amazonia); (b) the landscape scale (within 63 linear plots in the Médio Juruá region of the state of Amazonas) and (c) the local scale (within a 100-ha terra firme plot in the Uacari Sustainable Development Reserve). Trees were recorded if they were ≥100 cm CBH at the basin-wide scale, and ≥25 cm DBH at the landscape and local scales. Data are not shown for any species with ≤2 trees per forest type at any scale.*

		(a) Basin-wide scale			**(b) Landscape scale**			**(c) Local scale**		
Forest type	**Species**	**DBH (cm)**			**DBH (cm)**			**DBH (cm)**		
		N	**Mean**	**SD**	***N***	**Mean**	**SD**	***N***	**Mean**	**SD**
terra firme	*C. duckei*	7	41.38	10.23						
	C. glycycarpa	59	54.57	21.96						
	C. guyanensis				150	34.77	7.42	38	35.17	6.53
	C. langsdorffii	21	44.38	11.70						
	C. multijuga	42	43.70	10.73	66	36.28	9.06	51	37.18	7.12
	C. piresii				47	31.32	4.13	24	32.19	5.48
	C. reticulata	624	51.19	17.27						
várzea	*C. glycycarpa*	11	67.28	26.80						
	C. guyanensis				13	47.68	14.25			
	C. paupera				63	42.69	14.08			
	C. reticulata	93	56.49	25.35						
	Total (*Copaifera* spp.)	864	51.61	18.62	341	36.49	10.15	113	35.45	6.82

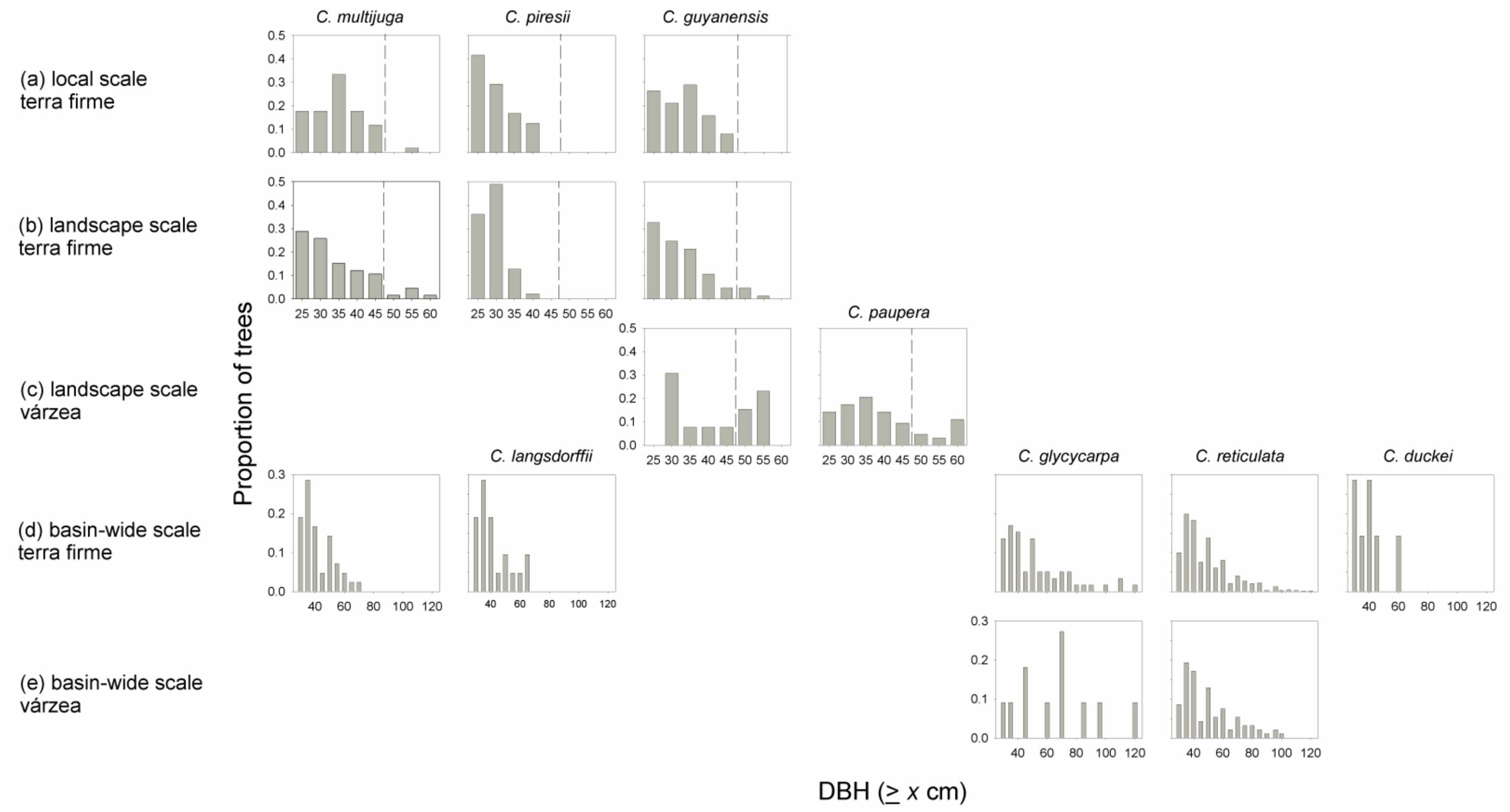

Figure 3.4. *Size distributions of* Copaifera *trees ≥25 cm DBH in either terra firme or várzea forest, Brazil. Data for four species surveyed in the Médio Juruá region of the state of Amazonas are presented from the (a) local scale (a 100-ha terra firme plot) and (b & c) landscape scale (63 linear plots in both forest types). Data for five species surveyed across Brazilian Amazonia are presented at the (d & e) basin-wide scale (2,343 1-ha plots surveyed by the Project RADAMBRASIL between 1968 and 1975). Four trees in (c), two in (d) and four in (e) were larger than the maximum DBH displayed. Dashed lines indicate the minimum permitted size of trees to be drilled for oleoresin extraction by the management plan of the Uacari Sustainable Development Reserve (SDS 2010).*

Table 3.3. Copaifera *spp. distributions across 37 terra firme and 26 várzea linear plots within the Médio Juruá region of the state of Amazonas, Brazil. Species occurrence indicates the number of linear plots within which each species was encountered; species richness indicates the number of linear plots containing 0 – 4 different* Copaifera *species.*

	Number of plots	
	terra firme	**várzea**
Species occurrence		
C. guyanensis	35	7
C. multijuga	21	0
C. paupera	2	18
C. piresii	14	0
Species richness		
0	0	4
1	13	19
2	12	3
3	11	n/a
4	1	n/a

and *C. piresii*) (*C. guyanensis* split by forest type; ANOVA (ln DBH): $F_{\text{Brown-Forsythe}} = 13.286$, df = 4, $p < 0.001$, Gabriel's post-hoc: $p < 0.05$; Table 3.2; Fig. 3.4).

There was evidence of clumping of trees within the linear plots for both the genus as a whole and for all four species. Of the 35 linear plots for which *Copaifera* abundance was sufficiently high to assess aggregation (≥4 conspecific trees ≥25 cm DBH per plot), six showed significant clumping (either pairwise or serial) of all congeners whilst nine showed significant clumping of at least one species. Of these, one out of five plots with ≥4 *C. multijuga*, all five plots with ≥4 *C. piresii*, three out of 18 plots with ≥4 *C. guyanensis* and two out of seven plots with ≥4 *C. paupera* exhibited clumping. The tendency for *Copaifera* to clump did not differ significantly between forest types (Fisher's exact test: $N = 35$, $p = 1.000$).

3.4.1.3 Local scale

A total of 113 *Copaifera* trees ≥25 cm DBH were encountered in the 100-ha plot, resulting in an overall *Copaifera* density of 1.13 trees ha^{-1}. Sixty two of the 100 1-ha subplots contained one or more *Copaifera* trees (mean per subplot = 1.13 ± 1.16 trees ha^{-1}; mean per occupied subplot = 1.82 ± 0.95 trees ha^{-1}). Three of the four species found in our entire study area occurred within the 100-ha terra firme forest plot: 38 *C. guyanensis*, 51 *C. multijuga* and 24 *C. piresii* were recorded. *C. paupera*, which was largely restricted to várzea forest, was missing from this plot. Species richness consequently ranged from one to three species per 1-ha subplot.

Within the 100-ha plot, the mean DBH of *C. multijuga* trees was significantly larger than that of *C. piresii* trees (ANOVA: $F = 4.707$, df = 2, $p = 0.011$, Gabriel's post-hoc: $p = 0.007$). *C. guyanensis* were not significantly different in size to the other two species (Table 3.2). Mean DBH was higher within the 100-ha plot than across the landscape linear plots for all three species (Table 3.2), but the local scale captured a smaller proportion of the total variance in population size range (Fig. 3.4). Size distributions indicate that populations of all species at all spatial scales typically have a low median size (many smaller and younger individuals) but a wide spread of sizes.

Nearest neighbour distances (NND) for *C. multijuga* were significantly shorter than for both *C. guyanensis* and *C. piresii* (one-way ANOVA (ln NND): $F = 8.853$, $p < 0.001$; Gabriel's post-hoc: $p < 0.01$; Table 3.4).

Table 3.4. *Descriptors of spatial distribution patterns of trees of three species of* Copaifera *in a 100-ha square plot in terra firme forest within the Uacari Sustainable Development Reserve in the state of Amazonas, Brazil. Statistics are shown for the Index of Aggregation (*R*) and associated z-value, and for mean nearest-neighbour distances (NND).*

Species	N	R^a	z^b	Mean ± SD NND (m)
C. guyanensis	38	1.08	0.90	94.5 ± 47.7
C. multijuga	51	0.82	-2.23	61.3 ± 40.5
C. piresii	24	1.06	0.50	118.6 ± 88.4
Total (*Copaifera* spp.)	113	0.87	-2.44	42.7 ± 27.4

[a] $R = 1$ if the spatial pattern is random; $R = 0$ if clumping occurs; R approaches a maximum of 2.15 if the pattern is regular

[b] the pattern is non-random if $z > \pm 1.96$

The spatial distribution of all *Copaifera* trees was significantly clumped (*R* = 0.87). Independent analyses of each species suggested that this clumping effect was due primarily to a stronger tendency for aggregation of *C. multijuga* (*R* = 0.82), whilst *C. piresii* (*R* = 1.06) and *C. guyanensis* (*R* = 1.08) did not deviate significantly from a random pattern (Table 3.4; Fig. 3.5). Plots of the linearised Ripley's K function *L(r)* confirmed a clumped distribution for *C. multijuga*, with aggregation of trees at distances >150 m (Fig. 3.6). *C. piresii* was also demonstrated to have a clumped distribution at distances >100 m.

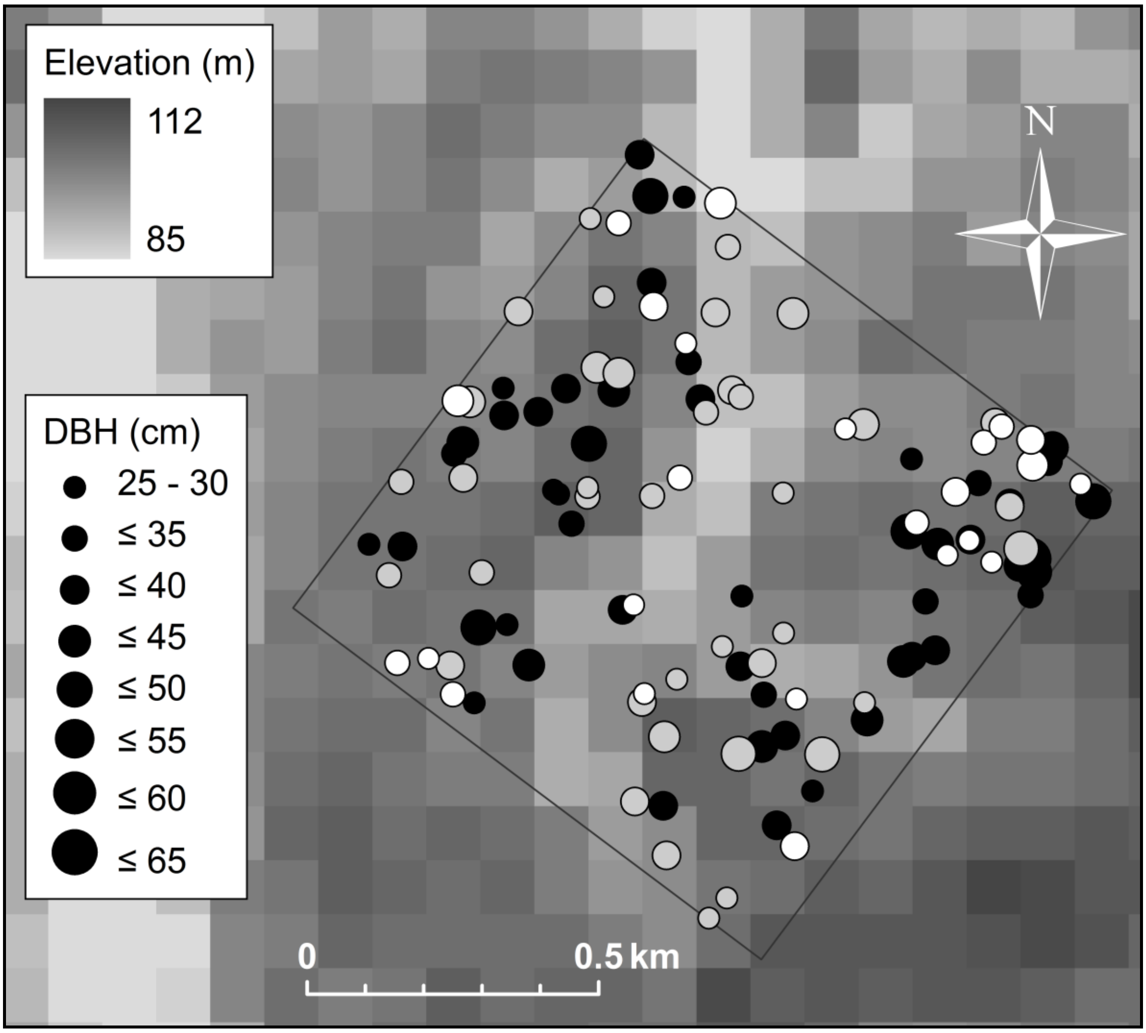

Figure 3.5. *Size-specific spatial distribution of three species of* Copaifera *trees within a 100-ha plot in terra firme forest within the Uacari Sustainable Development Reserve in the state of Amazonas, Brazil. Black, grey and white circles represent individual trees ≥25 cm DBH of* C. multijuga, C. guyanensis, *and* C. piresii, *respectively. Circle radii represent DBH classes. Shaded 90-m pixels indicate elevation above sea-level, according to Shuttle Radar Topography Mission (SRTM) data (Jarvis et al. 2008).*

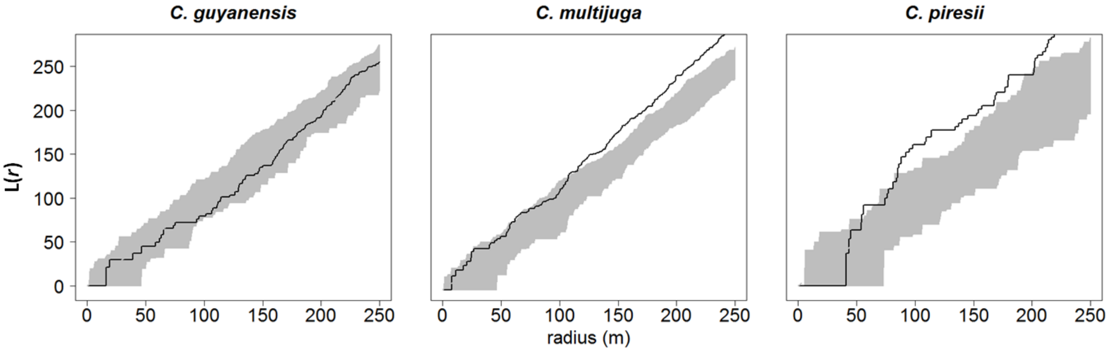

Figure 3.6. *Linearised Ripley's K analyses of the spatial distribution of three species of* Copaifera *trees within a 100-ha terra firme forest plot within the Uacari Sustainable Development Reserve in the state of Amazonas, Brazil. If* L(r) *(solid line) falls outside of the shaded envelope then tree distribution deviates significantly from complete spatial randomness.* L(r) *above the envelope indicates clustering at distance r, whereas* L(r) *below the envelope indicates spatial regularity.*

3.4.2 Effect of elevation on *Copaifera* distribution

At the landscape scale, *Copaifera* trees occurred along the entire elevation gradient between 88 m and 149 m (range of elevation sampled = 85 – 149 m). There was no significant difference between the elevation at which the three species were encountered in terra firme forest (ANOVA: $F_{\text{Brown-Forsythe}} = 0.153$, df = 2, $p = 0.858$). However, the mean elevation at which *C. guyanensis* occurred in várzea forest (87.2 ± 4.4 m, $N = 13$) was significantly lower than that of *C. paupera* (96.0 ± 4.6 m, $N = 63$), indicating habitat partitioning of the two species (t-test: $F = 0.042$, df = 74, $p < 0.001$). *C. piresii* also showed evidence of habitat specificity: the elevation of individual 0.1-ha subplots where at least one *C. piresii* tree occurred (mean = 107.1 ± 13.0 m, $N = 43$) was higher than those where no trees of this species were present (mean = 101.5 ± 10.9 m, $N =$ 3,099; t-test: t = –3.351, df = 3140, $p = 0.001$).

Within the 100-ha plot, elevation ranged between 94 m and 109 m (Fig. 3.5). Again, there were no significant elevational differences in the occurrence of the three species (ANOVA: $F = 1.652$, df = 2, $p = 0.196$). However, there was evidence of habitat specificity for both *C. multijuga* and *C. piresii*, which were more commonly encountered in areas of higher elevation. The elevation of 1-ha subplots containing at least one tree of these species (*C. multijuga*: mean = 103.9 ± 3.0 m, $N = 37$; *C. piresii*:

mean = 104.4 ± 2.4 m, $N = 21$) was higher than those of unoccupied plots (*C. multijuga*: mean = 102.5 ± 3.4 m, $N = 63$; *C. piresii*: mean = 102.7 ± 3.5 m, $N = 79$); (t-test (*C. multijuga*): $t = -2.067$, df = 98, $p = 0.041$; t-test (*C. piresii*): $t = -2.664$, df = 44, $p = 0.011$; Fig. 3.5). *C. guyanensis* occurred at similar abundances at all elevations.

3.4.3 Comparing densities at nested scales

Twelve of the Projeto RADAMBRASIL 1-ha plots were located within our surveyed landscape, but only two of these plots contained ≥1 *Copaifera* tree, with four trees (all recorded as *C. multijuga*) in total. The overall density estimate for our study area from these data was therefore 0.33 ± 0.89 trees ha^{-1}. This is comparable to the density of 0.25 ± 0.62 *Copaifera* ha^{-1} within the 55 1-ha plots located within the wider Juruá River watershed between the city of Eirunepé and the river's junction with the Solimões/Amazon River. Considering the same minimum size threshold of 31.8 cm DBH, the mean density of *Copaifera* across all 63 linear plots in our study landscape was 0.39 ± 0.30 trees ha^{-1}, and across all 100 sub-units of the 100-ha terra firme plot was 0.74 ± 0.93 trees ha^{-1}.

3.5 Discussion

At all spatial scales, our data showed that the density, DBH and aggregation of *Copaifera* trees varied between species, with elevation, and between forest types. The population size structure of all species and at all scales indicated populations with a wide spread of tree sizes, dominated by smaller trees. Next, we compare the explanatory congruence of different scales and discuss the relative merits of a cross-scale approach to understanding and managing tropical NTFP distribution.

3.5.1 Adult density

Studies that have recorded *Copaifera* trees at the genus or species level across Amazonia have reported tree densities ranging from 0.14 ha^{-1} (ter Steege and Zondervan 2000) to 1.69 ha^{-1} (Barbosa 2007) (Table 3.1). This variation in densities may be partly explained by: i) the minimum size threshold of recorded trees (range: ≥10.0 cm to ≥31.8 cm DBH; densities were higher when the minimum size cut-off was smaller); ii) the spatial extent of the surveyed area (range: 5 to 2,300 ha; variation was lower when larger areas were surveyed); or iii) the extent to which study site selection was biased by known *Copaifera* abundance. Including all congeners, our mean densities increased approximately two-fold from the basin-wide (0.37 ha^{-1}) to the landscape scale

(0.63 ha^{-1}), and from the landscape to the local scale (1.13 ha^{-1}), and lie within the range recorded elsewhere in the literature. However, our censused areas were much larger than most other studies, lending greater support and population-level significance to our estimates.

Similarly low densities have been recorded for other important Amazonian NTFP tree species. Brazil nut (*Bertholletia excelsa*) density has been reported as 1.35 trees ≥10 cm DBH ha^{-1} (Wadt et al. 2005), whilst rubber (*Hevea brasiliensis*) exhibits densities as low as 1 – 1.5 tappable trees ha^{-1} (Schroth et al. 2003). Other NTFP trees occur at much higher densities: Klimas et al. (2007) reported populations of *andiroba* (*Carapa guianensis*) occurring at 25.5 trees ≥10 cm DBH ha^{-1}, whilst the palm *Euterpe oleracea*, which is harvested for the fruit *açai*, occurs in natural abundances of up to 600 clumps of trees ha^{-1} (Weinstein and Moegenburg 2004).

At the basin-wide scale, it should be noted that our estimates are based on data collected ~40 years ago, reflecting pre-deforestation tree abundance in many areas which are no longer forested. Contemporary resource availability may be heavily depleted in areas within the ‘arc of deforestation’ of southern and eastern Amazonia.

At the landscape scale, densities within várzea forest were just 42.9% of those within terra firme forest, possibly as a consequence of historical logging activity which selectively removed larger *Copaifera* trees within mature floodplain forest of the Juruá River (Scelza 2008). Extraction of *Copaifera* trees within the two extractive reserves in our study area is now prohibited, so populations may eventually regenerate to former levels.

3.5.2 Species distribution

Our data describing *Copaifera* species’ distributions across both the basin-wide and landscape scales are an important step in understanding the potential for commercial harvesting of this resource. High inter-specific variability in oleoresin yield volumes (Newton et al. 2011) and chemical composition (Veiga Junior et al. 2007) mean that the incidence of economically-viable species will determine the local potential for initiating or developing extractive industries based on oleoresin harvesting.

The mapped ranges of trees recorded under the Projeto RADAMBRASIL taxonomy were based on more than three times as many sample points as the mapped geographic origin of the herbarium specimens used by Martins-da-Silva et al. (2008), though the latter is considered the definitive contemporary taxonomic arrangement of the genus (Fig. 3.3). Both taxonomies showed larger range sizes amongst more abundant species (Gaston and Blackburn 2000) and there was considerable geographic congruence between the two. For example, both maps in Fig. 3.3 indicate that *C. multijuga* – one of the most commercially important species – is widespread throughout western Amazonia and that *C. glycycarpa* is predominantly found in central Amazonia. Our mapped range of *C. langsdorffii* corresponds closely to that of *C. piresii* in Martins-da-Silva (2008), and we note that several type specimens in the INPA herbarium originally misclassified as *C. langsdorffii* (an Atlantic Forest species) were recorded as *C. piresii* by R. Martins-da-Silva (PN, *personal observation*). Irrespective of nomenclature, Projeto RADAMBRASIL plots in which at least two *Copaifera* species were recorded probably represent true areas of species overlap, since a single plant taxonomist is unlikely to have attributed two different names to a single species. Moreover, our accurate identification of the *Copaifera* species within our study area is supported by previous collecting effort (Fig. 3.3).

