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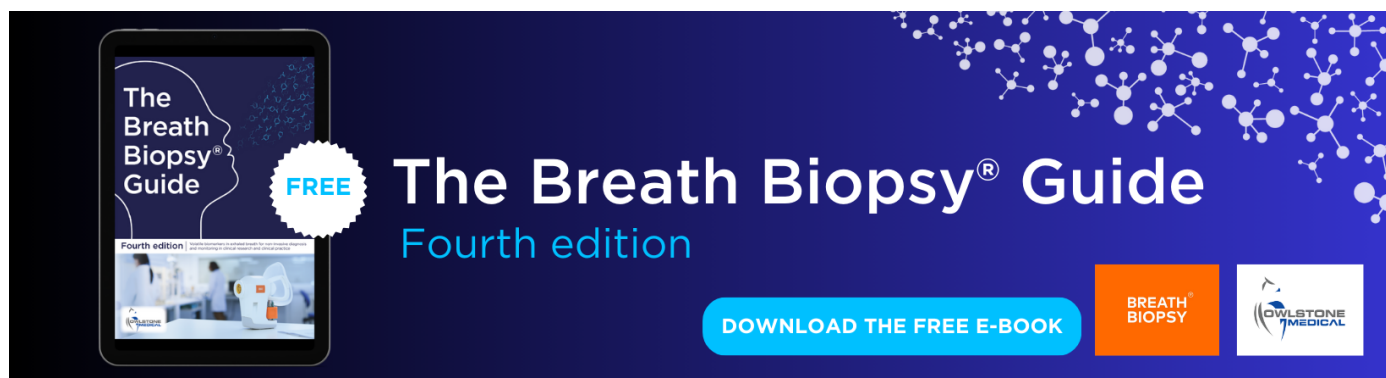
Impoverishment of local wild resources in western Amazonia: a large-scale community survey of local ecological knowledge

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Impoverishment of local wild resources in western Amazonia: a large-scale community survey of local ecological knowledge

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Abstract

A growing number of studies point to the depletion of flora and fauna along rivers of the Brazilian Amazon but the status of wild resources over large areas in Western Amazonia remains poorly known. In this paper we report on findings from the Peruvian Amazon based on the first large-scale community survey that uses local ecological knowledge to assess the presence of indicator species and expected harvest yields of game, fish and timber along four major rivers. Our findings from nearly 700 communities suggest that the forest and lakes near riverine communities have been impoverished over the past 50 years, especially of vulnerable species of high commercial value. A zone of species depletion is detected around the two major regional cities of Iquitos and Pucallpa as well as around an important oil town. Local extirpations are common though some recovery is noted for specific fish and timber species. Expected yields are falling and evidence is found for harvesting of previously non-preferred species. Newer communities face lower initial availability of wild resources and forest impoverishment is driven by market demand over subsistence needs. Our findings illustrate the value of drawing on local ecological knowledge and the importance of considering historical baseline conditions in assessments of the fate of wild resources in tropical forests.

1. Introduction

As world attention has focussed on tropical deforestation, a parallel concern has arisen over the fate of the flora and fauna in standing rain forests [1–3]. Over-harvesting of local wild resources can reduce biodiversity, ecosystem services and economic potential of tropical forests and rivers for future generations [4–6]. A growing body of evidence from studies of hunting and game abundance, in particular, supports the ‘empty forest’ hypothesis, i.e. standing forests become void of game [7–10]. A recent analysis of 176 studies of hunting across the tropics found that bird and mammal abundance declined by 58% and 83%, respectively, when comparing hunted and non-hunted regions [11]. In Amazonia, studies from Brazil point to the loss of large-bodied species of mammals, reptiles and fish as well as high-value timber species, especially from forests along roads and around towns and cities [12–15]. Similarly, local field-based

studies from western Amazonia highlight the role of hunting, logging and oil exploitation in defaunation [16–21].

Synoptic assessments in humid tropical forests are made difficult by low species density, low visibility, and high mobility of fauna as well as the cryptic nature of low-intensity selective harvesting [4, 11]. Studies of harvesting impacts have relied on line-transects and harvest censuses that, of practical necessity, are restricted in spatial scope and time. To assess larger-scale patterns and trends, researchers have turned to meta-analyses of extant studies (e.g. [11, 22]), which are highly instructive but limited by the spatial unevenness of the original sites selected for study, potentially leaving ‘blind spots’ in biologically and economically important areas. In the Brazilian Amazon, two complementary approaches have offered insights to changing game presence and hunting pressure over large areas. Antunes *et al* [15] examined commercial records and boat manifests to

track the fate of commercially exploited species in the central western Amazon region over decades to show their demise in the 20th century. To assess local abundance of hunted wildlife and drivers of game loss over large spatial scales, Parry and Peres [14] drew upon local ecological knowledge of hunters in 161 Amazonian riverine settlements that indicated significant depletion of large-bodied vertebrate species near urban centres. Such findings support those of local studies that have identified the importance of distance to roads, rivers, urban areas, settlement age and size, among other factors, on the abundance of wild resources [23–26]. An important limitation of research to date on the drivers of species loss is the lack of a historical baseline data for species range and abundance. Without baseline data, the attribution of loss to specific drivers is potentially biased, because how such drivers operate over time depends on species baseline conditions [27].