3.5.3 Size-class structure

Copaifera trees in várzea forest were larger-girthed than in terra firme forest (Table 3.2; Fig. 3.4). *C. glycycarpa* and *C. reticulata* at the basin-wide scale, and *C. guyanensis* at the landscape scale, occurred in both forest types but their mean DBH was up to 12.7 cm larger within várzea forest. At all three scales, mean *Copaifera* DBH differed between species. Differences in mean tree size have two practical implications. Firstly, it has been demonstrated that larger trees yield greater oleoresin yields, but that the relationship between DBH and yield volume varies between species (Newton et al. 2011). Inter-specific variation in population size structure reiterates the importance of quantifying this relationship for each commercially-harvested species. Secondly, government agencies set a minimum size for oleoresin extraction. For example, the RDS Uacari management plan imposes a lower limit of 50 cm DBH (SDS 2010), whilst other guidelines recommend a minimum of 40 cm DBH (Leite et al. 2001; Alechandre et al. 2005). None of these cases explicitly define how these cut-off values were selected. At a basin-wide scale, the mean DBH of four species was smaller than 50 cm, whilst at the landscape scale 88% of all *Copaifera* encountered were below this size threshold. All but one tree within the 100-ha plot were smaller than this criterion (Fig. 3.4). In contrast, several authors have found that trees larger than 25 cm DBH may yield oleoresin (e.g. Plowden 2003; Newton et al. 2011). These findings suggest that a blanket minimum size threshold for harvesting may be inappropriate and that management plans should be site- and species-specific in setting any lower size limit since *Copaifera* populations may vary geographically and taxonomically.

3.5.4 Aggregated distributions

We found evidence of aggregation of trees within populations of some, but not all, *Copaifera* species. At the local scale, all three measures of aggregation (NND, *R*, and Ripley's K) indicated that *C. multijuga* had a significantly clumped distribution (Fig. 3.5). Ripley's K suggested that this aggregation tendency also applied to *C. piresii* and this species showed consistently clumped distributions at the landscape scale. The mean distance between neighbouring *C. multijuga* trees (61 m) was half that between *C. piresii* trees (119 m). An aggregated population may indicate dispersal limitation, environmental conditions, historical events, or density dependence (Boll et al. 2005). *Copaifera* spp. are large-seeded species (seed size range = 2.2 – 3.6 cm length: J. Hawes, unpublished data) dispersed by large-bodied arboreal frugivores, including primates and birds (e.g. Aquino and Bodmer 2004). Since avian dispersal is often non-random (Hutchings 1997), the first of these mechanisms may be partly responsible for the aggregations observed. We discuss below the importance of environmental variability on the distribution of this NTFP resource.

Aggregated NTFP populations have implications for extractors wishing to harvest a given resource. Drilling *Copaifera* trees entails repeated visits to any given tree, since the oleoresin is exuded slowly. There is also uncertainty that a given tree will yield any oleoresin at all, so that individual extractors may drill several trees in a single day (Newton et al. 2011). Clusters of *C. multijuga* trees spaced just 61 m apart therefore offer opportunities for reduced travel distances, enhancing the efficiency and economic viability of the harvest process.

3.5.5 Environmental variables

Many environmental variables affect tropical tree distributions, with the importance of different factors expected to be scale-dependent (Willis and Whittaker 2002). In this study, *Copaifera* occupancy was closely associated with elevation at the landscape and local scales. In particular, *Copaifera* trees were frequently absent from low-lying, poorly drained terra firme forest, even when differences in elevation from surrounding areas of higher abundance was only a few meters (Fig. 3.5). These lowland areas often contained backwater swamps, characterized by monodominant stands of arborescent palms and very low densities of hardwood trees (Peters et al. 1989).

3.5.6 Comparing scales

3.5.6.1 Selection of minimum tree size

The Projeto RADAMBRASIL forestry inventory was restricted to trees ≥31.8 cm DBH. Our data suggest that 35% and 38% of *Copaifera* trees were between 25.0 and 31.8 cm DBH in the landscape scale linear plots and the 100-ha plot, respectively (Fig. 3.4). Because adult *Copaifera* spp. within this size class clearly occurred within many of the 1-ha plots which were recorded as zeros, the basin-wide inventory provides a severe underestimate of adult density, which could be as high as 0.51 trees ha^{-1}. Given that trees ≥25 cm DBH can produce viable oleoresin volumes and can easily be recorded by field surveys with little extra effort, we suggest that smaller trees are also recorded by future studies. In contrast, experienced observers in our study were not entirely confident of reliably recording trees ≤25 cm DBH, since the characteristic trunk markings are less recognizable at smaller sizes.

3.5.6.2 Selection of spatial scale

Basin-wide data cover many management units, so patterns of resource distribution may be applicable in interpreting species' ranges or planning regional conservation policy. The landscape scale is a useful resolution for examining variation within the resource population available to individual extractors, who may access several hundred hectares of forest (Peres and Lake 2003). On a local scale, mapping an entire population enables the characterization of a resource using more detailed spatial statistics. However, a limited study area may be unrepresentative, thereby failing to take account of variation between habitat types or across an entire management unit (e.g. a large reserve).

The proportion of the study area censused at each spatial scale differed by several orders of magnitude. Our survey at the local scale was exhaustive, with all trees ≥25 cm DBH within the 100-ha plot mapped and measured. The 63 linear plots at the landscape scale accounted for 530.6 ha (0.06%) of the 886,176-ha combined area of the two extractive reserves, whilst at the basin-wide scale the 2,343 1-ha plots accounted for only 0.000005% of the 500,640,904 ha extent of Brazil's *Amazônia Legal* (ARPA 2009). This enormous variation in survey coverage is an inevitable consequence of scale, but has important implications for interpreting our results.

Estimates of *Copaifera* distribution in the Juruá region obtained using the same (31.8 cm DBH) size threshold at all three spatial scales produced similar density estimates for the basin-wide (0.33 ha^{-1}) and landscape (0.39 ha^{-1}) scales, but a density more than twice as high for the local scale (0.74 ha^{-1}). Alternative sampling strategies within the same geographic area can affect assessments of spatial distribution, and patterns inferred from large-scale data may lead to conflicting conclusions in relation to those obtained from a more detailed study within the same site. In the Médio Juruá region, RADAMBRASIL data indicated relatively low densities of *Copaifera* trees, and critically failed to account for patches of locally-high density.

3.5.7 Conclusions

Studying *Copaifera* species populations at three spatial scales has enabled us to better understand variation in density and spatial distribution in relation to a forest resource of importance to millions of rural and urban Amazonians. Alternative spatial scales offer opportunities to variously explore and compare patterns of distribution, density and aggregation, and to cross-validate patterns observed at more than one scale. Basin-wide, landscape, and local studies are each associated with their own merits and limitations, but in combination offer a more holistic understanding of tropical forest resource distribution.

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Chapter 4

Determinants of yield in a non-timber forest product: *Copaifera* oleoresin in Amazonian extractive reserves

Photo: Harvesting *Copaifera* oleoresin

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4.1 Abstract

Developing sustainable extractive industries in otherwise intact tropical forest regions requires a sound understanding of the production potential of key resource populations. The oleoresin extracted from *Copaifera* trees is an economically important non-timber forest product harvested throughout the lowland Amazon basin. We studied oleoresin extraction from four species of *Copaifera* trees with known harvest histories within two contiguous extractive reserves in western Brazilian Amazonia. We conducted a large-scale experimental harvest of 179 previously unharvested *Copaifera* trees, in both seasonally-flooded (*várzea*) and adjacent unflooded (*terra firme*) forests. The likelihood of trees yielding any oleoresin was principally determined by their species identity: *C. multijuga* was the only species to regularly yield oleoresin (70% of trees). Yield volumes varied both among species and forest types: *C. multijuga* (restricted to terra firme forest) had the highest mean yield of 505 ml, whilst *C. guyanensis* produced higher volumes of oleoresin in várzea (139 ml) than terra firme (15 ml) forest. Intraspecific differences were driven mainly by tree size. To assess extraction sustainability, we reharvested a sample of *C. multijuga* trees and compared the oleoresin production of 24 conspecific trees that had been initially harvested one year previously with that of 17 trees initially harvested three years previously. Reharvested trees produced just 35% of the oleoresin volume compared to that when originally drilled, but this response was not affected by the time interval between consecutive harvests. We demonstrate that, within a population of *Copaifera*, both morphological and environmental factors restrict total productivity; consideration of these factors should inform sustainable management practises. We additionally raise methodological considerations that may improve the comparability of studies.

4.2 Introduction

Legally inhabited protected areas in Amazonia, including extractive reserves, sustainable development reserves and indigenous territories, aim to reconcile the interests of forest biodiversity conservation and ecosystem service provision with the needs of local livelihoods (Allegretti 1990). Such multiple-use reserves account for over 35% of the Brazilian Amazon, and are an integral component of governmental strategies to preserve intact areas of primary forest (Peres and Zimmerman 2001; Nepstad et al. 2006). One way in which reserve managers seek to achieve the dual roles of maintaining forest integrity whilst promoting sustainable extractive activities is to develop small-scale projects in which forest dwellers exploit non-timber forest products (NTFP).

The potential for NTFP extraction to play a role in tropical forest conservation has been widely discussed. Advocates highlight the potential for direct local revenues coupled with relatively benign impacts on forest ecosystem structure (e.g. Peters et al. 1989; Nepstad and Schwartzman 1992). Yet detractors have shown that resource degradation and market inequalities lessen the prospects of truly sustainable extraction (e.g. Arnold and Perez 2001). Whilst it is unlikely that NTFP extraction will ever provide a panacea for forest biodiversity conservation, small-scale extractive activities may still serve an important role in subsidising the economies of forest dwellers (Belcher and Schreckenberg 2007).

Tree oils and resins, in particular, represent an attractive extractive resource option, since these products are non-perishable and have a relatively high value per unit weight. However, detailed knowledge of the extraction of oils and resins, and the ecology of source populations, is largely unavailable (Santos et al. 2001; Moegenburg and Levey 2002), in contrast to other NTFP such as Brazil nuts (e.g. Peres et al. 2003) and palm hearts (e.g. Freckleton et al. 2003).

The translucent oleoresins extracted from trees of the genus *Copaifera* (Leguminosae: Caesalpinioideae), known in Brazil as '*óleo de copaíba'*, are harvested throughout the lowland Amazon basin (Plowden 2004). *Copaifera* oleoresins are valued for their medicinal uses: particularly for their antiseptic and anti-inflammatory properties (Veiga Junior and Pinto 2002). These oleoresins are used by most rural households in Amazonia, as well as being widely traded in towns and cities throughout Brazil. Wider marketing by pharmaceutical companies has been developing both the domestic and international markets for these therapeutic oils. The ~1.6 million km^2 state of Amazonas is the source of most of the *Copaifera* oleoresin produced in Brazil, accounting for 91% of the total of 514,000 kg traded in 2008 (IBGE 2010). However, the true socioeconomic value of this resource is severely underestimated by these official figures as much *Copaifera* oleoresin is consumed in local households or bartered across local communities rather than commercialised in large urban centres.

Copaifera oleoresin was historically often harvested in a destructive manner, with extractors axing into the basal tree trunk to access the oleoresin, or simply draining the oleoresin whilst felling the tree for timber (Plowden 2004). However, contemporary harvesting uses an alternative technique that is less invasive, using a borer to drill a hole into the trunk from which the oleoresin is drained for 1-3 days before the hole is plugged. If carefully harvested in this manner, a tree may survive many years to be redrilled repeatedly for further extraction of accumulated oleoresin (Leite et al. 2001).

It has been suggested that the factors that influence oleoresin production by *Copaifera* trees is a key priority within NTFP research (Santos et al. 2001). However, the alpha-taxonomy of this genus was poorly studied until the recent publication of a key describing the nine *Copaifera* species found across the Brazilian Amazon (Martins-da-Silva et al. 2008). Previous studies investigating the factors affecting *Copaifera* oleoresin production were consequently restricted to comparing different morphospecies (Plowden 2003) or to examining a single, easily-identifiable species (Alencar 1982; Medeiros and Vieira 2008).

This study examines the production of oleoresin by four species of *Copaifera* within a single study area along the Juruá River of the western Brazilian Amazon. Our aim was to determine the principal drivers of oleoresin production by comparing yields of previously-unharvested individuals over a large spatial scale. The study included trees in both permanently unflooded (*terra firme*) and seasonally-flooded (*várzea*) forests, the main forest types in much of lowland Amazonia. Our results are then compared with previous studies reporting yields of *Copaifera.*

4.3 Material and methods

4.3.1 Study site

The study was conducted within two contiguous protected areas bisected by the Juruá River (a tributary of the Solimões River) in the state of Amazonas, Brazil. The combined area of the federally-managed Médio Juruá Extractive Reserve (ResEx Médio Juruá) and the state-managed Uacari Sustainable Development Reserve (RDS Uacari), collectively termed “extractive reserves”, is 886,176 hectares (Fig. 4.1). Várzea forests closer to the main river channel are seasonally flooded between January and June, whilst terra firme forests on higher elevation are never flooded. These two reserves are inhabited by some 4,000 legal residents, living in small communities of between 1 and 89 households. Livelihoods are variably centred on a mixed-strategy approach of small-scale manioc (cassava) agriculture, fishing, and the extraction of

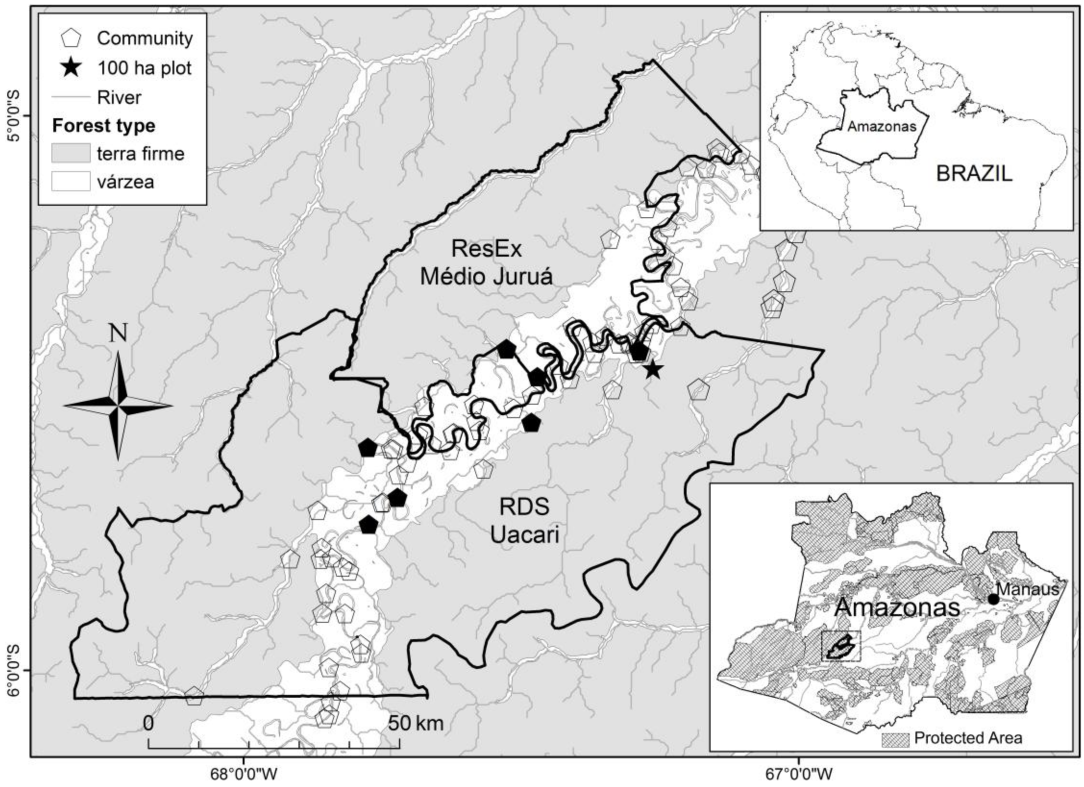

Figure 4.1. *Location of the* Copaifera *harvest study within two extractive reserves, Amazonas, Brazil. Individual drilled trees were located both within the 100 ha plot and close to extractive communities. Filled pentagons indicate those communities inhabited by one of the extractors involved in the study; hollow pentagons indicate other communities.*

rubber, oils, seeds (principally *Carapa guianensis*), and other plant products, all of which may be used for either domestic purposes or commerce. There was no history of commercial extraction of *Copaifera* oleoresin in the reserves, although the genus is well-known to residents who formerly exploited its valuable timber.

4.3.2 Study species

Copaifera spp. are hardwood canopy trees occurring in primary forests throughout both the Neo- and Afro-tropics in much of South America and western Africa (Veiga Junior and Pinto 2002). *Copaifera* trees are commonly known in the Brazilian Amazon as '*copaíba*' and '*copaibeira*', but often with little local differentiation between, or recognition of, species. Nine *Copaifera* species are formally recognised in the Brazilian Amazon: *C. duckei* Dwyer, *C. glycycarpa* Ducke, *C. guyanensis* Desf, *C. martii* Hayne, *C. multijuga* Hayne, *C. paupera* Herzog, *C. piresii* Ducke, *C. pubiflora* Benth and *C. reticulata* Ducke (Martins-da-Silva et al. 2008). Four of these species occurred within the study area: *C. guyanensis*, *C. multijuga* and *C. piresii* occurred in terra firme forest, whilst *C. guyanensis* and *C. paupera* occurred in várzea forest. Species were initially identified using the key provided in Martins-da-Silva et al. (2008) and compared against voucher specimens previously identified by R. Martins-da-Silva in the herbarium of the Botany Department of the Instituto Nacional de Pesquisas da Amazonia (INPA), Manaus. Numbered voucher specimens of each species collected during this study have been deposited at the INPA herbarium. The leaf characters of each species could be easily differentiated so individual trees could be identified in the field.

4.3.3 Harvest of *Copaifera* oleoresin

An experimental harvest of 161 *Copaifera* trees was conducted between January and December 2009, incorporating individuals of all four species. Of these, 77 trees were located within a single 100 ha plot in terra firme forest, whilst the remainder were distributed throughout the two reserves in both forest types (eight in terra firme and 76 in várzea; Fig. 4.1). An additional 18 *Copaifera multijuga* trees within this 100-ha plot were drilled in April 2010, to obtain some indication of any inter-annual differences in oleoresin production.

4.3.3.1 Terra firme plot

The 100 ha plot was demarcated in terra firme forest approximately 2 km from the Bauana Ecological Field Station (S 5° 26' 19.032" W 67° 17' 11.688") in the RDS Uacari reserve. This 1 x 1 km plot contained a trail grid consisting of 11 parallel 1 km transects joined by two perpendicular 1 km transects at either end. All transects were marked every 20m using a Hip Chain®. All *Copaifera* stems ≥25 cm DBH within this plot were intensively searched for by observers walking both along, and midway between, the 11 parallel transects. All trees sighted were number-tagged with an aluminium plate, measured, mapped, and identified to species. We also recorded their DBH and an *x* and *y* coordinate, which were assigned by measuring the perpendicular distance to the nearest meter along the nearest transect. These coordinates were subsequently overlain onto a digital elevation model (Jarvis et al. 2008) to calculate the elevation (m) of each tree.

Copaifera trees in this plot were drilled in April 2009. Each tree was revisited approximately 24 h later. If oleoresin had been collected, it was removed and measured using a graduated cylinder. Return visits continued every 24 h for up to 72 h. Monitoring of oleoresin yields continued for a further 24 h only if progressively more oleoresin had accumulated during each of the previous three days. If there had been no oleoresin production since the previous visit (or since being drilled), the hole was tightly sealed using a cylindrical hardwood plug and the monitoring process terminated.

4.3.3.2 Wider reserve landscape

Reserve residents who had been previously equipped and trained to extract *Copaifera* oleoresin were asked to record the volumetric amount of oleoresin extracted from each tree that they drilled during 2009. A total of 100 trees were harvested in this manner by extractors from seven different communities. Extractors used the same methodology as in the 100 ha terra firme plot, except that they usually returned only once to the tree, three days after drilling. The extractor marked each harvested tree with a numbered tag, and recorded the dates of drilling and oleoresin collection. Oleoresin yields were measured by the extractors, using calibrated graduated cups. All trees were subsequently revisited by a member of the research team to record the height and position of the drilled hole, measure the tree DBH, identify its species, record the forest type and georeference its location and elevation with a GPS receiver. The research team had worked closely with all of these extractors for a significant period of time prior to this study, as part of a long-term project in the reserves. Absolute proof of oleoresin collection was established by proxy of oleoresin samples which were retrieved by PN for analysis in a separate study.

4.3.3.3 Repeated harvests

To examine the rate of oleoresin renewal by *Copaifera* trees and thus gain an indication of the sustainability of resource extraction, 24 of the *C. multijuga* harvested in the 100 ha plot that yielded oleoresin in 2009 were redrilled in April 2010. The same methodology was used as during the initial harvest, but in each case a new hole was drilled into the trunk, usually ~20 cm above or below the original hole (in accordance with extractors' training). In addition, 17 number-tagged *C. multijuga* that had yielded at least some oleoresin when first drilled by a local extractor in 2007 (three years previously) were relocated and redrilled. Since volumetric yields in 2007 were estimated by extractors rather than actually measured, we used these estimates for the analyses of *relative* yields between harvests, but we considered only those trees originally harvested in 2009 for analyses of *absolute* differences.

4.3.3.4 Harvest methodology

Only *Copaifera* trees with a diameter at breast height (DBH) equal to or greater than 25 cm were drilled. This DBH was used as a minimum cut-off since previous studies have indicated that trees below this size are unlikely to yield oleoresin (e.g. Plowden 2003). Drilling was undertaken by a total of ten local extractors who had been previously trained in the methodology of harvesting *Copaifera* trees using a borer. Trees were randomly selected from all of those encountered, at least within the 100-ha plot. In the wider reserve landscape, extractors may have avoided obviously hollow trees, but explained that they were otherwise unable to pre-determine yield likelihood or relative volume. Only one extractor expressed prior knowledge of species' relative productivity. None of the trees drilled showed scars or any other signs of having been previously harvested, and could therefore be defined as 'virgin'. Three quarters of trees (75%) were confirmed as being reproductively mature when drilled, on the basis of flowers, fruits/seeds or seedlings directly associated with that tree.

Each tree was drilled in an identical manner, closely simulating practices employed by local extractors in order to enhance comparability both with other studies and actual harvests. The general protocol is described by Leite et al. (2001), whilst specific details were determined by the methodology in which local extractors had been trained, in May 2008, by a visiting forest technician working on behalf of the Instituto de Desenvolvimento Agropecuário e Florestal Sustentável do Estado do Amazonas (IDAM). Each tree was initially drilled at a height of approximately 1 m (mean ± SD = 96.9 ± 20.2 cm) height above ground, using a 1.9 cm diameter borer. A single hole was drilled in the first instance, either beneath the main bough of the tree, or on the underside of any tree that was leaning. If there was no indication that the tree contained oleoresin, no additional holes were drilled. If no oleoresin was encountered but 'oily' debris was extracted on the borer, a second and occasionally third hole was drilled. Of all the trees harvested, 140 were drilled with a single hole, 33 with two holes and only six with three holes. Regardless of whether the tree showed immediate signs of producing oleoresin or not, at least one hole was tightly fitted with a rigid PVC pipe of 26 cm in length, leading into flexible plastic tubing (1.2 m length, 2 cm diameter) which in turn fed into a 2-litre plastic bottle on the ground. In accordance with the extractors' training, all holes were drilled to a minimum of half of the tree DBH, unless either oleoresin or a hollow was encountered at more superficial depths.

4.3.4 Data analysis

Data were analysed with respect to two response variables: whether or not an individual tree yielded any detectable amount of oleoresin (yield likelihood) and, for those trees that yielded at least 1 ml of oleoresin, the volume of oleoresin produced (yield volume). To better understand the predictors of this first variable, we ran binomial tests (chi-squared) and a logistic regression model entering species, DBH, forest type and terrain elevation as explanatory variables. Parametric tests (ANOVA, multiple regression) were used to identify significant predictors of the second response variable. Oleoresin yields of redrilled trees were compared using a paired *t*-test. All analyses were conducted in SPSS 16.0.

4.4 Results

A total of 179 previously unharvested *Copaifera* trees were drilled in 2009 and 2010. This included individuals of all four species occurring in the study region (80 *C. guyanensis*, 60 *C. multijuga*, 21 *C. piresii* and 18 *C. paupera*), with 103 trees in terra firme forest and 76 in várzea forest. Next, we examine the key morphological and environmental determinants of whether or not *Copaifera* trees produced any oleoresin.

4.4.1 Oleoresin production by *Copaifera* trees

4.4.1.1 Morphological factors

A total of 14 of the 179 trees drilled were hollow, effectively ruling out the possibility of oleoresin yields (although five of these trees did yield a negligible volume). Hollowness was not equally spread amongst species, with six *C. multijuga* (10%), four *C. guyanensis* (5%), and four *C. piresii* (19%) found to be hollow. No hollow *C. paupera* were encountered. Of the remaining 165 non-hollow drilled trees, only 71 (43.0%) yielded any oleoresin (≥1 ml). Hollow trees were then excluded from further analyses. The remaining trees either did not contain oleoresin or, possibly, the drilling method failed to drain the oleoresin that they did contain.

There was a significant interspecific difference in the frequency with which any oleoresin was extracted ($\chi^2 = 24.88$, $N = 165$, df = 3, $p < 0.001$). *C. multijuga* trees yielded oleoresin significantly more frequently (70.4% of all non-hollow harvested stems) than the other three species, each of which yielded oleoresin in less than half of all cases (Fig. 4.2). However, tree DBH was not a significant predictor of the likelihood of a tree yielding oleoresin (point-biserial correlation: Pearson statistic = 0.019, N = 165, p = 0.811) above our minimum cut-off of 25 cm in DBH.

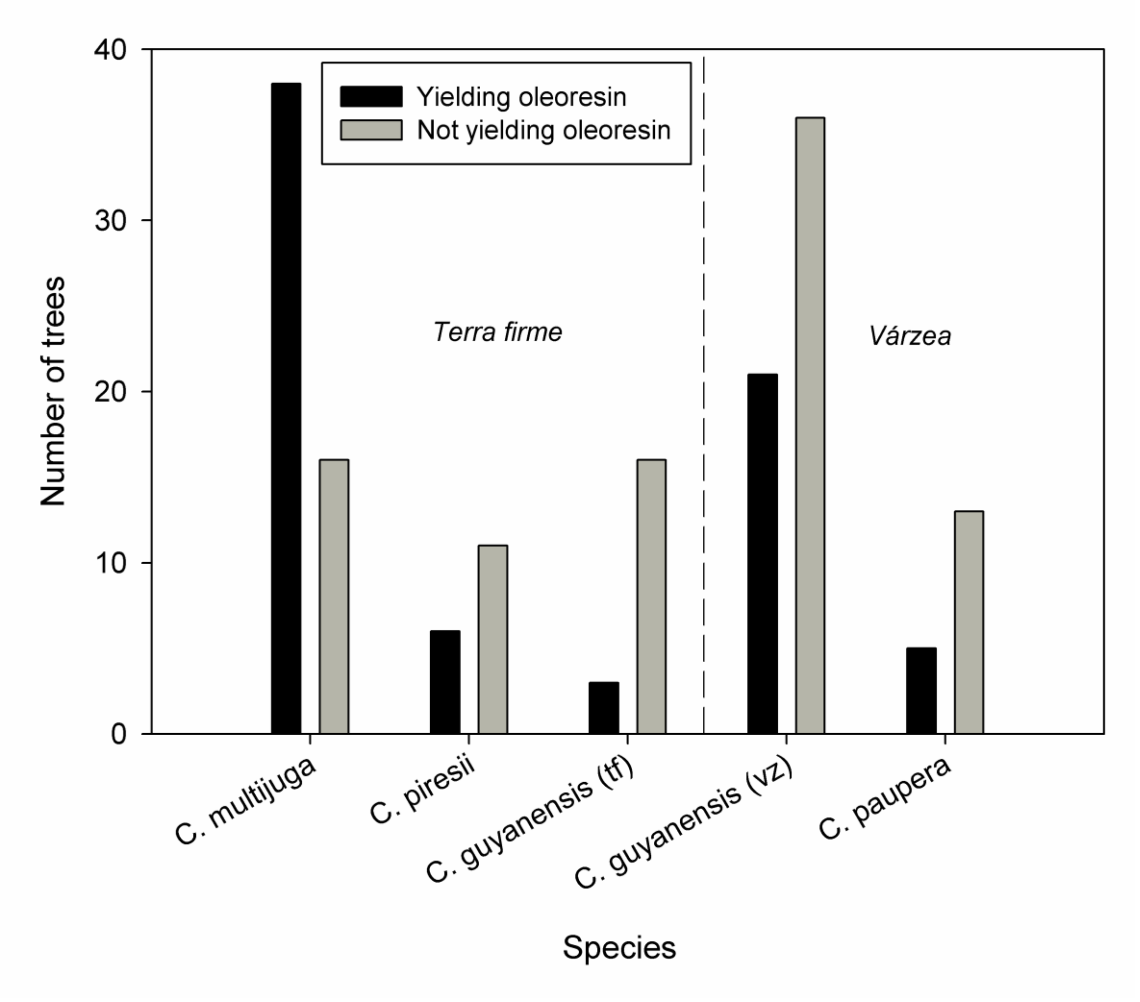

Figure 4.2. *Frequency with which trees of four sympatric congeners of* Copaifera *yielded oleoresin when harvested using a standard drilling technique (see Methods).* C. guyanensis *is a habitat-generalist and was therefore separated by forest type (tf: terra firme forest and vz: várzea forest).*

4.4.1.2 Environmental factors

Overall, *Copaifera* trees in terra firme forest were more likely to yield oleoresin than those in várzea forest (χ^2 = 3.92, N = 165, df = 1, p = 0.048). However, the four species were not equally distributed amongst the two forest types, with only *C. guyanensis* occurring in both terra firme and várzea forest. Considered separately, of the 76 non-hollow *C. guyanensis* drilled, a greater proportion of trees yielded oleoresin in the várzea forest (21/57, 36.8%) than in the terra firme forest (3/19, 15.8%), although this difference was not statistically significant ($\chi^2_{\text{Yates corr.}} = 2.030$, $N = 76$, df = 1, $p = 0.154$).

Species was the only variable retained by the logistic regression model, with *C. guyanensis*, *C. paupera* and *C. piresii* significantly less likely to yield any oleoresin than *C. multijuga*, the baseline category ($R^2_{\text{(Nagelkerke)}} = 0.28$, $\chi^2\ (6) = 37.94$, $p < 0.001$).

4.4.2 Volumetric yields

The morphological and environmental predictors of yield volume were assessed using correlation and regression analyses for those trees yielding at least 1 ml of oleoresin. False negatives may be prevalent in oleoresin harvest studies (Alechandre et al. 2005), in that it can only be concluded that oleoresin was not found, rather than that the tree did not actually contain oleoresin deposits. Our knowledge of the internal anatomy of *Copaifera* trunks is extremely limited (but see Langenheim 1973 and Plowden 2003), and so it is difficult to assert that these trees did not contain oleoresin stored in pockets or ducts that were not accessed by the drilling process. To avoid including false negatives, the remainder of the analysis considers only those trees that did yield ≥1 ml of oleoresin.

4.4.2.1 Morphological factors

The mean (± SD) oleoresin volume yielded from the 61 trees for which at least a 1 ml yield was recorded was 323.9 ± 618.4 ml (range = 1 - 4,246 ml, $N = 61$). However, of those trees that yielded oleoresin, there was considerable variation in yield volumes both within and between species (Table 4.1). The mean ln-transformed volume of oleoresin yielded by the highest-yielding species (*C. multijuga*) was significantly greater than that of the lowest-yielding species, *C. piresii* (one-way ANOVA: F = 3.528, $p = 0.020$; Gabriel's posthoc: $p = 0.038$; Fig. 4.3). There were no significant differences in yield volumes between the other species.

Larger trees yielded more oleoresin than smaller trees for both *C. multijuga* ($r = 0.506$, $N = 29$, $p_{\text{one-tailed}} = 0.003$; Fig. 4.4) and, within várzea forest, for *C. guyanensis* ($r = 0.690$, $N = 17$, $p_{\text{one-tailed}} = 0.001$; Fig. 4.4) when excluding trees that yielded a minimal oleoresin volume (<10 ml). When all trees (hollow, non-yielding and yielding) were considered together, there was a significant positive correlation between DBH and yield

Table 4.1. *Summary statistics of drilled trees and their resource population for four sympatric congeners of* Copaifera *in the Médio Juruá region of western Brazilian Amazonia.*

Species		***C. multijuga***	***C. piresii***	***C. guyanensis* (*tf*)**	***C. guyanensis* (*vz*)**	***C. paupera***
Forest type		*terra firme*	*terra firme*	*terra firme*	*várzea*	*várzea*
Number of trees drilled		60	21	22	58	18
DBH	Mean	38.3	34.8	34.3	50.6	72.3
	SD	7.8	12.0	7.7	11.4	16.0
Number of hollow trees		6	4	3	1	0
Trees not yielding oleoresin		16	11	16	36	13
Oleoresin yield (ml)	*N*	33	4	2	19	3
	Mean	505.1	16.9	15.3	139.2	114.9
	SD	778.5	11.9	16.6	245.1	137.3
	Min	1	3	4	2	1
	Max	4246	28	27	1036	268
Tree density (ha^{-1}) [a]		0.27	0.16	0.52	0.10	0.40
DBH [a]	Mean	36.2	31.3	34.8	46.7	45.4
	SD	9.1	4.1	7.4	14.2	14.1

[a] For all trees ≥25 cm DBH (P. Newton, unpublished data)

volume for *C. multijuga* (r = 0.238, *N* = 55, $p_{\text{one-tailed}}$ = 0.040) but not for *C. guyanensis* (r = 0.118, *N* = 56, $p_{\text{one-tailed}}$ = 0.118). Only two *C. guyanensis* (in terra firme), three *C. piresii* and four *C. paupera* trees yielded any oleoresin, so we are unable to examine yield responses to tree size for these species. All correlations are partly depressed by the minimum size cut-off (25 cm DBH) of trees sampled in this study.

4.4.2.2 Environmental factors

Across all *Copaifera* trees sampled, the average per tree oleoresin yield in terra firme forest was not significantly different from that in várzea forest (independent samples t-test: *F* = 3.983, df = 59, *p* = 0.185). *C. guyanensis* was the only species occurring in both forest types: only two trees of this species drilled in the terra firme yielded any oleoresin, but the average volume that they produced (mean ± SD = 15.3 ± 16.6ml) was nearly an order of magnitude lower than that of all the yielding conspecific trees in várzea (*N* = 19, mean ± SD = 139.2 ± 245.2 ml; Fig. 4.3).

We ran a multiple linear regression model (forced entry) to assess the predictors of ln oleoresin volume. Species, tree diameter, forest type, terrain elevation and year of harvest (to test for inter-annual differences in oleoresin yield) were included as predictor variables. The identity of local extractors was not included because they tended to access only one forest type, so these two variables were positively correlated (r =

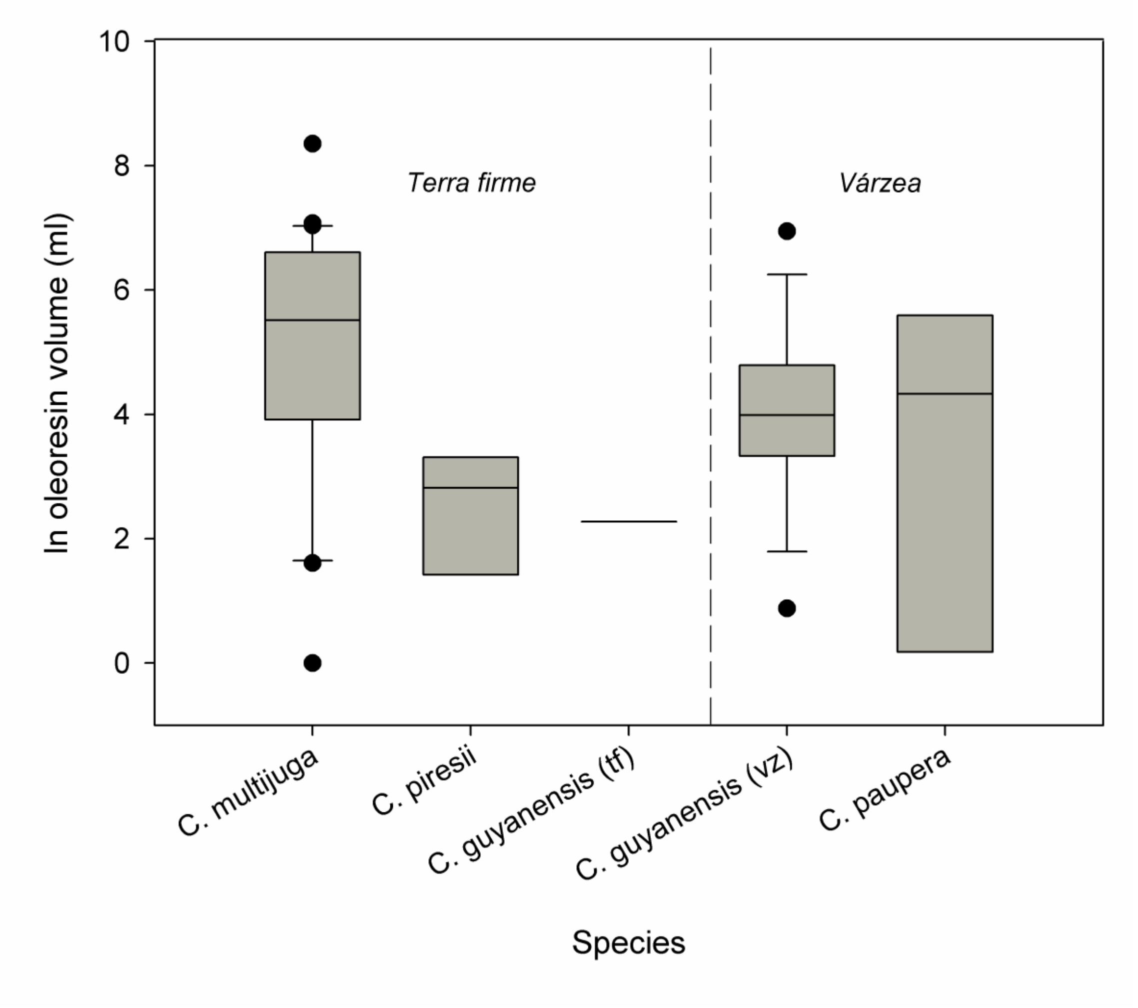

Figure 4.3. *Oleoresin volumetric yield (ln x) per tree for four species of* Copaifera *harvested for the first time in 2009 (*C. guyanensis *was separated by forest type; tf: terra firme forest and vz: várzea forest). Boxes show 25th and 75th percentiles and are bisected by the median value; whiskers indicate 10th and 90th percentiles.*

0.968). Elevation, forest type and year were eliminated as non-significant predictors of yield volumes but species identity and tree size (DBH) were retained by the model (Table 4.2).

4.4.3 Oleoresin renewal rate in *Copaifera multijuga*

Most of the redrilled *C. multijuga* trees, all of which yielded some oleoresin when initially drilled one or three years previously, also yielded oleoresin when harvested for the second time in 2010 (26/41, 63.4%). There was no significant difference in the likelihood of a tree yielding oleoresin in 2010 between trees originally drilled either one or three years previously ($\chi^2 = 1.373$, $N = 41$, df = 1, $p = 0.328$).

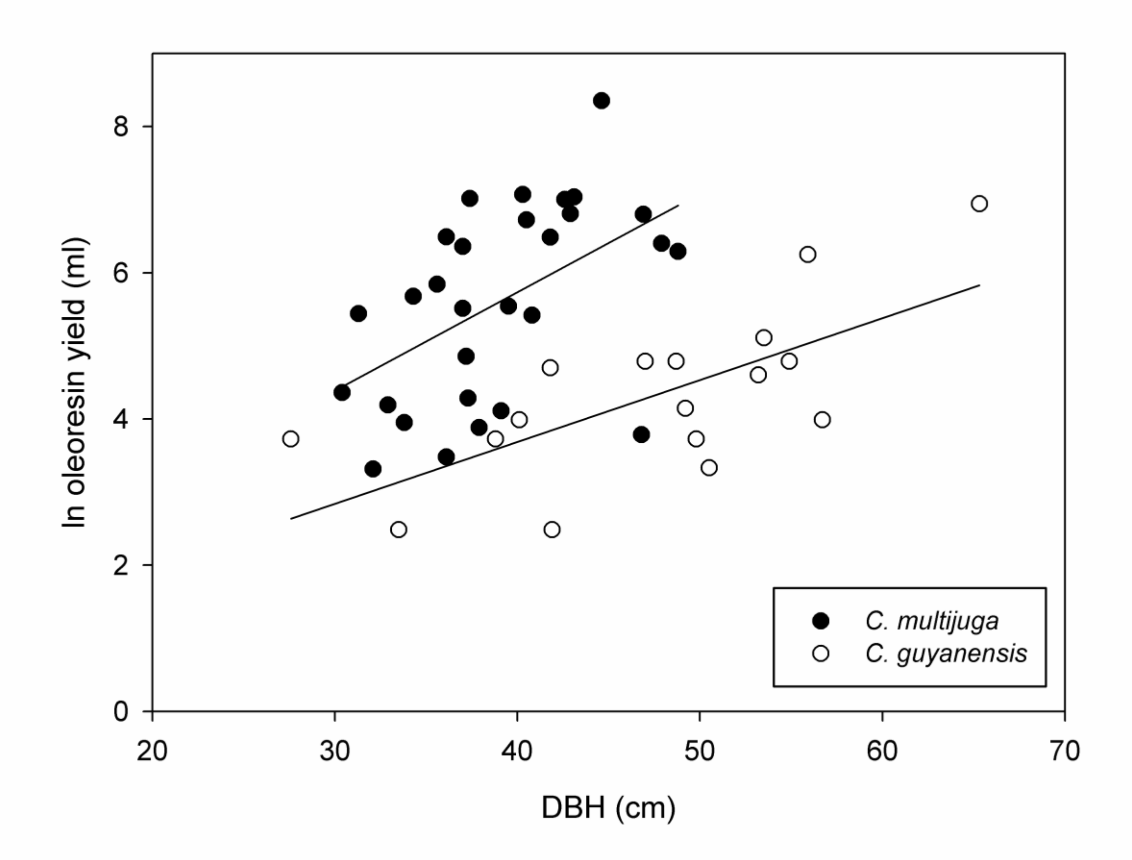

Figure 4.4. *Relationship between DBH and ln oleoresin yield for individual trees of* C. multijuga *in terra firme forest (*$R^2 = 0.26$*, N = 29,* $p_{\text{one-tailed}} = 0.003$*, ln oleoresin yield = 0.338 + (0.135 * DBH)) and* C. guyanensis *in várzea forest (*$R^2 = 0.48$*, N = 17,* $p_{\text{one-tailed}} = 0.001$*, ln oleoresin yield = 0.300 + (0.085 * DBH)).*

Table 4.2. *Summary of linear regression model assessing the predictors of oleoresin yield volume by drilled trees of four sympatric congeners of* Copaifera *in the Médio Juruá region of western Brazilian Amazonia. Yield volume is assessed relative to* C. multijuga.

Variable [a]	**Coefficient**	**SE**	**t-statistic**	***p***
Constant	2.04	0.83	2.46	0.018
Tree DBH	0.09	0.02	4.44	0.000
C. guyanensis	-2.01	0.35	-5.74	0.000
C. piresii	-2.32	0.64	-3.63	0.001
C. paupera	-4.21	1.11	-3.79	0.000

Of the 26 redrilled trees that yielded oleoresin, 18 (69.2%) yielded less oleoresin than the original harvest, whilst 8 (30.8%) yielded more. For trees yielding less oleoresin during the second harvest, the mean volumetric proportion which this second harvest accounted for compared to the first was 34.5 ± 26.3% ($N = 12$, range = 1 - 87%). For trees that yielded more oleoresin during the second harvest, this mean proportion was 403.2 ± 507.6% ($N = 5$, range = 103 – 1,295%).

The volume of oleoresin yielded by trees when first drilled in 2009 (mean ± SD = 478.0 ± 431.2ml) was correlated with ($r = 0.548$, $N = 17$, $p_{\text{one-tailed}} = 0.011$), and significantly higher than, the volume yielded by the same trees when redrilled in 2010 (mean ± SD = 209.1 ± 242.2; $t_{16} = 3.074$, $p = 0.007$, $r = 0.37$). However, the mean volume of oleoresin yielded by reharvested trees first drilled three years before (mean ± SD = 518.6 ± 1053.2ml) was not significantly different from that yielded by trees first drilled one year before (mean ± SD = 209.1 ± 242.2ml; independent samples t-test, $t_{24} = 0.559$, $p = 0.581$). The diameter of the three-year trees (mean ± SD = 46.5 ± 6.6cm) was significantly larger than those of the one-year trees (mean ± SD = 39.2 ± 5.5cm; independent samples t-test, $t_{24} = 3.026$, $p = 0.006$), so this could be an indication that smaller trees renew their oleoresin stores faster than larger trees (cf. Medeiros and Vieira 2008). However, yield volume and tree diameter were not significantly correlated ($r = 0.325$, $N = 26$, $p = 0.106$).

4.5 Discussion

Forest extractors and managers wishing to understand the potential for commercial exploitation of *Copaifera* oleoresin are interested in the factors that influence both the likelihood and volume of yield. This study showed that, in the Médio Juruá region of Brazilian Amazonia, yield was affected by hollowness, species identity, forest type and tree size. This is congruent with drivers cited by other authors, who additionally conclude that soil type (Alencar 1982) and season (Ferreira and Braz 2001) may help to predict yield volume (Table 4.3). This study has also confirmed that not all adult *Copaifera* trees will yield oleoresin when drilled and that not all individuals produce predictable amounts of oleoresin with equal regularity (Alencar 1982; Medeiros and Vieira 2008; Plowden 2003; Rigamonte-Azevedo et al. 2006). It may be that current harvesting methods occasionally fail to extract oleoresin from some trees that do contain oleoresin (‘false negatives’). However, all trees in our study were harvested using a standardised methodology, and so the interspecific differences in yield

Table 4.3. *Summary of studies of the oleoresin production ecology of* Copaifera *spp. within the Brazilian Amazon. Volumes and proportions always refer to a single drilling event, with oleoresin usually being drained from a tree for between 1 and 3 days.*

Study	**State**	**Location**	**Species**	**Number of trees drilled**	**Proportion of trees yielding**	**Mean volume per drilled tree (ml)**	**Mean volume per yielding tree (ml)**	**Max volume per yielding tree (ml)**	**Season drilled**	**Forest type**	**Variation in yield attributed to**
Alencar 1982 [c]	Amazonas	Reserva Ducke	*C. multijuga*	82	0.49	175.6 [a]	228.5 [a]	2850			Soil
Ferreira and Braz 2001	Acre	Floresta Estadual do Antimari	*Copaifera spp.*	62	0.50	900	1,805		Both	Both	
			of which	16	0.44	1,360	3,119.3		Rainy	*terra firme*	Season (rainfall) & forest type
				28	0.39	120	309.5		Rainy	*várzea*	
				14	0.86	2,100	2,451.7		Dry	*terra firme*	
				4	0.25	325	1,300.0		Dry	*várzea*	
Plowden 2001	Pará	Alto Rio Guamá Indigenous Reserve	*Copaifera spp.*	57	0.32	72.5	230	2,028			Tree diameter
Lisboa et al. 2002	Pará	Caxiuanã	*C. multijuga*	26	0.38						
Rigamonte-Azevedo et al. 2006	Acre	Tarauacá & Xapuri	*Copaifera spp.*	388	0.32	940	2920	18,000			(Morpho) species
Oliveira et al. 2006	Pará	Campo Experimental do Moju	*C. duckei*			221			Monthly		(Morpho) species & rainfall
			C. martii			467			Monthly		
			C. reticulata			38			Monthly		
Scudeller et al. 2007	Amazonas	RDS Tupé	*C. multijuga*	16	0.44			3,000			
Medeiros and Vieira 2008	Amazonas	Reserva Ducke	*C. multijuga*	43	0.63	660	1,040	7,200			Tree diameter
This study	Amazonas	RESEX Médio Juruá & RDS Uacari	*Copaifera spp. (inc hollow trees)*	179	0.40	117.5	323.9	4,246			
			Copaifera spp. (exc. hollow	165	0.43	127.5	323.9	4,246			
		of which	*C. multijuga*	54	0.70	340.2	505.1	4,246		*terra firme*	Species, forest type & tree diameter
			C. piresii	17	0.24	4.0	16.9	28		*terra firme*	
			C. guyanensis - terra firme	19	0.16	1.7	15.2	27		*terra firme*	
			C. guyanensis - várzea	57	0.37	48.1	139.2	1,036		*várzea*	
			C. paupera	18	0.28	21.5	114.9	268		*várzea*	
All studies	**3 states**		**7 species**	**853**	**0.39**	**653.2 [b]**	**1750.6 [b]**	**18,000**			

[a] Data available only for trees yielding ≥25 ml oleoresin (N = 28).