Local ecological knowledge has been shown to enhance species monitoring and assessment of species status over extensive, data-poor regions [28–32]. In tropical forests, indigenous peoples have long and rich cultural traditions intertwined with nature and naturalistic cosmologies. As forest peoples depend upon local resources for their subsistence and market income, their knowledge is especially valuable in assessing the abundance of key species [28, 33, 34]. Such knowledge is also of vital importance in the promotion of local resource management, from communal lakes and forests to species protection [25, 35, 36]. Researchers have drawn upon the knowledge of local experts, e.g. hunters or fishers, as those who typically are more aware of environmental conditions, animal behavior and signs, phenology, etc (e.g. [14, 37, 38]). Other researchers have relied on the notion of ‘cultural consensus’ whereby perceptions of local forest dwellers guide assessments of game abundance and persistence (e.g. [33, 34]). In Amazonian rain forest communities, which tend to be small in size and relatively isolated, households rely on fish and/or game for food and on the forest for a wide range of products as medicinals, building materials, and food, and so are very well acquainted with hunting, fishing and forest product harvesting [39]. Although forest-dwelling households practice pluri-activity for subsistence, many do specialize in one or more activity for market, from palm fruit collection to hunting or fishing [40–43]. Still, heavy reliance on local wild resources and common sharing of perceptions about resources begets a pervasive awareness of the status of key species of importance as food and/or for market [14, 34].

This paper reports on a survey—the largest as yet undertaken in Amazonia—that systematically assessed wild resource availability using local ecological knowledge derived from over 900 forest-based communities. Our study focuses on the Peruvian Amazon, a region of exceptional biological diversity,

with relatively few roads or major settlements, and limited colonization and deforestation. Considerably less research attention has been devoted to conditions in the Peruvian Amazon compared to neighbouring Brazil. The study provides initial insight into species status along four major rivers for a portfolio of species of game, fish and timber of importance to local people for their sustenance and livelihoods. Whereas previous studies tend to report on a single group, with an emphasis on game and hunting, our study examines all three species groups because fishing, hunting and forest product harvesting are complementary activities in household livelihoods [40, 44]. A further novel contribution of our study is to capture historical as well as current species presence and abundance, allowing us to reduce shifting baseline bias [45, 46] and discern analytically the importance of potential drivers of wild resource impoverishment while controlling for differences in the initial availability of species.

2. Methods

Data were gathered as part of the Peruvian Amazon Rural Livelihoods and Poverty (PARLAP) project (www.parlap.geog.mcgill.ca) in the administrative regions of Loreto and Ucayali, which cover about 85% of the area of the Peruvian Amazon (figure 1). Situated at <200 m of elevation, the study area is dominated by lowland humid tropical rain forest and extensive wetlands along the major rivers. Two cities—Iquitos (population: 437 400) in Loreto and Pucallpa (population: 211 700) in Ucayali [47]—act as major markets and administrative centres. Pucallpa has been connected with Lima by road since the 1940s, whereas Iquitos can be reached only by river boat or by air. Small towns, ranging in population from 5000 to 30 000, serve as secondary markets and are often district capitals. A myriad of smaller settlements, of 100–300 inhabitants, line the main rivers and streams. Rural communities are situated on either the upland (*terra firme*) above river flood levels or in the lowland (*várzea*) on the river floodplain and all communities rely on river transport to send products from agriculture, livestock production, fishing, timber and non-timber forest product harvesting, and hunting to market [48]. Whereas most communities draw upon local natural resources, some were established for other purposes including petroleum extraction.

A community survey was undertaken by two field teams in December 2012 through March 2014 along four major rivers—the Amazon, Napo, Pastaza and Ucayali—selected to capture diversity of ecological conditions, economic activity, history, and ethnicity over a large geographical area (117 680 km²). Along each river, the teams were guided by maps from the Peruvian *Instituto Nacional de Estadística e Informática* (INEI) for the 2007 census [49], the