[b] Calculated as total oleoresin (476,171.9 ml) divided by the 729 drilled, and 272 yielding, trees for which data were presented.

[c] Studies were excluded from the totals of ‘All studies’ due to insufficient data.

likelihood must represent a true absence of oleoresin in at least a proportion of these trees. The proportion of non-yielding trees ≥25 cm DBH in this study (0.40) is extremely close to the average of all trees across all previous studies (0.39; Table 4.3).

A minimum size threshold was used by this study and others to select individual trees for drilling, restricting the proportion of the population available for harvest. Of these, a total of 7.8% of trees that we drilled were hollow. Interspecific differences further affected both the yield likelihood and volume. *C. multijuga* was the only species to regularly produce oleoresin (70% of drilled trees), though *C. paupera* (28%) and *C. guyanensis* (37%) both occasionally produced oleoresin in várzea forest. *C. guyanensis* rarely produced oleoresin in terra firme (16% of drilled trees), indicating that the production physiology of a single population may be affected by environmental variables such as forest type and hydrology, which are intrinsically linked to soil fertility.

Species identity was also important in determining the yield volume of those trees that did yield oleoresin, with *C. multijuga* producing a higher mean yield (505 ml) than any other species. Trees of larger diameter yielded more oleoresin than smaller ones: for *C. multijuga* yield increased 3.9 fold for each 10 cm increase in DBH, while for *C. guyanensis* yield increased 2.3 fold. Finally, yields were reduced by an average of 65% between initial and subsequent harvests, but the length of inter-harvest rest period did not seem to affect the yield volume.

4.5.1 Time-period of harvest

In this study, for every tree that was drilled, we left a plastic tube in place for a minimum of 24 h after drilling. Some studies (e.g. Medeiros and Vieira 2008; Plowden 2003) closed the bored hole immediately if the tree did not exude oleoresin. However, of the 33 *C. multijuga* trees for which we have data, 11 showed no indication of containing oleoresin at the point of being drilled, but had yielded ≥1 ml by the time we returned 24 h later. In other words, they began to exude oleoresin only after we had left the tree. The mean volume of oleoresin yielded by such trees (122.9 ml) was not as high as that for trees that began to exude oleoresin immediately (696.3 ml). However, had we followed an alternative protocol (e.g. Medeiros and Vieira 2008), we would have underestimated production and recorded 11% of our oleoresin-yielding trees as containing no oleoresin.

In their study, Rigamonte-Azevedo et al. (2006) noted that the volume of oleoresin collected from a tree did not significantly increase after the initial 24 h and concluded that this was therefore a sufficiently long period over which to monitor oleoresin production by a drilled tree. Whilst we found a weak significant difference between the total volume collected and that exuded in the first 24 h (t = –2.037 , df = 28, p = 0.051), in 13 cases the tree exuded less than 80% of the total oleoresin volume collected in the first 24 h period following drilling. Overall, only 54.8% of all oleoresin collected was exuded in the first 24 h. Scudeller et al. (2007) similarly noted one tree that yielded only 65% of its oleoresin within a day of being drilled, the rest being exuded only after 5 days.

Since most published and reserve management guidelines advocate a rest period of up to 3 years between harvest events, the volume of oleoresin extracted from an individual tree on a single extractive event therefore represents that tree’s entire annual or triennial productivity, which extractors wish to maximise. Additionally, extractors with whom we worked were trained to leave the oleoresin to drain for a minimum of 3 days. Therefore, in the interests of realistically simulating an actual harvest and producing results that are more comparable both with other studies and with actual harvests, it may be prudent to retain the tubing in place for longer than 24 h if a tree is still producing oleoresin.

4.5.2 Hollowness and oleoresin cavities

It is sometimes, but not always, possible to predict whether a tree is hollow before beginning the extraction process. Within our 100 ha plot, all trees selected for drilling were harvested, regardless of whether or not they were suspected of being hollow. However, when extractors operated unsupervised throughout the two reserves they likely avoided sampling trees that were obviously hollow, perhaps explaining why no hollow *C. paupera* trees were encountered, since these were all harvested outside of the 100 ha plot. Our range of up to 19% of hollow trees of any given species therefore represents a conservative estimate of the proportion of individuals that is actually hollow.

4.5.3 Interspecific differences

Within the Brazilian Amazon, *C. multijuga* is one of the most geographically widespread species in the genus (Martins-da-Silva et al. 2008). Yield likelihood of harvested trees of this species (70%) was comparable with that in previously studied conspecific populations elsewhere (49%: Alencar 1982; 63%: Medeiros and Vieira 2008; Table 4.3). In contrast with Plowden (2003), who found no significant differences between (morpho) species, we found significant interspecific differences between the yield likelihood and the yield volume (cf. Rigamonte-Azevedo et al. 2006). The yield likelihood of *C. multijuga* was significantly higher than that of the other three congeners, but the yield volume was not significantly higher than that of *C. guyanensis* and *C. paupera*. In other words, it is more difficult for extractors to find productive trees in várzea forest (cf. Ferreira and Braz 2001; Table 4.3), but those trees that yield oleoresin produce comparable quantities. *C. piresii* and *C. guyanensis* in terra firme forest exhibited both very low yield likelihoods and yield volumes, indicating that they are less likely to become commercially viable species. Overall, per tree *Copaifera* volumetric yield within our study site (mean = 117.5 ml) was lower than that across all previous studies (653.2 ml), emphasising the existing variation between sites. Whilst the number of published studies available for comparison is low, higher yields in the state of Acre suggest that such variation may be regional, either as a consequence of species composition or environmental differences (Table 4.3).

4.5.4 Tree size

Previous *Copaifera* studies have found that the smallest size-classes did not yield any oleoresin (Plowden 2003). We did not find a statistically significant relationship between DBH and yield likelihood, but this could be attributed to our sampling method. We imposed a minimum DBH of 25 cm as a selection criterion for harvesting, with the implication that smaller trees were not sampled.

We found a positive correlation between tree size and oleoresin production beyond our minimum critical DBH. In contrast, both Medeiros and Vieira (2008) and Plowden (2003) found that oleoresin production was highest amongst mid-sized trees. We did not include non-yielding or hollow trees in our analysis, which may explain some of the difference between studies. Additionally, tree size (most commonly measured as DBH) is a continuous variable, yet these authors have searched for relationships between oleoresin yield and categorical size classes. Since we found positive correlations between tree DBH and oleoresin production we suggest that linear analyses may be a more informative means of exploring yield data. This may be especially true given that the population size structure varies across species (P. Newton unpublished data).

There was a significant positive relationship between tree size and oleoresin yield volume for both *C. multijuga* and *C. guyanensis*. Such relationships have been previously identified for similarly-harvested tree species in extractive industries elsewhere (e.g. sugar maple: Blum 1973). For *Copaifera*, this relationship is crucial to determining appropriate minimum and optimal tree size-classes for extraction and in planning long-term exploitation strategies. It is likely that species-specific rather than genus-specific studies will help inform such management decisions.

4.5.5 Forest type

The clear distinction between terra firme and várzea forests affects many aspects of Amazonian forest ecology (Haugaasen and Peres 2005, 2007, 2008). The superior yield volume of *C. multijuga* supports the proposal of Ferreira and Braz (2001) that *Copaifera* spp. in terra firme forest may be more productive than those in várzea forest. However, we found that *C. guyanensis* yielded oleoresin more frequently in várzea (36.8%) than terra firme (15.8%), suggesting that intraspecific variation in oleoresin productivity in one forest type is not necessarily indicative of that in populations straddling into adjacent forest types. Species accounts presented by Martins-da-Silva et al. (2008) suggest that at least four *Copaifera* species occur in both terra firme and várzea forests, so this distinction in productivity may be true of other species too.

Habitat differences have implications for resource management on a temporal as well as a spatial scale. Our results indicate that várzea species (*C. guyanensis* and *C. paupera*) can yield oleoresin volumes of up to 1036 ml and 268 ml, respectively, which may render them target species for economically viable extraction. Given its persistent flood-pulse, however, the várzea is sufficiently dry to enable *Copaifera* tree location and drilling on foot for only approximately half of each year and this restricted access to the resource may limit its potential to fit into the activity budgets of extractors. In our study site, for example, activities such as rubber-tapping (of *Hevea brasiliensis* trees) dominate in the low water-level season. Furthermore, the optimal seasonality and timing of oleoresin harvesting within várzea forest remain unclear, given that the prolonged inundation period likely affects the physiology and internal resource allocation of *Copaifera* trees.

4.5.6 Harvest sustainability

In line with previous studies (Alencar 1982; Plowden 2003; Medeiros and Vieira 2008), the volume of oleoresin yielded was more than twice as high during the initial (mean = 478 ml) than in subsequent (mean = 209 ml) offtakes. However, we additionally found that there were no significant differences between trees re-harvested after either three years or one year, in terms of either the likelihood of oleoresin being yielded or the volume of oleoresin that such trees produced. This suggests that the process of oleoresin renewal by the tree begins within a year, or that oleoresin production is an annual process. It also suggests that trees may never fully replenish the volume of oleoresin that they originally contained, or at least come no closer to doing so after three years than they do after only one year. Published guidelines (e.g. Leite et al. 2001; Machado 2008) suggest a minimum redrilling interval of three years following an initial harvest, but this recommendation is not supported by our yield renewal data (though we are unable to provide data on longer-term implications of redrilling trees more frequently).

That oleoresin yields from the second harvests are renewed deposits is a poorly substantiated assumption, however, and our results may be confounded by the impossibility of knowing whether the initial extraction event depleted all available oleoresin. Eight trees actually yielded more oleoresin at the second harvest than the first (cf. Alencar 1982), by between 103% and 1295%. In these cases at least, perhaps not all oleoresin had been removed by the original drilling process, such that the oleoresin subsequently removed one to three years later could have been accessed during the first harvest. A third possibility is that the mechanics of the harvest extraction actually stimulate oleoresin production by the tree.

The extent of this problem can be minimised by careful methodological design of experimental harvests, which should mimic real-world methods used by local extractors as closely as possible. To this effect, we sealed all drilled holes with a hardwood plug between the initial and repeated harvests. This was justifiable since conversations with several local extractors suggested that (1) they rarely have access to sufficient materials to warrant leaving plastic tubing and stoppers in the forest, and (2) doing so would undesirably facilitate detection, access to, and removal of any accumulated oleoresin by other forest extractors using the same area. We therefore suggest that the alternative technique of leaving plastic tubing in place between harvests (e.g. Medeiros and Vieira 2008) is less realistic in determining potential resource offtake. Furthermore, 88% of our yielding *C. multijuga* trees exuded oleoresin over a period considerably longer than 24 h. Medeiros and Vieira (2008) ceased collecting oleoresin within hours of drilling the tree. Any oleoresin that subsequently collected in the plastic tubing that they left behind was presumably recorded as having been ‘produced’ after the initial drilling. In fact, the 6-month oleoresin volumes noted in their study may have included a significant quantity of oleoresin that was exuded within days of the initial drilling, remaining in the tubing until the tree was revisited 6 months later. We therefore emphasize the distinction between accumulated storage at any given time and renewal of *Copaifera* oleoresins.

4.5.7 *Copaifera* research priorities

Explaining the determinants of yield likelihood and volume is critical to understanding an individual tree’s oleoresin productivity. To estimate the harvest viability of an entire extractive system, however, a suite of additional factors need to be considered. These include the heterogeneity in density and distribution between species and forest types (Table 4.1), as well as resource accessibility, temporal and spatial patterns of extractor activities and market variables. The study of *Copaifera* productivity as an economically-viable NTFP therefore warrants further consideration within the context of an integrative spatial analysis.

By drawing together and critically assessing the methodologies of several decades of disparate research on the exploitation of *Copaifera* spp. (Table 4.3), we hope to increase the likelihood of comparability between future studies. We suggest that future studies should adopt methodologies that closely match real-world extractive practices, and specifically ensure sufficient time for exhaustive collection of oleoresin deposits before drilled holes are sealed. In terms of priorities, scant evidence exists in the literature of the longer-term renewal of oleoresin stores by individual trees; this enquiry would benefit from a means of ensuring exhaustive extraction during the initial harvest. It also remains unclear whether the harvest of *Copaifera* oleoresin has any detectable impact on the fecundity (e.g. seed crop size), seed/seedling viability or survival and growth rate of drilled individuals; such questions require longer-term monitoring of harvested populations (Ticktin 2004; Gaoue and Ticktin 2010).

4.5.8 Conclusions

We have shown that the production ecology of an NTFP resource population may be affected by species identity, morphological (e.g. hollowness, tree size) and environmental (e.g. forest type) factors. A comprehensive understanding of the relationship between these factors and resource offtake is clearly an important part of designing sustainable extraction protocols for all key NTFP resources in tropical forest regions. Such protocols are currently being developed within the context of many sustainable development reserves and will need to be well-informed if these reserves are to succeed in promoting both economically-viable and sustainable extractive industries capable of both supplementing the incomes of their resident populations and retaining a relatively intact forest cover in the long run.

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Chapter 5

Spatial, temporal and economic constraints on the commercial exploitation of a non-timber forest product in Amazonian extractive reserves

Photo: *Copaifera* oleoresin products for sale in Amazonas

5.1 Abstract

Commercial extraction of non-timber forest products (NTFPs) contributes to the livelihoods of millions of forest dwellers whilst purportedly having a more benign impact on tropical forest ecosystems than alternative income-generating activities such as agriculture. The increasing prevalence of government- and NGO-sponsored programmes to encourage NTFP extractivism in the humid tropics has highlighted the need for ecological and socioeconomic appraisal of the viability of extractive industries. We adopted a holistic approach to examining NTFP resource potential and produced robust landscape-scale estimates of the projected value of an economically important Amazonian NTFP, the medicinal oleoresin of *Copaifera* trees, within two large contiguous extractive reserves in Brazilian Amazonia. We integrated results derived from spatial ecology and harvesting studies with socioeconomic and market data, and mapped the distribution of communities within the reserves to create anisotropic accessibility models which determined the spatial and temporal access to permanently unflooded (*terra firme*) and seasonally-flooded (*várzea*) forest. The density of productive tree species was higher in várzea forest but per tree productivity was greater in terra firme forest, resulting in similar estimates of oleoresin yield per unit area (64 – 67 ml ha^{-1}) in both forest types. The estimated total volume of oleoresin accessible within the two reserves was 38,635 litres for an initial harvest, with projected offtake for a subsequent harvest falling to 8,274 litres. A greater area of várzea forest was accessible within shorter travel times of ≤250 min; longer travel times allowed access to increasingly greater volumes of oleoresin from terra firme forest. Socioeconomic data demonstrated that a household that extracted just two litres of oleoresin per month could generate 5% of its mean income; market data suggested that certification could increase the value of the resource five-fold. We discuss the constraints to commercial viability of NTFP extraction and conclude that whilst commercial harvests are unlikely to provide a panacea for either tropical forest conservation or rural development, some resources can make meaningful contributions to rural household economies.

5.2 Introduction

Non-timber forest products (NTFP) support the livelihoods of millions of rural people and are harvested globally for both domestic consumption and commercial trade, particularly throughout the tropics (Shackleton et al. 2011). Advocates of the NTFP paradigm have highlighted the apparent convergence of social development and conservation objectives (e.g. Nepstad and Schwartzman 1992). This mutualism may be facilitated by links between NTFP commercialisation and extractive reserves, payments for environmental services (PES) programmes, or government-sponsored extractive initiatives. Extractive reserves combine the goal of socioeconomic development with that of biodiversity and environmental service conservation (Allegretti 1990), and many reserves encourage the commercial extraction of NTFPs as a more ecologically-benign income-generating alternative to swidden agriculture or cattle-ranching. Similar objectives are embraced by PES programmes and other emerging Reducing Emissions for Deforestation and Forest Degradation (REDD) schemes that prohibit forest clearance (Wunder 2008). Such programmes often fund the development of commercial extraction as a means of inducing preferable land-use behaviours. This has been met with policy endorsement from the federal government which has recently announced significant investments to support extractivism throughout rural Brazilian Amazonia (Fiorese 2009). The commercial exploitation of NTFPs will therefore be an integral component of the future development of rural economies across the region, irrespective of whether or not these activities are ultimately ecologically desirable. Consequently, there is a clear need for an assessment of the viability of NTFP extraction to guide this process, particularly in areas with no history of commercial harvesting.

The NTFP paradigm is characterised by a discrepancy between the apparent abundance of useful products contained in intact primary forest areas, and the difficulty of developing a commercial trade in an NTFP resource that is economically and ecologically sustainable (Belcher and Schreckenberg 2007). Pioneering valuations of primary forests demonstrated the high density of plant resources with a utility value (Myers 1988; Peters et al. 1989) but failed to account fully for the many ecological, social, and economic factors which, in aggregate, determine the potential for commercial NTFP harvesting. Ecological constraints include the spatial distribution (Klimas et al. 2007), demographic impacts of harvesting (Freckleton et al. 2003), and harvest yields (Medeiros and Vieira 2008) of the resource. Socioeconomic constraints to commercial viability include the physical accessibility of the resource to extractors (Peres and Lake 2003), the financial and opportunity costs of harvesting (Marshall et al. 2006), and the characteristics of local markets (Ruiz-Perez et al. 2004).

A comprehensive synthesis that draws together these elements of NTFP harvesting can facilitate a quantitative assessment of the potential of a resource to generate revenue and contribute to rural livelihoods. However, few studies have addressed the multiple constraints to a single NTFP case-study. Here, we adopt a holistic approach to estimate the potential offtake of an Amazonian NTFP, focussing on the distinction between the actual resource stock and that which is available to extractors.

The oleoresin harvested from trees of the genus *Copaifera* is an economically-important NTFP occurring throughout the neotropics (Plowden 2004). Tree oils and resins represent an attractive extractive resource option, since these products are non-perishable and have a relatively high value per unit weight (Menezes et al. 2005). *Copaifera* oleoresin was historically collected using destructive harvest methods by either axing a wedge in the basal tree trunk, or simply draining the oleoresin when felling the tree for timber (Plowden 2004). Contemporary extractors drill a hole into the trunk from which oleoresin is drained; if the hole is then plugged, oleoresin deposits may be replenished over time (Newton et al. 2011). Widely harvested in Brazilian Amazonia, the oleoresin is valued for its therapeutic properties, which include anti-inflammatory and analgesic uses (Veiga Junior and Pinto 2002). The state of Amazonas is the principal source of *Copaifera* oleoresin in Brazil, producing 89% of the total 538 metric tons recorded in sales in 2009 (IBGE 2011). The state's production was worth R$3.4 million (approximately USD 2.2 million; R$1 = USD 0.64, June 2011) in 2009, but 94% of this oleoresin originated in just two adjacent municipalities, Apuí and Novo Aripuanã, in south-eastern Amazonas. *Copaifera* oleoresin is therefore a good candidate resource for commercial harvesting in other areas seeking to expand their extractive economies (Menezes et al. 2005).

Using *Copaifera* oleoresin as an example, this study aims to demonstrate how an integrative approach can contribute to an understanding of the extractive resource potential of an NTFP. We aim to address the multiple constraints that contribute to an assessment of the viability of commercial offtake, to generate robust landscape-scale estimates of the potential volumes and economic values of this important Amazonian resource.

5.3 Methods

5.3.1 Study site

The study was conducted within and around two large contiguous extractive reserves bisected by the Juruá River, a major white-water tributary of the Amazon (Solimões) River of western Brazilian Amazonia. The federally-managed Médio Juruá Extractive

Reserve (hereafter, *ResEx Médio Juruá*) occupies 253,227 hectares, whilst the larger, state-managed Uacari Sustainable Development Reserve (hereafter, *RDS Uacari*) is 632,949 hectares in area (ARPA 2009; Fig. 5.1).

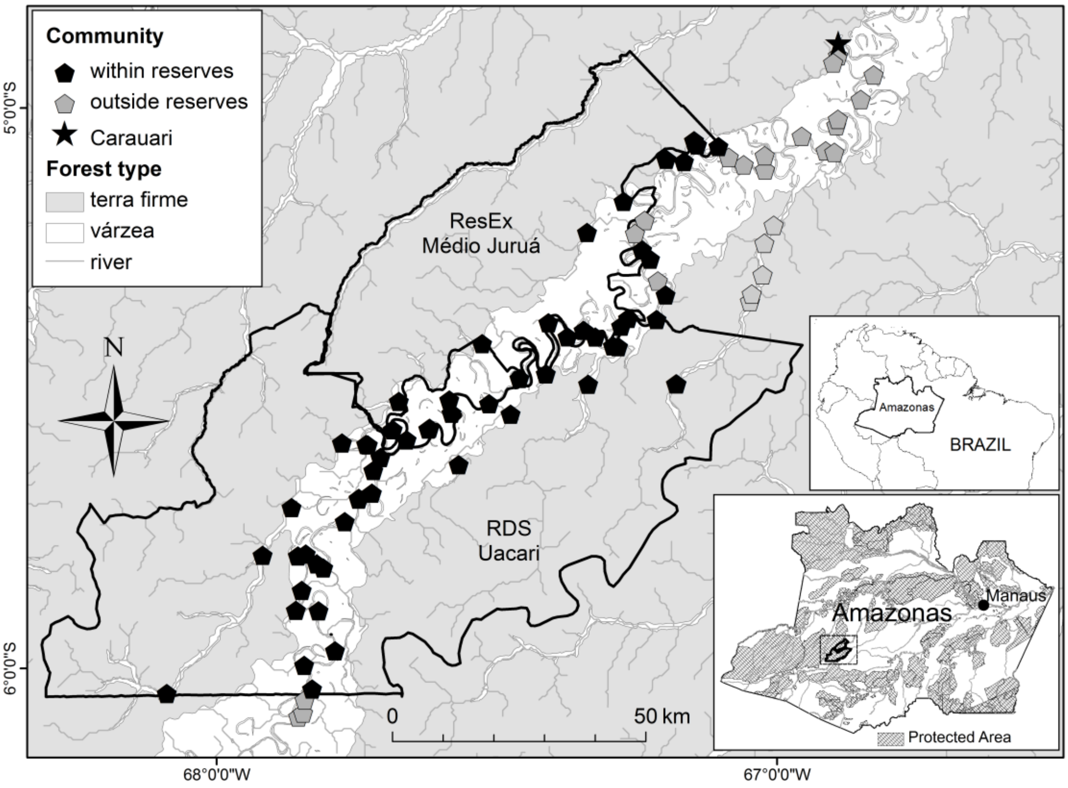

Figure 5.1. *Location of communities within and immediately outside the boundaries of the Uacari Sustainable Development Reserve and the Médio Juruá Extractive Reserve in the state of Amazonas, Brazil. Insets show the locations of Amazonas within Brazil (above), and the study area within the full protected area network of Amazonas (below).*

A 10 – 20 km wide band of seasonally flooded (*várzea*) forests spanning the main river channel is subjected to a prolonged flood-pulse every year between January and June, whilst *terra firme* forests on higher elevation have never flooded, at least since the Pleistocene. The elevation is 65 – 170 m above sea level and the terrain is flat or moderately undulating. The area has a wet, tropical climate; rainfall recorded at the Bauana Ecological Field Station (S 5°26' 19.032" W 67°17' 11.688") during the study period indicated that 3,659 mm and 4,649 mm of rain fell annually in 2008 and 2009, respectively. The study area consisted of intact primary forest which had experienced virtually no logging activity except for some historical selective removal of key timber species (including *Copaifera* spp.) from várzea forest between 1970 and 1995 (Scelza 2008). There is little historical tradition of *Copaifera* oleoresin extraction within this area, but the commercial harvesting of this resource is currently being actively encouraged through the provision of training and materials by a state government agency (the *Instituto de Desenvolvimento Agropecuário e Florestal Sustentável do Estado do Amazonas* (IDAM)).

The ResEx Médio Juruá and the RDS Uacari, which were decreed in 1997 and 2005, respectively, are currently inhabited by some 4,000 legal residents, living in ~74 communities of 1 – 89 households each. Many communities are located on the main river channel, whilst others are found on the banks of tributaries and oxbow lakes on either side of the Juruá River. Residents of these extractive reserves are variously engaged in agricultural and extractive activities for both subsistence and cash income (SDS 2010).

5.3.2 Study species

Copaifera species are hardwood canopy trees occurring in primary forests throughout both the neo- and afro-tropics in much of South America and western Africa (Veiga Junior and Pinto 2002). A recent review recognised nine species of *Copaifera* in Brazilian Amazonia (Martins-da-Silva et al. 2008). Four of these species occurred within the study area: *C. guyanensis*, *C. multijuga* and *C. piresii* occurred in terra firme forest, whilst *C. guyanensis* and *C. paupera* occurred in várzea forest (Newton et al. in review). These species were identified using the taxonomic key provided by Martins-da-Silva et al. (2008) before being compared against voucher specimens previously identified by R. Martins-da-Silva in the herbarium of the Botany Department of the Instituto Nacional de Pesquisas da Amazônia (INPA), Manaus. Numbered voucher specimens of each species identified during this study have been deposited at the INPA herbarium.

5.3.3 Data acquisition

This study was conducted within the context of an interdisciplinary research project aiming to understand the dynamics of extractive practices within multiple-use Amazonian forest reserves. In this paper we combine data on human population distribution, forest accessibility, and market values with data on *Copaifera* spatial distribution (Chapter 3), *Copaifera* oleoresin yields (Newton et al. 2011), and household incomes (Newton et al. in press *b*).

5.3.3.1 Ecological data

Two previous studies, both of which were conducted within the same study landscape, were used as sources of ecological data from which to estimate potential oleoresin yield. We combined mean density values of *Copaifera* spp. trees ≥25 cm DBH, with data on the spatial distribution and adult size distribution of each *Copaifera* species (Chapter 3). Estimates of oleoresin yield likelihood and harvest volumes from initial and repeat harvests, adjusted by tree DBH, were taken from Newton et al. (2011) (Table 5.1).

5.3.3.2 Socioeconomic data

We collected socioeconomic data from 127 households across 10 communities in the ResEx Médio Juruá, three communities in the RDS Uacari, and two communities immediately outside these reserves, all of which were located along a 380-km section of the Juruá River (Fig. 5.1). Comprehensive weekly offtake surveys were conducted in 82 households across 10 communities between March 2008 and July 2010 (see Newton et al. in press *a* for details of methods). Mean weekly household incomes were taken from Newton et al. in press *b*). The location of every settlement within the study site was mapped using a handheld GPS unit and the number of households recorded.

5.3.3.3 Market data

The economic value of *Copaifera* oleoresin was assessed from surveys of sales at three hierarchical market levels. Within the reserves, in addition to the surveyed households, known extractors were asked to note the volume and transaction prices of oleoresin offtakes that they sold. In the nearest municipal town (Carauari) we interviewed the owner of the only wholesale retailer regularly purchasing *Copaifera* oleoresin. In the state capital (Manaus) we conducted market price surveys in the main city port and with nearby retailers.

5.3.4 Data analysis

5.3.4.1 Reserve area

We calculated the combined area of the two reserves in ArcGIS 9.3, using polygon shapefiles which matched the physically demarcated boundaries of these protected areas. We excluded all areas outside the reserve boundaries; although this intact forest is accessible to reserve residents, it is also used by people living outside of the reserves and so was discounted from our estimates of reserve-scale productivity. However, we

Table 5.1. *Empirical values of tree size, tree density and oleoresin yield volumes used to estimate the reserve-scale stock of* Copaifera *oleoresin within the Uacari Sustainable Development Reserve and the Médio Juruá Extractive Reserve in the state of Amazonas, Brazil.*

						Initial harvest			Repeat harvest	
Forest type	**Species**	**DBH (cm)** [a]		**Density (trees ha $^{-1}$)** [a]		**Proportion of yielding trees** [b]	**Oleoresin yield (ml)** [c]		**Proportion of yielding trees** [b]	**Mean proportion of original yield** [b]
		Mean	**SD**	**Mean**	**SD**		**Mean**	**SD**		**Mean**
terra firme	*C. multijuga*	36.3	9.1	0.22	0.28	0.63	481.2	936.2	0.63	0.44
várzea	*C. guyanensis*	47.7	14.2	0.05	0.11	0.36	175.5	319.2		
várzea	*C. paupera*	42.7	14.1	0.31	0.28	0.28	170.9	674.6		

[a] values taken from Chapter 3

[b] values taken from Newton et al. (2011)

[c] values calculated using the size (DBH) vs. yield relationships described in Newton et al. (2011) (the same relationship was assumed for *C. paupera* as for *C. guyanensis*)

Table 5.2. *Travel velocity parameters (in km h $^{-1}$) used to estimate the spatial accessibility of forest areas used by extractors from local communities in the Uacari Sustainable Development Reserve and the Médio Juruá Extractive Reserve in the state of Amazonas, Brazil.*

		Season	
Transport	**Habitat**	**High-water**	**Low-water**
Foot	Terra firme	3 km h^{-1}	3 km h^{-1}
	Várzea	inaccessible	3 km h^{-1}
Motorised canoe	Upstream	6 km h^{-1}	4 km h^{-1}
	Downstream	8 km h^{-1}	6 km h^{-1}

included the small pocket of nominally unprotected forest encapsulated between the two reserves (Fig. 5.1), since this is accessible only by reserve residents. The total area included (889,499 ha) was thus slightly larger than the combined official areas of the two reserves (ARPA 2009). The area covered by terra firme and várzea forest was calculated in ArcGIS, using the vegetation classification used by Projeto RADAMBRASIL (1977).

5.3.4.2 Forest accessibility

Anisotropic accessibility models were generated in ArcGIS 9.3 to estimate the total forest area physically accessible to communities in both the low- and high-water seasons. We considered resource accessibility to be determined by the combined constraints of transport, time, and land-use (Geurs and Ritsema van Eck 2001). We imposed an upper limit of 12 hours per day to harvest the resource and allocated four hours for locating and drilling trees, thereby capping the return travel time at eight hours. Travel from a community could be by motorised canoe, on foot, or by canoe and then on foot. Travel velocity parameters were estimated from GPS tracks recorded *in situ* and varied according to the mode and direction of travel (up- or down-stream), the habitat traversed (terra firme or várzea) and the season (Table 5.2). High-water season fluvial travel velocities were increased as a proxy for reduced travel distances resulting from available fluvial short-cuts through meandering channels. However, várzea forest was inaccessible on foot during the high-water season (approximately January – June).

Two cost distance analyses were conducted to estimate the total accessible area of forest. Firstly, we calculated the geographic limits of fluvial travel for each community, using the WWF hydrosheds river network data for Amazonia (Lehner et al. 2006). Each 250-m stretch of river was allocated a cost value based upon the time expended to reach it from the nearest community. Secondly, we modelled the accessibility of terra firme and várzea forest on foot, radiating from the entire extent of accessible rivers, oxbow lakes, and perennial streams and constrained by the remaining travel time. Major streams, rivers and lakes were modelled to act as barriers to travel on foot.

5.3.4.3 Total forest productivity

The estimated oleoresin production (ml ha^{-1}) of each forest type was calculated as a function of mean tree density and oleoresin productivity for each species, using the parameter values presented in Table 5.1. We interpreted the mean oleoresin yield frequencies and volumes (Newton et al. 2011) as indicating that *C. multijuga* was the only species providing viable offtakes in terra firme forest, and that both *C. guyanensis* and *C. paupera* were viable sources of oleoresin in várzea forest. Potential offtake was therefore calculated for these three species, assuming that no trees had been previously harvested. Estimates were repeated using an empirically-derived lower value of oleoresin yields to represent the realistic potential for repeated harvests (Table 5.1). The stock volume of oleoresin available to extractors was estimated by multiplying the physically accessible area (ha) of each forest type by the per hectare oleoresin productivity values. Estimated volumes were in turn converted to monetary values based on trade survey data. Standard deviation values were used throughout to generate estimates of variance.

5.4 Results

5.4.1 Total forest productivity

The combined forest area of the RDS Uacari and ResEx Médio Juruá was 889,499 ha, of which 685,362 ha were terra firme forest and 204,137 ha were várzea forest. The density of *C. multijuga* trees ≥25 DBH within terra firme forest (mean ± SD) was 0.22 ± 0.28 trees ha^{-1} whereas the combined density of *C. guyanensis* and *C. paupera* within várzea forest was 0.36 ± 0.30 trees ha^{-1} (Table 5.1), resulting in a total estimate for the combined reserve area of 150,780 ± 191,901 *C. multijuga* trees in terra firme forest and 73,489 ± 61,411 *Copaifera* spp. trees in várzea forest.

Várzea forest had a higher density of trees than terra firme forest but the mean per tree productivity of *C. multijuga* (481.2 ± 936.2 ml) was more than twice as high as either of the two várzea forest species (Table 5.1). The estimated potential initial yield volume of oleoresin available per ha was therefore very similar in both terra firme forest (67.0 ± 155.9 ml ha^{-1}) and várzea forest (63.9 ± 235.8 ml ha^{-1}).

5.4.2 Proportion of forest accessible to extractors

In the low-water season, an estimated total of 305,906 ha of terra firme forest (44.6 % of the total) and 191,431 ha of várzea forest (93.8 % of the total) were accessible within an 8-hour return travel time by at least one community within the two reserves. A more extensive area of terra firme forest (393,869 ha) was accessible in the high-water season, since higher water-levels allowed farther upstream travel. Conversely, várzea forest was inundated and therefore inaccessible on foot during this period (Fig. 5.2).

Our models show that a greater area of várzea forest than terra firme forest was accessible within shorter travel times of less than ~250 min (Fig. 5.3), since most communities were located along the main river channel. Longer travel times (~250 – 480 min) allowed access to increasingly greater proportions of terra firme forest, since most of the accessible várzea forest could be reached within a ~300-min return journey.

5.4.3 Estimate of harvestable resource volume

The similarity of the estimated per ha yield volumes meant that the predicted availability of oleoresin in the two forest types at different travel distances closely matched that of forest accessibility (Fig. 5.3). The total aggregate volume of *Copaifera* oleoresin that might be accessed by communities from the initial harvest of trees was estimated to be 38,635 ± 1,176,251 litres (26,408 ± 903,892 litres in terra firme forest and 12,227 ± 752,692 litres in várzea). In the low-water season, the maximum aggregate volume across both forest types was 32,737 ± 1,021,651 litres, whilst the high-water season total was 26,408 ± 903,892 litres. A subsequent reharvest of the same tree populations was estimated to produce an additional potential volume of 8,274 ± 2,888 litres (terra firme: 7,324 ± 2,878 litres; várzea: 950 ± 235 litres). However, the longer-term sustainability of extraction depends upon subsequent rates of oleoresin renewal, for which no data are available.

5.4.4 Economic value of *Copaifera* oleoresin

5.4.4.1 Current harvest levels and market values

The harvest of *Copaifera* oleoresin was an uncommon activity in these reserves, being reported on just eight occasions by four different households – from a total of >6,000 weekly surveys across 127 households. Extracted oleoresin volumes ranged from 300 ml to 3 litres, and was both sold (3 occasions) and consumed (5 occasions). Additionally, one extractor living in the RDS Uacari reported selling 5.8 litres of oleoresin between May and October 2009, principally to other residents within the two reserves ($N = 20$ sales). Oleoresin was sold for R$14 litre^{-1} if sold in larger quantities (≥500 ml), or for R$30 litre^{-1} if sold in 100 ml bottles. A second extractor reported making a single sale of 1.5 litres for R$25 to a trader in the port of the nearest municipal town, Carauari. The main trader of oleoresin in Carauari reported buying the product from extractors for R$12 – 15 litre^{-1} and selling to consumers for R$20 litre^{-1}. This was consistent with the prices reported by extractors. Both extractors and the shopkeeper

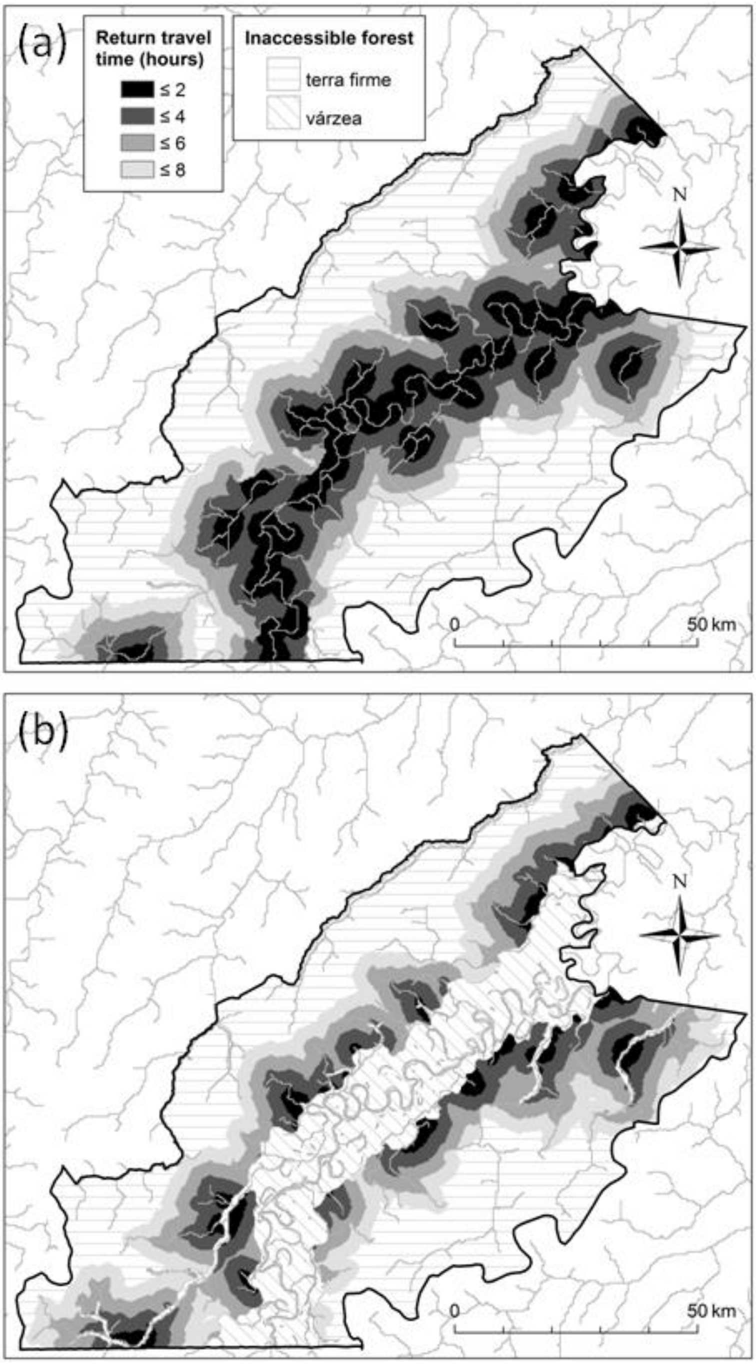

Figure 5.2. *Accessibility of forest within the Médio Juruá Extractive Reserve and the Uacari Sustainable Development Reserve, in the state of Amazonas, Brazil. Grey-scale shading indicates forest areas that may be accessed from a community within a maximum eight-hour return journey time in either the (a) low-water or (b) high-water season. Hatched areas indicate forest that was inaccessible to all communities, as a consequence of either seasonal flooding (várzea forest) or remoteness (terra firme forest).*

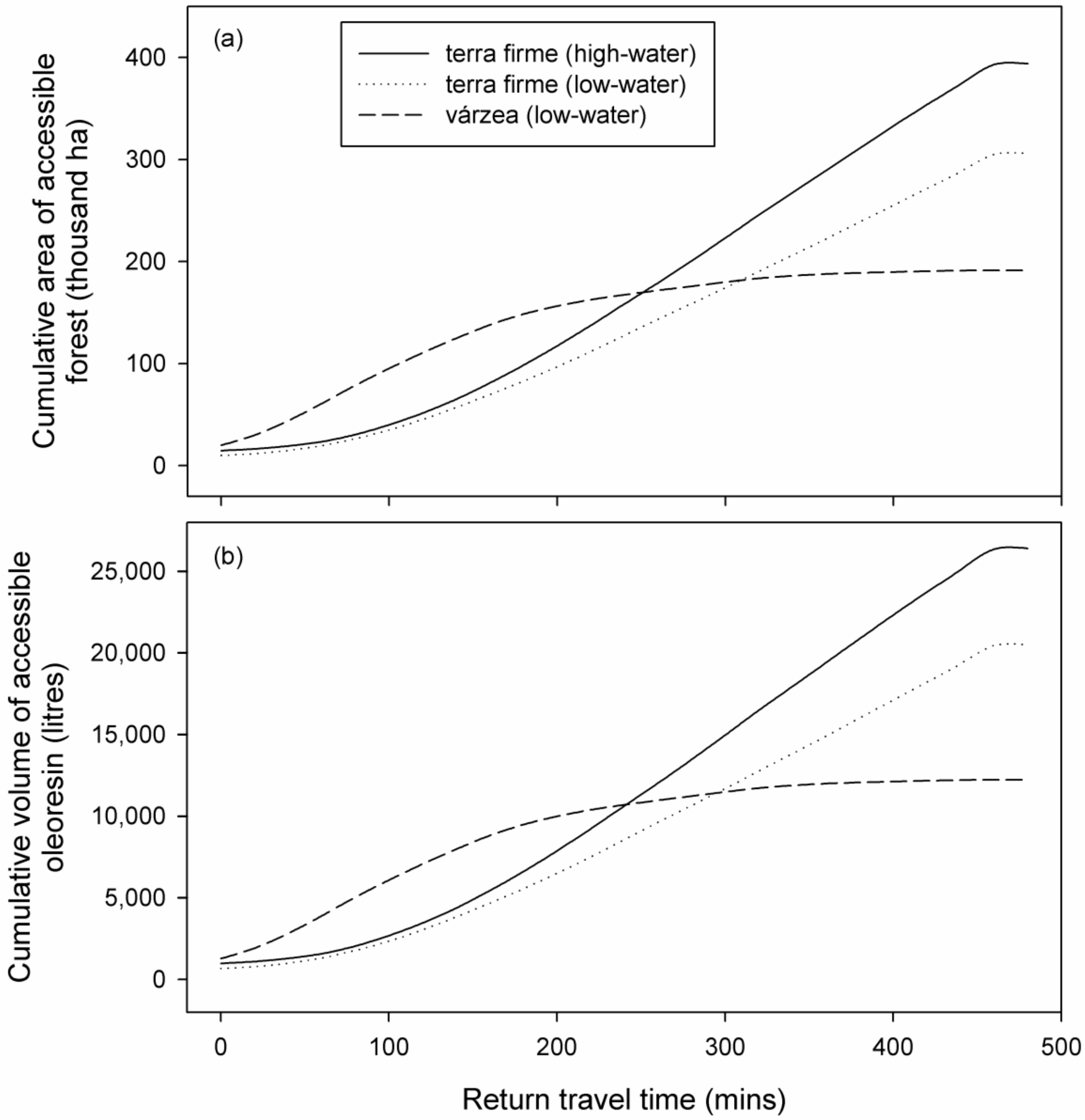

Figure 5.3. *Relationship between metrics of forest accessibility and extractor travel time from communities in the Médio Juruá Extractive Reserve and the Uacari Sustainable Development Reserve, in the state of Amazonas, Brazil. In relation to the time (min) allocated to a return trip by canoe and/or on foot, and for terra firme and várzea forest in the high- and low-water seasons, plots indicate (a) the cumulative area of accessible forest and (b) the estimated cumulative volume of* Copaifera *oleoresin within that forest.*

reported an unsaturated local market for *Copaifera* oleoresin, with demand consistently exceeding supply.

In the port of Manaus, the state capital of Amazonas (2010 population ≈ 1.8 million), four vendors of informally-labelled *Copaifera* oleoresin reported retail prices ranging from R\$20 – R\$50 litre^{-1} (mean = R\$32.19 ± 11.38, *N* = 10 products). Bottled oleoresin volumes ranged from 50 to 1000 ml. Two other vendors sold more formal products that were labelled with the source location, species, or processing company. These product prices ranged from R$100 – R$333 litre^{-1} (mean = R$188.89 ± 126.20, $N = 3$), for bottled volumes between 20 and 30 ml.

5.4.4.2 Potential economic value of the accessible resource

Using a conservative trading value to the extractor of R$14 litre^{-1}, we estimated the stock of *Copaifera* oleoresin accessible from previously-unharvested trees within these two reserves to be worth R$540,889 ± R$16,467,514. At the same market value, the value of oleoresin from a subsequent repeat harvest is projected to be R$115,838 ± R$40,431.

5.5 Discussion

The distribution, productivity, and accessibility of tropical NTFPs are highly spatially and temporally variable. The total yields that can be viably extracted are constrained by characteristics of the resource, the geography of the harvest landscape, the demography and distribution of the extractor population, and market idiosyncrasies. In aggregate, these constraints exacerbate the discrepancy between the potential and actual resource stock volumes that can be feasibly harvested, regardless of the degree to which these offtakes are sustainable. Here, we explore these constraints and show how they can limit NTFP commercialisation in both space and time.

5.5.1 Spatial and temporal constraints

5.5.1.1 Resource distribution and productivity

The potential stock volume of any plant NTFP is determined largely by the product of the species density across the landscape and the per plant productivity. Within this study site, as in others, productive *Copaifera* trees were sparsely distributed; only one species in terra firme forest and two in várzea forest provided evidence of significant oleoresin production, and these species were found at low densities (0.05 – 0.31 ha^{-1}). Moreover, only 28 – 63% of trees of these species yielded any oleoresin at all and even then the volume produced within a single extraction event varied by several orders of magnitude (1 – 4,246 ml) (Newton et al. 2011). Therefore, although individual trees may produce up to 4.2 litres of oleoresin in a single harvest, extractors may have to drill numerous trees before encountering one that yields an economically-viable oleoresin volume.

Consequently, our estimates of per unit area oleoresin production are relatively low, averaging only 67.0 ml ha^{-1} and 63.9 ml ha^{-1} in terra firme and várzea forest, respectively.

Similar constraints apply to other important Amazonian NTFP tree species. For example, densities of Brazil nut (*Bertholletia excelsa*) trees have been reported as being similarly low, at 1.35 trees ≥10 cm DBH ha^{-1} (Wadt et al. 2005). Secondly, and similarly to *Copaifera*, rubber (*Hevea* spp.) trees show variation in yield between species and forest types. Not all rubber trees produce latex, and densities of tappable trees may be as low as 1 – 1.5 ha^{-1} (Schroth et al. 2003). In our study site, *Hevea* spp. occurred in both forest types but in terra firme forest the congener produces an inferior quality of latex for which no market is currently available. Finally, some NTFPs such as Brazil nuts and other trees harvested for their fruits and seeds show large supra-annual variation in productivity at either the individual or population level (Bhat et al. 2003; Kainer et al. 2007). Even in productive years, such NTFPs are only available for harvest during a limited period of the plant phenological cycle. In contrast, *Copaifera* trees may be harvested at any time of year – although seasonality may influence the yield volumes of oleoresin (Ferreira and Braz 2001).

5.5.1.2 Physical accessibility

The spatial distribution of the human population of much of rural Amazonia is largely determined by fluvial geography. In the absence of roads, rivers provide the principal means of transport, so that all communities in our study area were located along the edge of permanent water-bodies including the main Juruá river channel, perennial tributaries, and oxbow lakes. We estimated that within an 8-hour return journey, reserve residents could travel up to 27 km along this fluvial network and up to 12 km on foot within the forest to harvest forest resources for subsistence and commerce. We capped travel time at a single day’s maximum travel distance, but extractor incentive to travel to these farther areas is clearly a trade-off between resource value and the investment of time, energy, and fuel required to harvest that resource, in addition to the opportunity cost incurred. Here we applied our accessibility models to the extraction of *Copaifera* oleoresin, but the models could be equally extended to any other extractive resource for which similar spatial and temporal constraints apply.

5.5.1.3 Local geography

As a consequence of the spatial configuration of local communities and the desire of extractors to minimise travel costs, a resource is likely to become locally depleted in more accessible areas (Belcher and Schreckenberg 2007). In contrast, 379,476 ha of the forest in our study reserves farther from the main river channel (44.7% of the total reserve area) were entirely depopulated and essentially inaccessible to extractors (Fig. 5.2). Resources contained within these remote forest areas were therefore likely to remain unexploited.

The potential for communities to harvest resources depends in part on the relative accessibility of terra firme and várzea forest, which varied widely in these reserves. For example, terra firme areas for different communities accounted for between 0% and 66% of forest within a 5-km radius (Newton et al. in press; Fig. 5.1). Similar yields per unit area were estimated for várzea forest as for terra firme forest, but the former forest type was more easily accessible. In terms of reduced costs of transport and time, we therefore predict that *Copaifera* oleoresin harvesting will be more profitable – and more attractive – for extractors in communities with greater access to surrounding várzea forest.

The spatial distribution of, and current engagement with, other resources may also be a constraint on the total realised harvest. An extractor may be more incentivised to exploit an NTFP resource if it can be harvested opportunistically whilst engaging in a secondary activity such as hunting, effectively reducing the cost associated with harvesting a single class of product.

5.5.1.4 Seasonality

Várzea forest is accessible on foot only during the low-water season, so extraction of terrestrial resources from this forest type is restricted to these months (Fig. 5.2). For example, rubber is one of the principal commercially-exploited NTFP in our focal reserves but can only be harvested from várzea forest between August and December, and the same constraint applies to the extraction of *Copaifera* oleoresin. In contrast, terra firme forest is accessible on foot all year-round – although the accessible area of this forest type was 29% greater in the high-water season. Furthermore, for many communities it is easier to access terra firme forest during the high-water season when canoes can be used to both bypass the intermediary várzea forest and facilitate transportation of forest resources; a walk of up to several hours may be necessary during the low-water season just to overcome the várzea floodplain and reach the terra firme boundary.

5.5.2 Economic constraints

5.5.2.1 Current markets

The sales prices per litre of *Copaifera* oleoresin recorded by our trade surveys were lower than those reported by a recent national report on Amazonia-wide trade values (range: R$15 – R$50 litre^{-1}; Imazon 2011) but higher than those previously reported (e.g. Belem: USD 10 litre^{-1}, Shanley et al. 2002; Rio Branco and Porto Velho: R$0.50 – R$15 litre^{-1}, Leite 1998; R$1 ≈ USD 0.64, June 2011). This discrepancy probably results from the increasing value of *Copaifera* oleoresin: Shanley et al. (2002) reported a doubling in price of this resource between 1994 and 2000, and national trade data showed that the value per ton of oleoresin increased linearly from R$281 to R$7,710 between 1990 and 2009 (IBGE 2011). Price elasticity in response to dynamic supply and demand curves clearly affects the value of the product to extractors, but the general trend for increasing prices and greater demand from international as well as domestic markets is an indication that markets for this and other NTFPs may be growing.

Accessibility of stable urban markets has often been cited as a significant barrier to trade opportunities (e.g. Parry et al. 2010). However, the importance of distance from individual communities to the nearest urban centre may be much reduced by favourable product and market conditions. For example, *Copaifera* oleoresin is a non-perishable resource with a long shelf-life and a high value per unit weight. Extractors can therefore afford to wait for the optimum timing to transport these goods to markets, often by combining these trips with other reasons for visiting the town. Additionally, in our focal reserves, *cantinas* (small shops) operated by residents' associations are now operating in many communities, providing local trade opportunities for agricultural and extractive products. These purchase agricultural and extractive goods and sell non-perishable consumables at prices that match those of urban markets. These local markets effectively subsidise reserve residents by removing the traditional barrier of prohibitive transport costs associated with settlements far from urban markets.

5.5.2.2 Contribution to rural economies

Rural Amazonian communities vary in the extent to which they engage in either agricultural or extractive income-generating activities (Newton et al. in press *a*). Communities whose cash economies are derived primarily from extractive resources may more readily engage with an extractive initiative such as *Copaifera* oleoresin exploitation, which is likely to be more compatible with their current time-budgets and patterns of forest access. Household cash incomes within these reserves ranged from R$55 to R$1,656 month^{-1} (mean = R$563 ± 349, $N = 82$; Newton et al. in press *b*). At a price of R$14 litre^{-1}, a household harvesting only two litres of *Copaifera* oleoresin per month would generate 5% of this mean revenue. Our estimates of accessible oleoresin volumes suggest that the resource stock is insufficient to support this level of offtake by all reserve households, but imply that, even given current market values, oleoresin extraction could make a meaningful contribution to some households' incomes.

5.5.2.3 Adding value

NTFP certification is a mechanism by which to add value to a product whilst encouraging sustainable forest resource management (Shanley et al. 2005). Schemes that certify the geographic source, extraction method, tree species, and purity of a product are likely to benefit both consumers and extractors (Shanley et al. 2005). Certification standards have been approved for many NTFP, including *Copaifera* oleoresin in some areas (Imperador et al. 2009). However, the adulteration of *Copaifera* oleoresin with vegetal oils by traders remains a widespread problem that can reduce the value of the resource by artificially inflating supply and lessening consumer confidence in the product (Barbosa et al. 2009). The development of simple purity tests based on refractive indices and thin layer chromatography could help to eliminate this problem (Barbosa et al. 2009). A greater understanding of the variation in physical and chemical properties of oleoresins from different *Copaifera* species may also add considerable value to this resource (Veiga Junior et al. 2007). Our market data suggest that labelled and marked oleoresin may generate revenues five times higher than equivalent quantities that are less formally sold.

5.5.2.4 Subsidised extractive industries

Formal markets for many NTFPs are an increasingly common component of the economies of many extractive reserves, particularly as PES programmes and government initiatives actively support the start-up of extractive industries. For example, several NTFPs extracted within our focal reserves benefit from secure markets with annually-designated buying prices. Firstly, the fixed price at which extractors sell *Hevea* latex (from rubber trees) has been maintained by subsidies from both a reserve cooperative and the state government. Secondly, the local cooperative equitably allocates an annual contract of purchase quotas for forest-harvested *andiroba* seeds (*Carapa guianensis*, Meliaceae) and then collects these directly from each community (Rizek 2006). The oil extracted from these seeds within a small processing plant in a community in the ResEx Médio Juruá is then sold directly to a large national cosmetics company (Natura 2007). This bypasses the traditional market chains consisting of several middlemen, thereby attracting more favourable buying prices for extractors. Our data showed minimal current engagement with commercial *Copaifera* oleoresin harvesting, but we suggest that if a similarly well-defined market chain can be developed for this resource then its value to extractors, and thus their motivation to harvest, would increase substantially.

5.5.3 Conclusions

Forest extractivists have an excellent knowledge of the spatial distribution of forest resources and are able to optimise the efficiency of harvesting trips by minimising travel times and distances between resources. However, we have shown how the interaction of ecological, sociodemographic, and economic constraints can affect the potential for the commercial exploitation of an NTFP resource. In particular, spatial and temporal access to different forest types determine the total value of resource available to extractors. An extractor may be more incentivised to harvest a commercially valuable resource if a stable or subsidised market exists for that NTFP. Under favourable market conditions, *Copaifera* oleoresin could be a valuable addition to a diversifying portfolio of extractive resources in Amazonian reserves.

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Chapter 6

Consequences of actor level livelihood heterogeneity for additionality in an undifferentiated payment-based payments for environmental services programme in a tropical forest region

Photo: Payments for environmental services (Wunder et al. 2005)

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6.1 Abstract

Primary tropical forests provide crucial environmental services, including carbon storage and hydrological regulation. Options for promoting forest conservation include payments for environmental services (PES) programmes that provide financial incentives to local actors, in exchange for reduced forest clearance. The success of voluntary PES (defined in terms of avoided primary forest conversion) is contingent upon behavioural changes in enrolled actors. As both the degree of enrolment and likelihood of sustained behavioural change depend upon how PES compensation structures interact with existing actor economies, local heterogeneity in livelihood strategies may play a strong role in the ultimate success of PES programmes, particularly when compensation is not differentiated with respect to opportunity costs. We examined the influence of livelihood heterogeneity on the potential success of a deforestation-reduction PES with an undifferentiated reward structure. We collected socioeconomic and demographic data at the household and community levels across two large Amazonian extractive reserves where a spatially extensive PES programme (*Bolsa Floresta*) operates. We show that demographic and socioeconomic status varies widely across both households and communities, and found that households and communities that are most and least likely to convert primary forest receive similar financial incentives. Those households most engaged in manioc agriculture (the primary driver of local primary forest conversion) both benefitted from the highest annual incomes and incurred the greatest opportunity costs. We show that avoided primary forest conversion could be greatly increased with differentiated payment structures adjusted for local differences in opportunity costs and livelihood strategies, and present two metrics that could help to achieve that goal.

6.2 Introduction

Tropical forest biomes harbour the highest levels of terrestrial biodiversity on Earth, provide key environmental services, and support the livelihoods of millions of rural people (Chhatre and Agrawal 2009). However, tropical forest loss continues – driven by a multitude of factors including human-induced land-use change and forest degradation (Rudel et al. 2009). In the last two decades, emissions from tropical deforestation have contributed 15-23% of the annual global carbon emissions, particularly if subsequent land-use is considered (van der Werf et al. 2009). To stem future losses of forest cover, government and non-governmental agencies are increasingly embracing the implementation of payments for environmental services (PES) programmes.

Environmental services (ES) are aspects of ecosystems used to produce human wellbeing, either actively or passively (Boyd and Banzhaf 2007; Fisher et al. 2009). PES programmes provide a mechanism through which the values of these services can be converted into financial incentives for conservation (Engel et al. 2008; Wunder et al. 2008). Economic decision-making often fails to fully account for environmental service provision (Liu et al. 2010); direct or market-based incentives such as PES therefore seek to transfer funds from those that benefit from environmental services to those that contribute to their production or conservation by inducing benign land-use practices (Wunder 2005; Sommerville et al. 2009). PES have been broadly defined as "(1) a *voluntary* transaction where (2) a *well-defined* ES (or corresponding land use) is (3) being 'bought' by a (minimum one) ES *buyer* (4) from a (minimum one) ES *provider* (5) if and only if ES provision is secured (*conditionality*)" (Wunder 2005).

There is a growing demand to understand the extent to which PES programmes contribute to concrete environmental gains (Wunder et al. 2008; Redford and Adams 2009). The overall success of any given PES programme can be measured in terms of enrolment, conditionality, additionality, permanence, and leakage (Engel et al. 2008). Firstly, potential service providers must be voluntarily attracted to *enrol* in the programme. Secondly, the *conditionality* of service supply requires not only adequate compensation for enrolled providers but also a monitoring system and penalty structures (Meijerink 2008). Thirdly, enrolment and compliance must jointly produce *additionality*; a change in land-use beyond what would have happened in the absence of the programme. Should unrewarded land-use decisions by PES recipients be exactly the same, no additional services have been secured (Engel et al. 2008). Whether additionality can be expected to persist over time (*permanence*) and whether gains in additionality come at the cost of displacing ecologically perverse land-use practices to areas outside the project boundaries (*leakage*) are important additional metrics of success for any PES programme.

Fundamental to enrolment, compliance, and ensuing additionality are PES programmes' payment structures (Wunder et al. 2008). Many programmes compensate enrolled participants depending on the opportunity cost incurred by transitioning to the PES-compliant land use, using metrics to assess the degree of behavioural change entailed or the relative value of the land involved. Programmes with such *differentiated payments* are more often seen in user-financed (rather than government-sponsored) programmes implemented across small spatial scales. Examples of PES structures involving at least a degree of differentiation include the *Pago de Servicios Ambientales Hidrológicos* (PSAH) in Mexico (Muñoz-Piña et al. 2008), the Vittel watershed protection programme in France (Perrot-Maître, 2006), and the *Pimampiro* programme in Ecuador (Wunder and Albán 2008). The degree of refinement of differentiated payment schemes varies greatly; from broad categories of land type (e.g. the PSAH pays a higher rate to landowners protecting cloud forest), to custom pricing for individual plots within landholdings (e.g. the Vittel PES). In contrast, other programmes uniformly distribute benefits across all enrolled ES providers, regardless of variance in individual opportunity costs (i.e. *undifferentiated payments*). Such programmes include many government-financed schemes and pay undifferentiated rates per unit land area. This flat-rate reward structure is often necessary as a consequence of vast spatial extents, equity concerns or intractable transaction costs. Examples of undifferentiated payments programmes include *Socio Bosque* in Ecuador (Chíu 2009) and *Los Negros* in Bolivia (Asquith et al. 2008). PES programmes whose payments are neither differentiated by opportunity cost nor by the extent of land area committed include the *Simanjiro* PES agreement in Tanzania (Nelson et al. 2010) and *Bolsa Floresta* in Brazil (Viana 2008).

Although the development and poverty alleviation goals of PES programmes are usually considered secondary to their environmental aims (Engel et al. 2008), PES are often implemented in poor areas, where perceived or actual financial or development benefits may influence both the initial commitment and subsequent adherence to programme requirements by individual actors (Wunder 2008). Given that payments in PES programmes are often targeted at both the actor (households) and community levels, an understanding of local economic or livelihood factors that influence enrolment or compliance at both levels of organisation will have strong implications for ultimate programme success (Wunder 2007). However, few data are available to explicitly link local livelihood strategies to the effect size of alternative PES payment structures.

The rural livelihood strategies of individual households and communities within legally-occupied Amazonian reserves (hereafter, *extractive reserves*) tend to be very heterogeneous, with variable engagement with agricultural and extractive activities and consequential reliance on different forest types (Takasaki et al. 2001; Coomes 2004; Long 2010). Households show strong congruence in livelihood strategy within any given community, but accessibility to alternative forest types results in strong inter-community variation in both livelihood strategy and the degree to which local economies rely upon forest conversion into agricultural land (Newton et al. in press). Households and communities enrolled in a PES programme designed to avoid small-scale deforestation will therefore incur variable opportunity costs, depending on the extent to which their behaviour must change in order to ensure PES compliance.

Here we consider how local heterogeneity in economic or livelihood factors affects the effectiveness of undifferentiated payment structures in a PES programme designed to reduce rates of primary forest conversion. As a case study, we examined the *Bolsa Floresta* (Forest Conservation Allowance), an extensive PES programme established across extractive reserves within Amazonas, the largest Brazilian state. Bolsa Floresta (BF) began in 2007 and provides compensation to traditional populations for ES flowing from primary forest retention, in the form of cash payments and developmental support. The BF programme explicitly suppresses clearance of primary forest areas, limiting agricultural expansion to the extent of previously available *roçados* (swidden fields) and *capoeira* (secondary forest). With 7,190 households enrolled across 15 reserves to date, and an ambitious projected expansion into other reserves, BF represents one of the largest-scale PES programmes implemented in a tropical forest region (FAS 2011a). Like many PES in developing countries, BF is a hybrid programme, mixing government and user financing (via international agencies, private investors and NGOs) with local, NGO-based administration.

Heterogeneity in livelihood strategies of actors voluntarily enrolled in PES programmes with undifferentiated payment structures may result in reduced social and environmental benefit, when payments do not adequately exceed opportunity costs, or are inefficiently spent on areas with low expected additionality. Within agricultural communities, the opportunity costs of prohibited primary forest conversion depend heavily on the availability of existing swidden fields and secondary-forest patches. For example, compared to newly-established communities, older communities may have a greater pool of surrounding secondary-forest to draw upon as a result of previous cycles of swidden/fallow agriculture. Conversely, the largest communities may have saturated all of the forest (primary and secondary) within a viable travel distance. Each of these scenarios would lessen the likelihood of primary forest clearance in the absence of PES payments, with a lower associated opportunity cost of foregone primary forest conversion.

We assessed the potential scope of BF payments based on pre-PES livelihoods and incomes, using data obtained across two large extractive reserves in western Brazilian Amazonia. We explored the relative economic impact of BF compliance on recipients' incomes, and discuss the likelihood of the programme achieving its goals.

6.3 Methods

6.3.1 The Bolsa Floresta PES programme

The Bolsa Floresta is a voluntary PES programme that grants financial compensation to individual households and communities in exchange for a commitment to zero conversion of primary forest (Viana 2008). Deforestation in this region is largely driven by chainsaw-operated clearance of small (0.1 – 6.6 ha, in our study area) patches of primary, upland (*terra firme*) forest to cultivate food crops – primarily manioc, which is the staple source of carbohydrates in Amazonia. Annual monitoring of deforestation inside reserves is performed by partnering institutions using a combination of site inspections and satellite images. All residents of participating reserves are actively invited to enrol in the programme.

BF offers compensation at four different levels that can be accessed simultaneously by participating communities. *Bolsa Floresta Familiar* (BFF) is a monthly payment of R$50 (~ USD 30) awarded to individual families. Equal payments are awarded to all enrolled households, regardless of the extent of intended avoided primary forest conversion. In addition, two different compensation grants can be accessed at the community level. *Bolsa Floresta Renda* (BFR) supports alternative income-generating activities that do not rely on deforestation, including fishing and the extraction of non-timber forest products such as natural oils, fruit, and honey. Enrolled communities are awarded through development support averaging R$4,000 (~ USD 2,560) per community per year (based on an average community size of 11.4 households). The second community-level support programme, *Bolsa Floresta Social* (BFS), offers enrolled communities a range of development infrastructure; also averaging an annual cash reward of R$4,000 per community, this grant funds improvements in water sanitation, basic education, health, communication, and transport (Viana 2008). Finally, *Bolsa Floresta Associação* (BFA) supports the political organisation and cooperatives of residents' associations active within each protected area. The BFA is calculated as 10% of the aggregate value of all BFFs within a given extractive reserve and provides logistical support to local leaders to promote social justice and guard the interests of reserve residents. The benefit of the BFA is thus effectively divided evenly across all enrolled communities within a target reserve. This study considers all four components, although we focus on the BFF because this is the largest cash payment to individual families.

6.3.2 Study site

This study was conducted within the context of a 3-year, interdisciplinary research project aiming to understand the dynamics of extractive practices within multiple-use Amazonian forest reserves. The study was conducted within and around two contiguous extractive reserves: the federally-managed Médio Juruá Extractive Reserve (hereafter, *ResEx Médio Juruá*) and state-managed Uacari Sustainable Development Reserve (hereafter, *RDS Uacari*) (Fig. 6.1). The reserve complex is bisected by the Juruá River, a large white-water tributary of the Amazon (Solimões) River in the state of Amazonas, Brazil. A wide band of seasonally-flooded (*várzea*) forests along the main river channel is inundated between January and June, whilst *terra firme* forests on higher elevation are never flooded. The elevation is 65–170 m above sea level and the terrain is flat or undulating.

The ResEx Médio Juruá and RDS Uacari were decreed in 1997 and 2005, respectively, and are currently inhabited by some 4,000 legal residents distributed across approximately 60 settlements of between 1 and 89 households (mean ± SD = 10.3 ± 13.2, median = 7, $N = 50$). Household occupancy was also extremely variable (mean ± SD = 7.0 ± 3.0, range = 1 - 17, $N = 179$). Most communities are located along the main river channel, while others are settled on the banks of tributaries and oxbow lakes on either side of the Juruá River. Reserve residents variously engage in agricultural, extractive and fishing activities for both subsistence and cash income (SDS 2010). We collected socioeconomic data from 181 households across eight communities in the ResEx Médio Juruá, 17 communities in the RDS Uacari, and two communities immediately outside these reserves, all of which were located along a 380-km section of the Juruá River (Fig. 6.1).

Currently, only residents of the RDS Uacari qualify for the BF programme, since the programme has yet to be implemented in the ResEx Médio Juruá. However, to explore the range of household and community livelihoods and economies, we consider data from both reserves, because the geographic, sociopolitical and economic conditions faced by residents of the ResEx Médio Juruá are essentially identical. *De facto* reserve

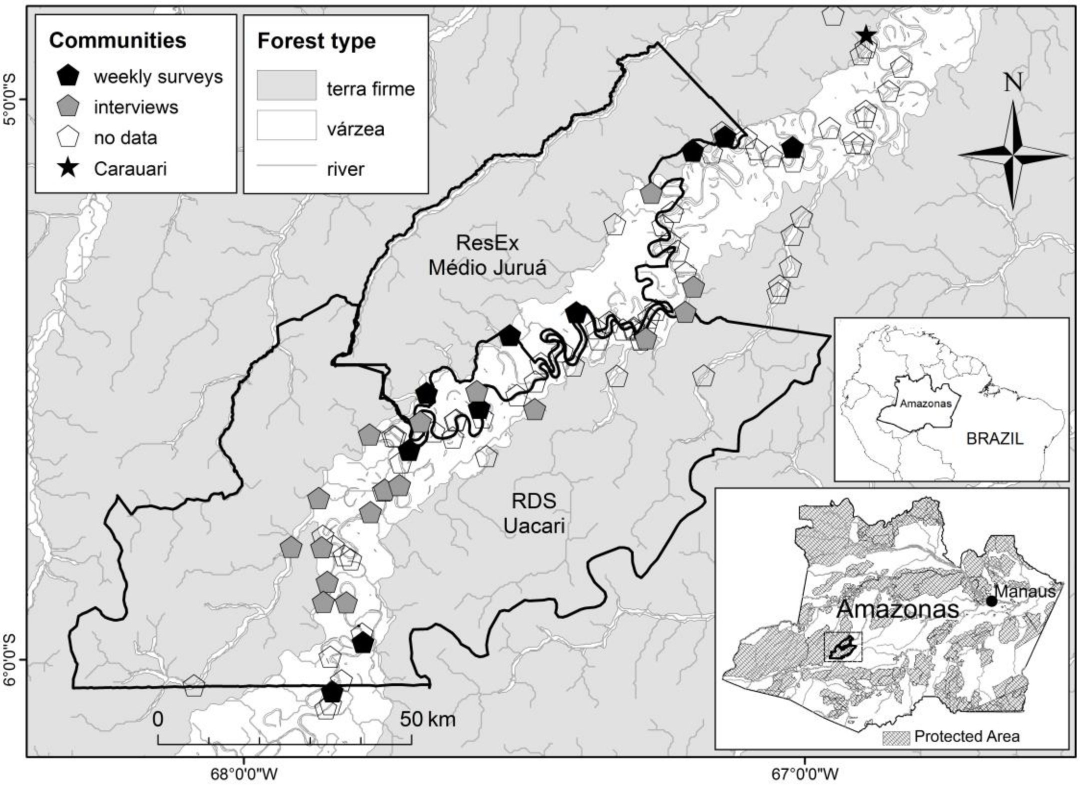

Figure 6.1. *Location of communities within, and immediately outside, the boundaries of the Uacari Sustainable Development Reserve and the Médio Juruá Extractive Reserve in the state of Amazonas, Brazil. Insets show the locations of Amazonas within Brazil (above), and the study area within the full protected area network of Amazonas (below).*

management by either federal or state agencies is of relatively little practical consequence to the livelihood strategies or income opportunities of reserve residents. Our data were collected at the very inception of the BF programme, when PES payments made negligible impact on the income-generating activities of reserve residents.

6.3.3 Weekly monitoring

Weekly surveys were conducted in 127 households across 14 communities between March 2008 and July 2010. This sampling effort represented ~23% of all active households in the two reserves. One previously trained resident from each community visited up to 10 randomly-selected households per community on a weekly basis and recorded all extractive and agricultural activities of each household. Because median community size was seven households, our weekly sampling protocol effectively captured most households within a given settlement. Each week, this trained resident (*household monitor*) questioned a senior household member about three types of cash-income activities: i) cultivation of agricultural products; ii) extraction of plant forest resources; and iii) fishing. For each activity, the household-scale quantities of all resources collected or produced were recorded, together with the transaction values of traded goods. We analysed data from all households for which data acquisition included at least 40 weeks spread over a period of at least 365 consecutive days, resulting in a subset of 82 households from 10 communities (mean number of weekly samples per household = 66.6 ± 10.3). Other households sampled ($N = 45$) failed to capture a full year-round seasonality cycle, and were therefore excluded from the analyses. All monetary values are reported in Brazilian Reais (exchange rate R$1 = USD 0.64, June 2011).

6.3.4 One-off interviews

Two modes of voluntary, one-off interviews targeting all 181 households belonging to 27 communities were conducted between June and December 2009. Household interviews were undertaken with one or more senior members of each household to document household scale demographic profiles, income and perceptions of the BF programme (RDS Uacari communities only). Community-level interviews were conducted with a senior member of each community (usually the locally elected leader) to document the overall demographic profile, physical geographic setting, infrastructure, and material assets of each community. Both forms of interviews were structured, although additional information was recorded on an ad-hoc basis whenever offered.

6.4 Results

6.4.1 Household cash economies

Mean monthly income varied widely between households (R$563 ± 349, $N = 82$, range = R$55 – R$1,656 per household). Community-level income, estimated as the sum of all household incomes and extrapolated to additionally account for those households that were not surveyed weekly**,** was also highly variable (R$1,1701 ± 17,880, range = R$2,722 – R$61,308 per community per month, $N = 10$). Unsurprisingly, communities with more households had a higher total community income ($r = 0.995$, $p < 0.001$).

Manioc production accounted for 62.3% of all agricultural yield, but varied widely across households (47.5 ± 50.6 kg, range = 0 – 270.4 kg of manioc per household per week, $N = 82$). Production for consumption ranged from 0 to 59.9 kg of processed manioc per household per week (mean = 14.5 ± 12.1 kg), whilst revenue generated from sales ranged from R$0 to R$227.72 per household per week (mean = R$29.78 ± 42.25). Prices per 50-kg sack were relatively stable both temporally and spatially (R$46.11 ± 16.20, $N = 1{,}441$ 50-kg sacks).

Most interviewed households (139/180; 77.2%) received at least one form of cash state benefit other than Bolsa Floresta. In particular, 73.3% of households received a *Bolsa Família* allowance, which is paid at a rate of R$68 per family plus R$22 per school-aged child, for up to a maximum of three children. Additionally, 14.4% of households contained one or more persons (elderly or disabled) in receipt of a state pension, who on average were paid R$453 per month.

6.4.2 Potential role of Bolsa Floresta payments in household cash economies

The monthly R$50 BFF flat-rate payment to individual households accounted for between 2.9% and 69.5% of mean monthly income ($N = 82$, mean ± SD = 11.9 ± 11.1%). In addition, the cash value of community-level grants (BFR and BFS) each equated to an extra R$29.24 per household per month (R$4,000 per 11.4 households per year). The *per capita* value of the set-rate payments of BFF ranged between R$2.9 and R$50.0 (R$ 9.2 ± 6.5) per month, depending on the number of occupants within the household. The majority of households (135/180) were in receipt of a higher cash income from other welfare payments than offered by the direct cash payment of the BFF (mean ± SD recipient household income per month: from *Bolsa Família* = R$122 ± 277, $N = 132$; from pensions = R$558 ± 210, $N = 26$).

6.4.3 Livelihood heterogeneity

The relative subsistence and monetary importance of manioc cultivation was highly variable across households and communities, implying that opportunity costs incurred in forgoing future cultivation in former primary forest areas varied widely across individual families and communities. There was a positive correlation between household size and the number of equally spaced stems of manioc in cultivation (a good proxy of aggregate crop volume) in neighbouring swidden fields ($r = 0.341$, $N = 171$, $p_{\text{one-tailed}} < 0.001$). Manioc crop size and estimated planted area were strongly correlated ($r = 0.719$, $N = 22$ fields, $p_{\text{one-tailed}} < 0.001$), indicating that larger families tended to cultivate larger areas, thereby placing correspondingly higher demand on suitable agricultural land in unflooded terrain.

The proportion of total income represented by manioc agriculture also varied widely between weekly-surveyed households (mean ± SD = 21.1 ± 22.3%, $N = 82$). Most household and community-level variation in manioc cultivation in this swidden agriculture system was driven by accessibility of surrounding terra firme forest (Newton et al. in press). Hence, entire terra firme communities tended to engage heavily in manioc agriculture, with a high level of intra-community congruence in the overall livelihood of individual households. The proportion of total community income represented by manioc was accordingly highly variable (range = 0 – 32.6%, mean = 11.2 ± 13.2%, $N = 10$).

6.4.4 Implications of income heterogeneity for Bolsa Floresta

Households that produced more manioc reported higher total income ($r = 0.465$, $N = 82$, $p < 0.001$), thereby receiving a lower proportion of their total income from the set-rate payments of the BFF, compared to households engaged principally in alternative income-generating activities. The relative contribution of BFF payments to mean monthly household income was therefore lower for those households more heavily reliant on agriculture (Fig. 6.2).

6.4.5 Perceptions of opportunity costs

In general, BF participants were positively engaged with the concept of the PES programme, with 43/45 respondents stating that they supported the programme. However, six respondents indicated that the fixed value of the payments was too low. For example, one informant from an upland community commented that “a swidden field can make much more money [than the monthly R$50 BFF grant]” (interview number: J183). In contrast, an interviewee from a seasonally-flooded forest community whose income was principally derived from fishing rather than manioc cultivation stated that he supported the programme “because I don’t need to change anything I do [to qualify for the BFF grant]” (J131). Another highlighted inter-community heterogeneity, noting that “some [communities] have more secondary forest available than others” (J184), which permits continued agricultural expansion into secondary forest, while remaining compliant with BF requirements.

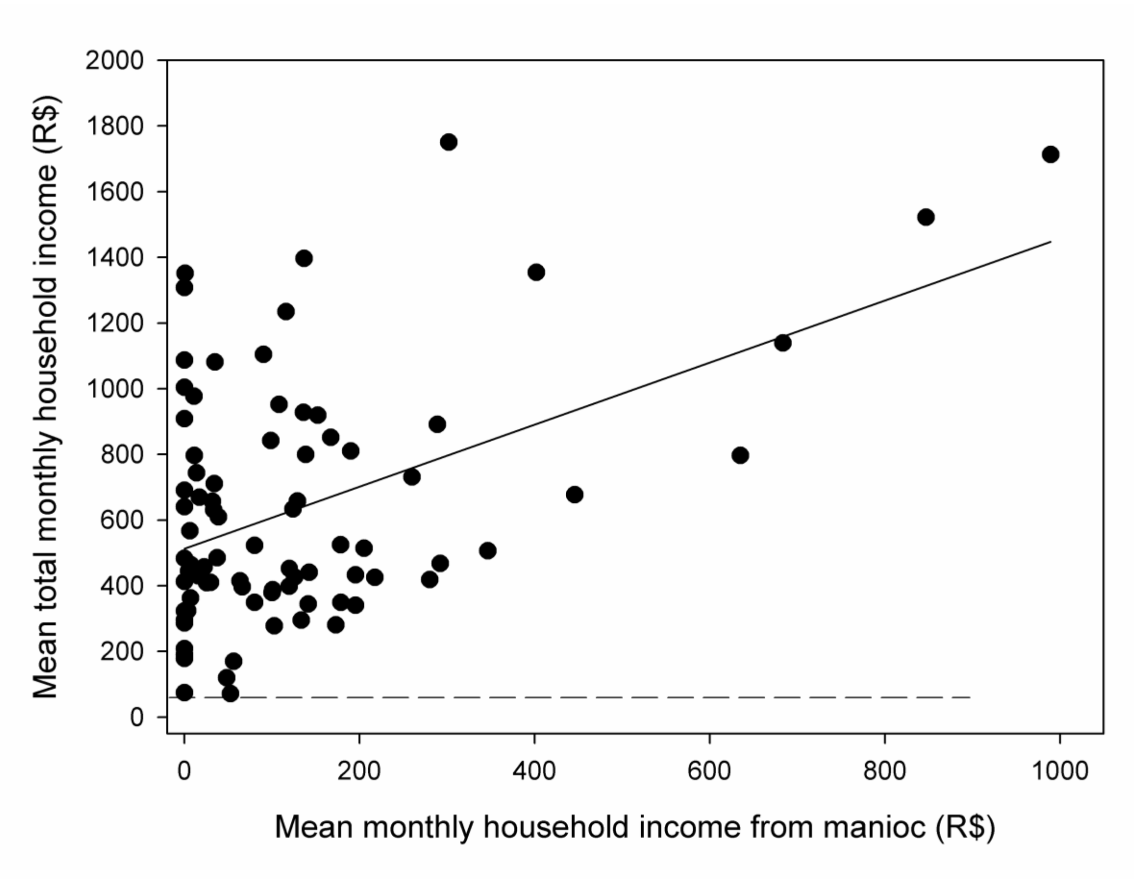

Figure 6.2. *Relationship between agricultural income derived from manioc cultivation and total income from all sources for 82 households in the Médio Juruá region of western Brazilian Amazonia between March 2008 and July 2010 (R$ 1 = USD 0.64). The distance between the linear regression (solid) line and the monthly R$50 grant awarded by the Bolsa Floresta programme (dashed line) indicates the relative contribution of BFF to the total household income.*

6.5 Discussion

The implementation of PES programmes in tropical forest regions is still largely incipient and is beset by poorly explored questions of optimal design and administration. Using the Bolsa Floresta case study, we explored how local heterogeneity in demographic, economic or livelihood factors affects the opportunity costs incurred by rural Amazonians in the context of a PES programme with an undifferentiated payment structure. In designing and implementing the BF programme, its proponents stated "that to promote forest conservation and sustainable development, different strategies should be formulated for each Amazonian sub-region, since it is clearly heterogeneous" (Viana 2008). We agree with this assertion, and additionally highlight the importance of taking into account local and landscape-scale heterogeneity in incomes and livelihood strategies of PES participants to maximise the value of conservation programmes while minimising local opportunity costs.

Evidence suggests that the economies of individual households and communities of tropical forest dwellers vary significantly according to geography and local demographics (Takasaki et al. 2001; Newton et al. in press). Our data show that household and community income, family size, and livelihood strategy vary widely across the two focal reserves. This is likely to contribute to similarly varying opportunity costs faced by individual actors (households) as they decide to join the BF programme, or to comply with its zero-primary forest conversion policy following enrolment.

6.5.1 Cash-payments and development support

BF's fixed-value monthly payments to households and communities represented varying proportions of household-scale cash income. The monthly R$50 BFF payment awarded to individual families represented between 3.0% and 90.2% of mean monthly household income. The large variation in household size (1-17 people per household) resulted in much lower *per capita* values for the monthly BFF payment for larger families. A family of two received R$25 per person per month, compared to just R$2.94 per person per month in a household of 17 people.

In addition to this wide-ranging *per capita* contribution to household revenues, BFF represents a lower cash contribution to household incomes relative to other existing welfare payments. *Bolsa Família*, for example, is a poverty-alleviation government subsidy available to all families with a mean monthly income lower than R$140 (Lindert et al. 2007). Most households interviewed received a *Bolsa Família* grant, with a mean value of R$122 per month that was 2.5-fold greater than the BFF payment. In addition, monthly state pensions (for the elderly or disabled) of ~R$453 per entitled person again accounted for a much higher contribution to recipient households. Whilst these other forms of welfare support are conceptually and administratively isolated from the PES programme, recipient households tended to associate them together and frequently compared the benchmark value of one against the other. In this light, BFF not only carries a lower cash value than other subsidy programmes, but additionally demands behavioural changes in cultivation practices that potentially incur a cost far exceeding its benefit.

Household-level cash payments are just one component of the BF programme, which also includes reserve-level grants to residents' associations (BFA) and community-level grants for health and education programmes (BFS) and extractive industry infrastructure (BFR). Translated into monetary worth this represents an estimated annual investment of R$13,560 to the RDS Uacari (number of enrolled households in September 2010 = 226), plus a mean R$5,193 per community (mean RDS Uacari community size = 7.14 households). These payments effectively increase the benefit to each household to a total of R$113.48 per month, with the total BF investment thus representing a much higher proportion of the sum of households' annual income (range = 6.5 – 157.6%, mean = 27.1 ± 25.2%, N = 82).

BF relies on three inter-related collective payments targeting communities or whole protected areas for avoided primary forest clearance, in addition to individual household level payments. Enrolled household decisions of whether or not to open a new primary forest clearing, thereby falling out of compliance with the BF programme, are therefore modulated by a larger social context, as they can threaten continued community level payments. As both economic incentives and social norms are important drivers of individual behaviour, participants who decide to not comply may be exposed to a range of social pressures that together confer a greater likelihood of adherence to the programme's requirements than financial incentives alone (Chen et al. 2009). Further research into the interplay between household economies, social norms, and community power structures will be important in clarifying the principal drivers of behavioural change (e.g. Sommerville et al. 2010a).

6.5.2 Livelihood options and opportunity costs

Livelihood strategy is a crucial determinant of the pressure that an individual household or community may place on standing forest. Since manioc production in swidden/fallow systems is the principal driver of primary forest loss in these reserves, opportunity costs of participating in BF faced by participants depending heavily on agriculture are higher than those engaged primarily in fishing or plant extractivism. Within our two focal reserves, economic specialisation is typical of most households, which derive over half of their income from either agriculture or extractivism of fish or plant forest products (Newton et al. in press). Heterogeneity may occur on a community level, with congruence in livelihood strategy between households within the same community but considerable variation between communities. Extractive communities in Amazonia are often located closer to seasonally-flooded (várzea or *igapó*) forest habitat and often plant the majority of their crops in cleared várzea forest patches and on fertile beaches which require no regular clearance of additional forest, since they are annually replenished by floodwater nutrients. They have a greater reliance on annual crops that can be harvested within the six-month period during which these areas are above water. Agricultural communities tend to be sited in upland areas located on oxbow lakes and tributaries farther from the main river channel. These communities also tend to be larger than extractive communities and swidden fields in these terra firme areas require fallow periods of over 3 years between successive crops; two factors that result in a higher demand for cleared forest areas. In this system, payments to households within communities surrounded by seasonally-flooded forest are far less effective than payments to households within communities embedded in terra firme forest. Extractive households place the least pressure on primary forest, yet receive an equal value of reward (Fig. 6.3).

We show that those households and communities that derive the highest incomes from manioc agriculture (as opposed to plant extractivism, fishing or other agricultural yields) are also those that generate the largest overall cash incomes. As a consequence, the relative value of BF payments is lower for these households. Therefore, ironically, heavily agricultural households, whose behaviour the BF programme specifically aims to alter, receive the lowest financial incentives from its introduction.

Finally, if a PES programme precludes an economic activity it should consider the substitute income-generating activities available, since it is usually easier for some households to adapt than others. The opportunity costs incurred by a given household reflect not just the proportion of income provided by PES compensations, but the availability of income-generating activities that do not demand new forest clearance (Fig. 6.3). Terra firme forests in our study landscape tend to have lower natural densities of frequently marketed non-timber forest products (e.g. *Hevea* spp. rubber, *Carapa guyanensis* oilseeds etc.). This poses additional questions for the appraisal of the economic viability of alternative income-generating extractive activities that can be pursued within relatively undisturbed forests.

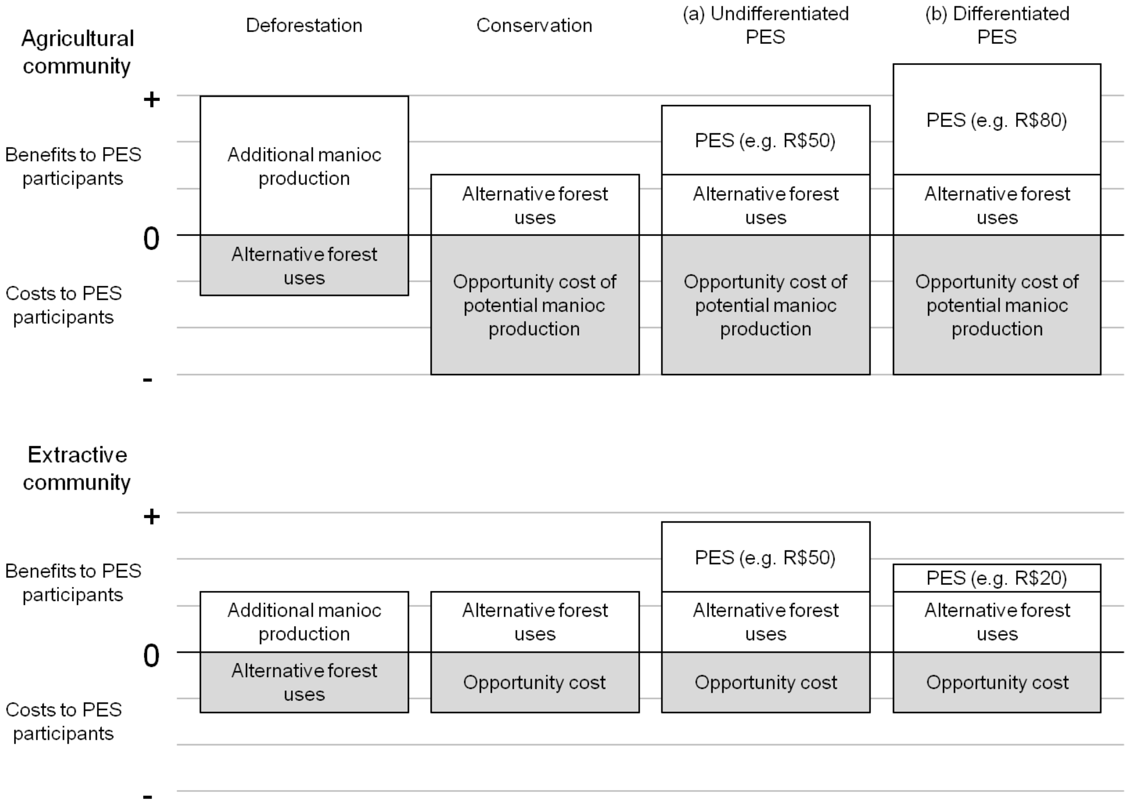

Figure 6.3. *The logic of differentiated payment structures in payments for environmental services (PES) programmes, in which the costs and benefits to potential PES participants are schematically illustrated. In the study system of the Médio Juruá region of the Brazilian state of Amazonas, suppression of primary forest clearance confers greater opportunity costs to an agricultural community than it does to an extractive community. (a) Under the* undifferentiated payment structure, *the extractive community is unnecessarily over-rewarded; as a result, limited funding means that the higher opportunity costs of the agricultural community may not be adequately compensated. (b) Under the* differentiated payment structure, *on the other hand, benefits outweigh the costs for both communities. Adapted from Engel et al. 2008.*

6.5.3 Participant perception, enrolment and compliance

Compliance with a PES programme may be induced by positive attitudes towards the scheme or may be driven by fear of being caught and penalised (Sommerville et al. 2010a). Although the BF programme conducts annual independent assessments of primary forest conversion, specific plot-level tracking of land use change that can be associated to enrolled individuals is difficult, complicating the monitoring of recipients' adherence to the BF programme's requirements. Participant perceptions of the programme may therefore be a critical indicator of its likely success in the medium and long-term.

Ad-hoc comments made by interviewees, and those surveyed elsewhere, indicate that many recipients believe the value of the BFF payments to be too low (FAS 2011b). The minimum production of manioc flour (*farinha*) must be sufficient to feed all household members on a year-round basis. Smaller households therefore require smaller cleared areas to meet their basic subsistence needs, but also have lower demand and a reduced labour supply to clear-cut large forest areas for commercial production of manioc. In our study area, there was a linear relationship between household size and the area of former terra firme forest cleared for manioc monoculture. Larger households are therefore likely to place the highest pressure on standing terra firme forest, yet receive the lowest *per capita* compensation for agreeing not to do so. While our data are insufficient to quantify whether households more heavily reliant on *farinha* production were more dissatisfied with the value of the BFF payments, anecdotal evidence indicates this to be a widespread concern within our focal reserves across both enrolled and non-enrolled households.

6.5.4 Undifferentiated distribution of PES compensation

The undifferentiated payment structure of the *Bolsa Floresta* PES programme minimises transaction costs in a spatially extensive and logistically challenging project that pays hundreds of enrolled households across multiple conservation units. However, this programme structure may ultimately cap the effectiveness of the BF programme. If the value of PES compensation reflected the degree to which households depend on primary forest clearance, the payments might be more effective in influencing the behaviour of their recipients (Fig. 6.3).

Most undifferentiated PES programmes implement their payments according to the total land area committed to the programme by the enrolled landowner. The *Socio Bosque* programme in Ecuador awards payments of up to USD 30 per ha per year to farmers based on the area of forest that they preserve (Chíu 2009). Similarly, the programme at Los Negros in Bolivia rewards PES participants with one bee-hive per 10 ha of forest protected per year (Asquith et al. 2008). Since land within Amazonian extractive reserves is not actually owned by reserve residents, who are instead granted long-term usufruct rights of the reserve territory, determining payments directly on the basis of area is not a simple option. However, this in itself does not present an absolute barrier to the development of differentiated payments and the relative opportunity costs of enrolled PES participants can be assessed in alternative ways (Pagiola 2008).

Differentiated payment structures may bring significant efficiency benefits by employing spatially-explicit rates that are tailored to the variable ES provision potential and opportunity costs of different forest landscapes (Wunder 2005; Chen et al. 2010). Such spatially targeted payments have been successful in a range of existing forest PES schemes involving retention of carbon stocks or hydrological services. For instance, the PSAH programme in Mexico pays a per hectare rate to enrolled landowners, with higher rates in areas where the value of the ES provided is considered to be higher (Muñoz-Piña et al. 2008). The Vittel PES programme discriminates four groups of landowners, each with unique opportunity costs to PES compliance (Perrot-Maître 2006). Whilst administratively more complex, such an approach may enhance the likelihood of distributing limited funds in a manner most likely to achieve the maximum return in terms of forest protection (Wünscher et al. 2008). Conversely, undifferentiated payment structures risk economic inefficiency, with many payments being directed at low deforestation-risk landowners (Fig. 6.3).

Our data suggest that there is high potential for BF payments to be distributed across households and communities that are unlikely to contribute to additionality of avoided deforestation in this system, at least in the short-term (May and Millikan 2010). One means to achieve a more efficient distribution of funding might be to develop a conditional metric by which to assign BF payments to single households or communities. While a community-level assessment of the location, abundance, ownership, and land tenure system associated with secondary forest areas available to expand manioc cultivation would have the highest likelihood of achieving true additionality in avoided deforestation, the transaction costs of such a programme are likely to be prohibitively high. Here we propose two proxies relying on simple household-level interviews that can achieve a large degree of conditionality.

A *demographically-adjusted payment structure* would help to lessen the variation in *per capita* value of BFF payments. Although households are the fundamental unit for resource-use decision-making, household traits are rarely considered in determining opportunity costs (Chen et al. 2010). Community payments already acknowledge demographic heterogeneity by calculating the value of the BFR and BFS according to the size of the recipient community. Extending the same logic to take account of household size for BFF payments would also reduce inter-household variability in *per capita* payment values. Other subsidies, such as the *Bolsa Família* grant, already take account of varying family size by adjusting payments in proportion to the number of school-age children. Of the 180 households we surveyed, 73% were already receiving *Bolsa Família*, which was implemented nationwide, implying that the data required to adjust payments by family size are already available.

A *livelihood-adjusted payment structure* could be applied in systems where the relationship between opportunity costs and land-use in different habitat types can be approximated (Fig 6.3). Explicit accounting of the pressure of individual households to clear new forest areas can be used as a proxy for opportunity cost. The strong household-scale relationship between *farinha* production and the number of manioc stems planted in swidden fields or the area of these fields (Newton et al. in press) can act as such a proxy in this system. These data can be more readily obtained from a single interview, and in our experience can be accurately quantified by most senior members of households.

The availability of terra firme and seasonally-inundated várzea forest within the immediate vicinity of a community is the strongest determinant of household-scale livelihood strategies within Amazonian reserves (Newton et al. in press). Alternatively, therefore, landscape structure and composition can be readily assessed using satellite imagery, thus serving as a straightforward and objective proxy of livelihood pattern. This fails to consider variation in secondary-forest availability, which may be a key determinant of opportunity costs, but even suboptimal payment differentiation is demonstrably more efficient than complete undifferentiation (Chen et al. 2010).

A number of factors can reduce the desirability of a conditional approach in a PES programme such as BF. The first of these is the fundamental question of whether payments are acting solely as financial incentives to discourage primary forest conversion, or also as a reward for those who have sustained forest permanence over the years (May and Millikan 2010). This question applies both to entire protected areas and to individual households. Many of the sustainable development reserves targeted by BF are under little immediate deforestation pressure (INPE 2011), and we have argued that many households within a given reserve may not engage in forest clear-cutting for manioc agriculture. Such households pose a minimal threat to forest cover, so are perhaps not immediate candidates for incentive-based mechanisms that compensate for the opportunity cost of avoiding primary forest clearance. Their behaviour is unlikely to be altered by anti-deforestation financial payments, which must be interpreted either as economic inefficiency or as a reward for maintaining forest cover rather than an incentive not to diminish it.

Secondly, whilst PES is fundamentally concerned with ES conservation, many PES programmes, including BF, promote development goals as a secondary but core aspiration. Poverty alleviation and socioeconomic development goals may not track local variation in the ecological effectiveness of payments, and indeed may demand the undifferentiated distribution of financial and practical investment across all individuals within a system, for reasons of social equity and perceived fairness (Sommerville et al. 2010b). However, such social equity goals may eventually undermine the efficacy of PES programmes in achieving their conservation goals (Pagiola et al. 2005; Wunder 2008).

Finally, a possible pitfall of a conditional approach can result from non-qualifying households or communities that may realign their behaviour to become qualified for PES, but in a manner detrimental to ES provision. For example, a household with no previous history of manioc cultivation in terra firme areas could clear a field in order to claim compensatory benefits or a community considering where to resettle in the imminent future may be influenced by geographic variables that determine their qualification for PES payments.

Wunder et al. (2008) note that other government-financed programmes are moving away from undifferentiated payment structures in order to account for local heterogeneity in land use practices. Developing differentiated payment systems based on individual opportunity costs, whilst maintaining the benefits of a large-scale programme, could considerably strengthen the likelihood of BF and other PES programmes achieving their goals (Fig. 6.3; Wünscher et al. 2008).

6.5.5 Conclusions

Bolsa Floresta is a pioneer and ambitious PES programme that aims to curb deforestation within Amazonian extractive reserves. However, its success is contingent upon inducing behavioural change in those enrolled; a process which the programme is catalysing by paying resident families an average 12% of their mean annual income whilst providing financial and practical support to community development projects.

Here we draw attention to the economic inequality that an undifferentiated payment structure may create given the large variation in family size, household income, livelihood strategy and settlement geography – particularly in the degree to which different families engage with manioc agriculture. Households and communities pose varying degrees of threat to primary forest integrity and face unequal opportunity costs. The current system of compensatory payments thus results in heterogeneous impacts on recipients' economies and on their willingness to adhere to the programme's requirements. Addressing such challenges in the design and implementation of community-based PES interventions will be critical to the fine-tuning of BF and the development of other PES programmes in tropical forest regions. More broadly, PES programmes should consider this variability in determining the most effective means by which to modulate land-use practices of programme recipients.

6.6 References

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Chapter 7

Concluding remarks

Photo: Juruá River

7.1 Key findings

For over two decades, considerable academic, governmental, and NGO attention has focused on management strategies that help alleviate poverty and improve the socioeconomic wellbeing of tropical forest-dwellers whilst conserving the biodiversity and environmental services associated with those forests. This thesis examined some of the costs and benefits of two mechanisms that aim to achieve these dual goals – the commercialisation of non-timber forest products (NTFPs) and payments for environmental services (PES) programmes. We assessed the potential contribution of these two mechanisms to rural economies and forest conservation, within the context of the extractive forest reserve land-tenure system.

The first major finding of this thesis is that, even within a single site, there may be considerable variation in the livelihood strategy and the extent of forest-dependency of rural Amazonians. Forest extractivism, agriculture and fishing were important to all households, but significant variation existed in their engagement with income-generating activities. Much of this variation was attributed to the accessibility of permanently-unflooded land suitable for perennial agriculture, which was manifested in the congruence in livelihood strategies within communities but high variation between communities. Different groups of forest-dwellers, even those sharing the same forest reserve, thus place unequal demands and pressures on forest resources. These differences need to be considered when implementing conservation and development initiatives.

Secondly, this thesis found heterogeneity in the spatial distribution, size structure and harvest yields of the neotropical tree genus, *Copaifera*, which is valued for its medicinal oleoresin. Variation between congeners and between forest types affected the degree to which this resource was accessible and determined the potential for commercial harvesting. Considering the effects both of spatial scales and of environmental determinants is fundamental to the management of non-timber forest resources.

Thirdly, this thesis showed that programmes that aim to conserve environmental services by financially compensating rural people to avoid undesirable land-use practices may benefit from a careful consideration of programme design in relation to the opportunity costs of programme participants. Undifferentiated cash payments made by the *Bolsa Floresta* programme to Amazonian reserve residents accounted for an average of 12% of household incomes, but failed to account for the greater costs incurred by households that were more heavily dependent on agrarian than extractive activities.

A final key finding, recurrent throughout the study, was the heterogeneity in resource availability and utilisation between the two main forest types of western Amazonia: terra firme and várzea. Livelihood strategies, NTFP distribution, harvest yields, resource accessibility, and opportunity costs of altered land-use behaviour all varied significantly between these two forest types. Ecological differences between terra firme and várzea forests have been previously well-documented, but the implications of these differences for forest-dependency and environmental policy have not been as clearly emphasised. The spatial configuration of forest types in the neighbourhood of Amazonian communities is therefore a key determinant of the likely impact of conservation and development policy.

7.2 Conservation and extractivism in Amazonia

This study focused on western Brazilian Amazonia, which contains the world's largest remaining tract of intact primary tropical forest. This region remains relatively free of many of the pressures – cattle-ranching, soya cultivation, road-building, and fires – that threaten the forests in southern and eastern Amazonia. Conservation strategies within that 'arc of deforestation' aim to minimise or reduce the impacts of these pressures, conserving biodiversity and environmental services within a heavily human-modified landscape (Peres et al. 2010). It has been argued that because deforestation is driven much more by urban population growth and commercial agriculture than by rural communities, measures to reduce pressures on forests by rural populations will be of little effect in addressing the main causes of forest loss (DeFries et al. 2010). However, the future of even relatively intact forest regions is far from certain, and there is a strong case to be made for putting systems in place now to secure those forest areas against inevitable future pressures (Soares-Filho et al. 2006). Contemporary conservation and development programmes may help to forge strong allegiances between rural forest users and management agencies, which could act as a powerful barrier to shifting deforestation frontiers. By ingraining the ideas of forest conservation psychologically, physically, and economically now, inhabited protected areas are much more likely to constitute an effective conservation force in the future. To focus attention entirely on those areas most impacted by current deforestation whilst ignoring intact forest areas would be to take a considerable risk.

7.2.1 Extractive reserves

Extractive reserves are an integral part of implementing this conservation strategy within Brazilian Amazonia. With 41.8% of the state of Amazonas now designated as legally-inhabited protected areas, the future of forests within this region is intricately associated with the success of the extractive reserve concept. Reserves inhibit deforestation and fire, and their creation is a fundamental step in the conservation process (Nepstad et al. 2006; Oliveira et al. 2007). However, designation alone is insufficient since park effectiveness correlates with basic management activities and a protected area may exist as little more than a ‘paper park’ – with little on-the-ground enforcement (Peres and Terborgh 1995; Bruner et al. 2001). The extractive reserve network is thus the foundation upon which successful management strategies need to be built, providing the necessary administrative and institutional framework within which to implement carefully-designed conservation and development programmes (Brown and Rosendo 2000).

However, the rate and extent of expansion of the reserve network in Amazonia has been shaped by a combination of political will and land-tenure opportunities, leading to a complex matrix of reserve types and configurations (Silva 2005). This configuration may not always optimise management efficiency – for example, our contiguous study reserves along the Juruá River encompassed the same ecological, physical, and socioeconomic systems, but were politically and administratively distinct. Separate management of communities that access the same resources makes little objective sense and may result in inequality – for example, in opportunities to engage in PES programmes. By considering the wider landscape, studies such as this may help to achieve greater management efficiency.

7.2.2 Non-timber forest product commercialisation

Forest resources are harvested for both subsistence needs and cash income across tropical forest regions. Many of the ecological and socioeconomic costs and benefits of commercial NTFP extraction have been well documented (Belcher and Kusters 2004). The ubiquitous nature of commercial extractivism means that the debate in the academic literature has necessarily shifted from asking whether NTFP extraction is a good idea *per se*, towards asking how forest extractivism can best be managed to meet both conservation and development goals. Which resources have the greatest potential for commercialisation, and what the likely economic benefits and ecological costs of harvests may be, are important questions for managers seeking to implement extractive initiatives. This thesis shows how a holistic appraisal of NTFP potential, which draws on the spatial ecology, harvest yields, and socioeconomic context of extraction, can be used to begin to answer some of these questions.

Particularly relevant to the contemporary study of NTFP commercialisation are the dynamic socioeconomic context of extractivism and the changing nature of markets available for tropical forest resources. Since this dynamism is removing many of the traditional barriers to NTFP commercialisation, the economic system within which resources are traded is increasingly usurping taxonomy as the criterium by which products are grouped and evaluated. Within our study area, the economic landscape for commercial NTFP extraction is being rapidly reshaped by reserve residents' associations, government subsidies, emerging local markets, trade co-operatives, direct contracts with end-retailers, NGO training and material support, and PES development grants. In combination, these support mechanisms could increase the viability and attractiveness of forest resource extractivism as an income-generating opportunity to many rural Amazonians.

7.2.3 Payments for environmental services programmes

A growing body of literature has developed increasingly sophisticated methods for valuing the world's natural resources and environmental services (Fisher et al. 2009). At the same time, the general public in more developed countries has become more informed and worried about, and prepared to pay for, damage to the world's tropical forests (PRP 2008). In part as a consequence, the prevalence of PES programmes as a conservation mechanism is growing rapidly and will undoubtedly play a prominent role in future tropical forest conservation strategies. PES has the potential to effect direct changes in land-use behaviour, but this research highlights the importance of planning PES programmes carefully and with transparent intentions.

7.2.4 A synthesis for tropical forest conservation and development

Neither the designation of extractive reserves, nor NTFP commercialisation, nor PES programmes are likely to emerge as a panacea for tropical forest conservation. Indeed, no single livelihood option or conservation strategy in any context is ever likely to provide a straightforward solution, and there has perhaps been too much historical expectation – particularly in the case of NTFP extraction – for this to be the case. It may be that there are fewer easy income-generating options available to forest-dwellers than the literature has historically suggested.

This reality does not detract from the contribution that these strategies can make, in synthesis, to achieving both conservation and development goals. At the most fundamental level, protected areas, PES programmes, biodiversity conservation, and livelihood development are inherently compatible aspirations but which conflict with commercial logging and large-scale agriculture. Therefore, a multi-stranded strategy that incorporates compensation for allowing intact primary forest to stand (e.g. PES programmes) coupled with the development of sustainable income-generating activities that maintain biodiversity and ecosystem services (e.g. NTFP extraction) within the context of a strong administrative framework (e.g. extractive reserves) may represent a powerful approach to a complex problem.

7.3 Future directions

7.3.1 Temporal considerations

Although this research used continuous weekly household data collected over a two-year period – longer than many studies of rural livelihoods – these data still represent a temporal ‘snap-shot’ of the socioeconomic situation in this study site and say relatively little about longitudinal variation in resource utilisation. This inevitable consequence of engaging in a short-term project leaves some interesting questions unanswered.

It was shown that livelihood strategies were largely influenced by the physical characteristics of the environment such as forest type, at least at the coarse division of agricultural and extractive activities. However, finer scale components of household subsistence and income-generating activities are likely to be influenced by dynamic social and economic conditions. NTFP prices may fluctuate as a consequence of changes in demand, subsidies, or markets. PES programmes actively seek to alter behaviours and promote more ecologically-benign activities. Local communities grow as a result of high birth rates but may decline as individuals, families or entire villages emigrate to urban centres (Parry et al. 2010). Each of these processes was observed even during the three-year study period, and any one of them may influence the relative desirability or likelihood of a shift in livelihood strategy. Temporal shifts in income-generation have been documented in extractive reserves (e.g. Salisbury and Schmink 2007), but most studies rely on respondent recall in semi-structured interviews.

Repeated surveys of household resource-use would enable quantification of these changes over years or decades.

Of relevance to the study of NTFP extraction are doubts concerning the longer-term ecological consequences of harvests (Peters 1994). Harvest practices may alter biological processes at the individual, population, community, or ecosystem level, but there is a paucity of information available on the impacts of resin and oil harvests (Ticktin 2004). The repeated *Copaifera* harvests (after one and three years) go some way towards assessing the sustainability of this resource, but do not conclusively demonstrate the longer-term replenishment of oleoresin stocks after multiple harvests. Nor have they accounted for other potentially detrimental consequences of oleoresin extraction to tree fitness, such as defence or fecundity (e.g. seed crop size and germination success).

7.3.2 Towards a coherent understanding of extractive systems

This study is just one component of a multi-pronged project aiming to gain a holistic understanding of the ecology and socioeconomics of extractive systems in intact tropical forest areas (DEFRA 2011). Different research strands within the same project framework are currently exploring the floristic composition, forest structure, ethnobotany, fruit-frugivore interactions, density and distribution of large-vertebrate taxa (mammalian and avian) and other NTFP resources, and animal protein offtake from terrestrial vertebrates and fish within the same focal reserves. All of these data-sets are spatially-explicit and cross-referenced, creating considerable scope for exploring further questions regarding the agro-extractivist behaviour and resource utilisation of rural Amazonians, much of which will build upon the research presented in this thesis.

7.3.3 Lessons from multi-site comparisons

This thesis has attempted to relate its results to those of studies elsewhere, serving to place these data within a wider context. This objective was often impeded by a lack of comparability between research methods. Where appropriate, data-collection considerations have been suggested that would enhance comparability of data-sets across studies. However, this goal is more likely to be achieved by regional or global coordination to collect data using standardised sampling protocols. By increasing comparability between sites and systems, common patterns and processes and their drivers may be identified. Coordinated efforts are growing in prevalence, with the

Poverty and Environment Network project (Angelson et al. 2011), Global Comparative Study on REDD (CIFOR 2011), and RAINFOR plot network (Malhi et al. 2002) collating data from multiple partners on tropical forest livelihoods, REDD initiatives and floristic composition, respectively.

7.4 Policy and research dissemination

This study has produced a number of findings which may be of interest to government agencies responsible for managing these and other extractive reserves, and to NGOs involved in developing extractive activities and PES programmes in Amazonia. The most important findings from a management perspective are summarised in the form of a six-page brief in Portuguese, which has been disseminated to these agencies (Appendix).

This thesis represents an attempt to understand the role that non-timber forest product extraction and payments for environmental services programmes may have in determining opportunities for conservation and livelihoods in Amazonian extractive reserves. It is my hope that this research can contribute in a small way to the complex challenge of tropical forest conservation in Amazonia.

"*First I thought I was fighting for the rubber tappers, then I thought I was fighting for the Amazon, then I realised I was fighting for humanity.*"

Chico Mendes

7.5 References

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Appendix

Key findings and management implications

Photo: A community in the Uacari Sustainable Development Reserve

Disseminated to:

The *Secretaria do Estado do Meio Ambiente e Desenvolvimento Sustentável* (SDS) and the *Instituto Brasileiro do Meio Ambiente e Recursos Naturais Renováveis* (IBAMA), Manaus, Amazonas, Brazil.

Este documento contém um breve resumo de alguns dos principais resultados da pesquisa realizada por Peter Newton – membro da equipe de Projeto Médio Juruá – nas reservas RDS Uacari e ResEx Médio Juruá, Amazonas, Brasil, entre novembro de 2007 e julho de 2011. Os resultados apresentados aqui são parte da tese de doutorado do PN, e foram selecionados para compor este documento por apresentarem grande relevância para agências governamentais responsáveis pela gestão destas e de outras reservas habitadas, assim como para as ONGs envolvidas na conservação e desenvolvimento de projetos dentro delas. Para um detalhamento específico da metodologia utilizada no trabalho favor consultar a tese de doutorado em si ou entrar em contato com PN (peter.newton@uea.ac.uk). Este documento, assim como a tese, apresenta cinco principais enfoques comas seções a seguir apresentadas conforme aparecem na tese, para facilitar a procura das referências. Cada seção contém um objetivo e os principais resultados obtidos em nosso projeto sendo apresentadas algumas considerações de manejo.

1. Estratégias de subsistência dos moradores das reservas

Objetivo: Analisar a extensão e as causas da variação nas estratégias de subsistência entre famílias e comunidades.

Método: Pesquisas semanais em 82 casas em 10 comunidades (metodologia semelhante à utilizada pelo ProBUC, programa da SDS-CEUC).

Resultados principais

a. Todas as famílias e comunidades estudadas trabalham com a agricultura, o extrativismo florestal e a pesca para subsistência, mas tendem a se concentrar em apenas uma destas atividades quando buscam geração de renda.

b. Recursos agrícolas foram produzidos de forma mais consistente ao longo do ano do que os recursos extrativistas, que se apresentaram sazonalmente disponíveis.

c. Famílias dentro de uma mesma comunidade apresentaram estratégias de subsistência semelhantes, havendo, no entanto, variação significativa entre as comunidades.

d. Um grande número de recursos diferentes foram produzidos e extraídos pelas famílias, mas a cada atividade foi dominada por poucos recursos-chaves.

Agricultura: mandioca representando 63% da produção; *extrativismo***:** lenha 40%, e açaí 21%; *pesca***:** Characidae (tambaqui, pacu, piranha etc): 44%.

e. A variável determinante na variação da estratégia de subsistência entre as comunidades foi a disponibilidade de floresta terra firme para a agricultura em áreas próximas as comunidade.

Implicações para gestão

Os resultados apontam que a criação de programas que visem o desenvolvimento das práticas de subsistência dos residentes destas unidades de conservação deveria ser concebida em nível de comunidade – com a possibilidade de agrupamento de comunidades que tenham características (geográficas) similares. Programas que visem aumentar o rendimento (tendo como alvo à eficiência do processo de colheita ou coleta) ou que visem conservar os recursos mais raros (limitando o desperdício)deveriam ser realizados alvejando os recursos chaves identificados pela nossa pesquisa.

2. Distribuição espacial das espécies do *Copaifera* (copaíba)

Objetivo: Avaliar a densidade e distribuição de espécies de copaíba em três escalas de espaciais.

Método: Escala Amazônia: dados do Projeto RADAMBRASIL de 2.343 parcelas de 1-há; Escala das reservas: 63 transectos (4-5 km de cada) ao longo das duas reservas; Escala local: busca exaustiva em parcela de 100-há de terra firme.

Resultados principais

a. Quatro espécies de copaíba (gênero: *Copaifera*) ocorrem nas reservas do Médio Juruá: dois apenas em floresta de terra firme (*C. multijuga* e *C.piresii*), um só na floresta de várzea (*C. paupera*) e um em ambos ambientes (*C. guyanensis*).

b. A densidade media de árvores de *Copaifera* atráves das reservas foi de 0,83 ha^{-1} em terra firme 0,36 ha^{-1} em várzea; atingindo um máximo de 1,13 ha^{-1} na parcela de terra firme.

c. A densidade, tamanho médio, e agregação das árvores variou entre as espécies e entre os tipos de floresta. Por exemplo, as árvores em várzea foram maiores do que em terra firme.

d. O plano de manejo do RDS Uacari atualmente proíbe a extração do óleo de copaíba de árvores com DAP menores que 50 cm. Ao longo das duas reservas, 88% das árvores foram menores do que este tamanho mínimo.

Implicações para gestão

O levantamento realizado é representativo com relação às características das árvores presentes nas duas reservas. Desta forma os residentes de ambas as reservas segundo a legislação atual apenas podem ter acesso à uma pequena parte dos recursos disponíveis. Recomendo a realização de estudos específicos para a determinação de um tamanho mínimo viável em ambos os aspectos, biológico e econômico da utilização da copaíba para extração de óleo. Consulte a seção 3.

3. Volumes extraídos de óleo de copaíba (*Copaifera*)

Objetivo: Determinar os fatores que afetam a produtividade das árvores de copaíba.

Método: Extração experimental de 179 árvores em floresta de terra firme e várzea nas duas reservas estudadas.

Resultados principais

a. Nem todas as árvores de copaíba produziram óleo quando perfuradas. Apenas em uma espécie de copaíba (*C. multijuga* – em floresta de terra firme) a maioria (70%) das árvores produziram oleoresina.

b. O volume de óleo produzido variou entre as espécies. As duas espécies da várzea e apenas uma espécie da terra firme produziram volumes significativos de óleo. Volume médio por árvore: *C. multijuga* (terra firme): 505 ml; *C. guyanensis* (várzea): 139 ml; *C. paupera* (várzea): 115 ml. O volume máximo produzido por uma única árvore perfurado foi 4,2 litros.

c. Árvores maiores produziram mais óleo do que as menores, entretanto árvores de até 25 cm DAP produziram um pouco de óleo. Como comentado anteriormente o plano de manejo da RDS de Uacari atualmente proíbe aextração de óleo de copaíba de árvores com DAP menores que 50 cm.

d. Árvores perfuradas pela segunda vez após 1 ano e 3 anos produziram o mesmo volume de óleo por árvore. Não encontramos nenhuma evidência de que as árvores deixadas por um período de três anos entre as extrações foram mais produtivas do que aquelas que ficaram por apenas 1 ano. Árvores perfuradas pela segunda vez produziram em média 65% do volume original.

e. Espécies diferiram na proporção de árvores que produziram óleo, o volume produzido, e que o efeito do tamanho da árvore em volume.

Implicações para gestão

Devido a grande diferença encontrada entre as espécies, as mesmas devem ser consideradas separadamente no momento da geração de orientações de gestão para copaíba em ambas as reservas. Da mesma forma devem ser abordadas estratégias diferentes com relação à comunidades situadas próximas à áreas de terra firme ou de várzea.

4. Potencial para a extração comercial de óleo de copaíba (*Copaifera*)

Objetivo: Avaliar a acessibilidade dos recursos florestais pelos extrativistas e estimar o volume total de óleo de copaíba contida nas duas reservas estudadas.

Método: i) Dados sintetizados a partir das duas seções anteriores; ii) Modelos de acessibilidade.

Resultados principais

a. A produtividade por hectare de óleo de copaíba estimada é baixa, como resultado da baixa densidade de árvores, presença de espécies improdutivas baixas proporções de árvores produtivas e alta variabilidade entre árvores com relação ao volume produzido.

b. A densidade de árvores e a produtividade por árvore foram superiores em florestas de terra firme, o que significa que este tipo de floresta é potencialmente mais produtivo, em relação de óleo de copaíba, que a floresta de várzea.

c. O volume total de óleo de copaíba acessível ao longo das duas reservas é estimado em 8.745 litros (7.638 litros em floresta de terra firme; 1.107 litros em várzea) em uma extração inicial.

d. 65% da área das duas reservas são acessíveis para os extratores dispostos a gastar até 8 horas em uma ida e volta, de canoa e a pé, para acessar estes recursos.

e. Um proporção maior da floresta de terra firme é acessível na estação chuvosa (58%) em detrimento à estação seca (45%).

f. Uma área maior de floresta de várzea do que de terra firme é acessível em tempos de viagem de ≤ 250 minutos, devido à localização das comunidades, geralmente próximas ao canal principal. Longos tempos de viagem (entre 250 e 480 minutos) permitem o acesso a largas poções da floresta de terra firme.

g. O preço médio de compra de óleo de copaíba pelos varejistas em Carauari foi de R$ 14 litros^{-1}, e em Manaus foi de R$ 32 litro^{-1}. O óleo rotulado e certificado apresentou um valor maior.

Implicações para gestão

Existe atualmente uma pequena quantidade de óleo de copaíba sendo extraída dentro das reservas, talvez devido à baixa produtividade e a dificuldade de acesso. Entretanto, a atividade de extração de óleo de copaíba pode ser um suplemento econômico, particularmente no caso de que sejam garantidos um alto preço de revenda deste óleo - o que poderia ser feito através do desenvolvimento de programas de certificação do óleo ou através do estabelecimento de mercados formais (como acontece com o óleo de andiroba) para o óleo produzido na reserva.

5. Uma avaliação da programa *Bolsa Floresta*

Objetivo: Avaliar o impacto da remuneração obtida através deste programa de *Pagamento por Serviçios Ambientais* (PSA) sobre a economia dos moradores das reservas.

Método: Mesmo que o da seção 1.

Resultados principais

a. A renda da família e da comunidade, assim como o tamanho da família e a estratégia de sobrevivência variavam muito através das duas reservas.

b. Famílias menores receberam pagamentos do *Bolsa Floresta* maiores *per capita* do que famílias maiores.

c. Famílias mais dependentes da agricultura tiveram o rendimento familiar aumentado, recebendo desta forma um incentivo relativamente menor do *Bolsa Floresta*.

d. Famílias mais dependentes da agricultura tiveram um custo de oportunidade maior como resultado de não serem capazes de plantar em áreas de floresta primária.

e. Esperamos que famílias mais dependentes da agricultura sejam menos incentivadas a participar na programa *Bolsa Floresta* e tenham uma pressão maior para quebrar os termos de seu acordo de não plantar em floresta primária.

Implicações para gestão

A estrutura de pagamento poderiam ser ajustada para dar conta da variabilidade nos tamanhos das famílias ou estratégias de subsistência sendo um sistema mais justo e mais eficaz.