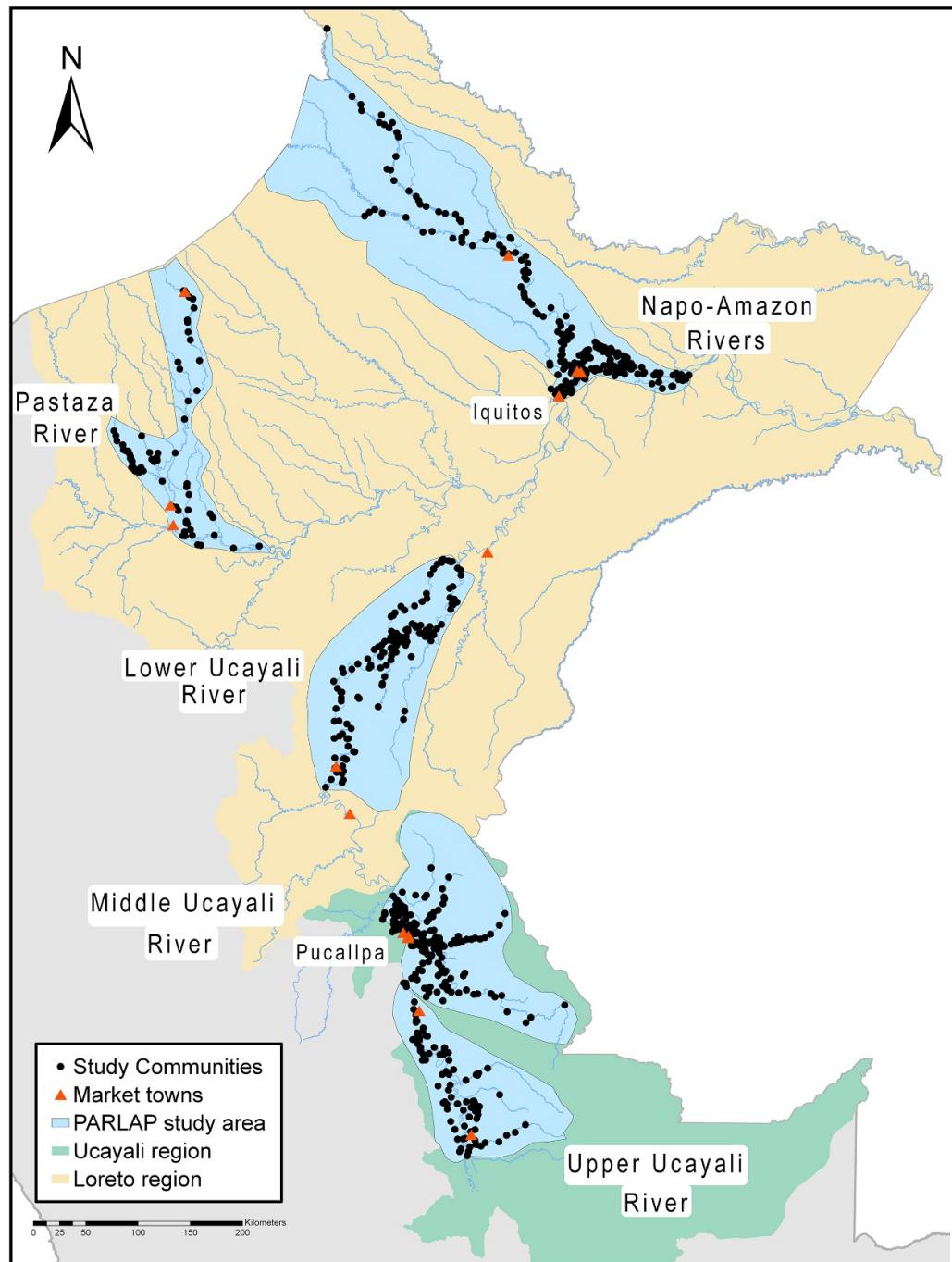


Figure 1. Location of study communities ($n = 689$) along the Amazon, Napo, Pastaza and Ucayali rivers, in the administrative regions of Loreto and Ucayali, Peruvian Amazon.

Instituto del Bien Común (IBC) for their census of indigenous communities [50, 51], and Google Earth imagery, supplemented by local enquiries by the teams to identify unmapped settlements. A total of 919 communities was visited over 19 months, which we estimate represents between 84 and 97% of all communities in each of the five sub-basins—Napo-Amazon, Pastaza, Lower Ucayali, Middle Ucayali and Upper Ucayali—in the study area (figure 1). In August 2014–July 2016 our teams returned to a stratified sample of 235 communities. Nearly 4000 households were interviewed on their livelihood activities, welfare

and resource perceptions that were then used for the validation of the data collected by the community survey.

Study communities are located primarily along the major rivers or tributaries and ranged in size from 5–13 098 individuals (mean: 46 households and 299 individuals). Forty-seven percent of communities self-identified as being indigenous. Settlements were founded between 1522 and 2012 with an average age since establishment in the current location of 38 years, and 36% of communities had relocated since first foundation. River boat service (*lancha*) was available

Table 1. List of indicator species of game, fish and timber used to assess species presence or absence with community leaders and elders in study communities, Peruvian Amazon.

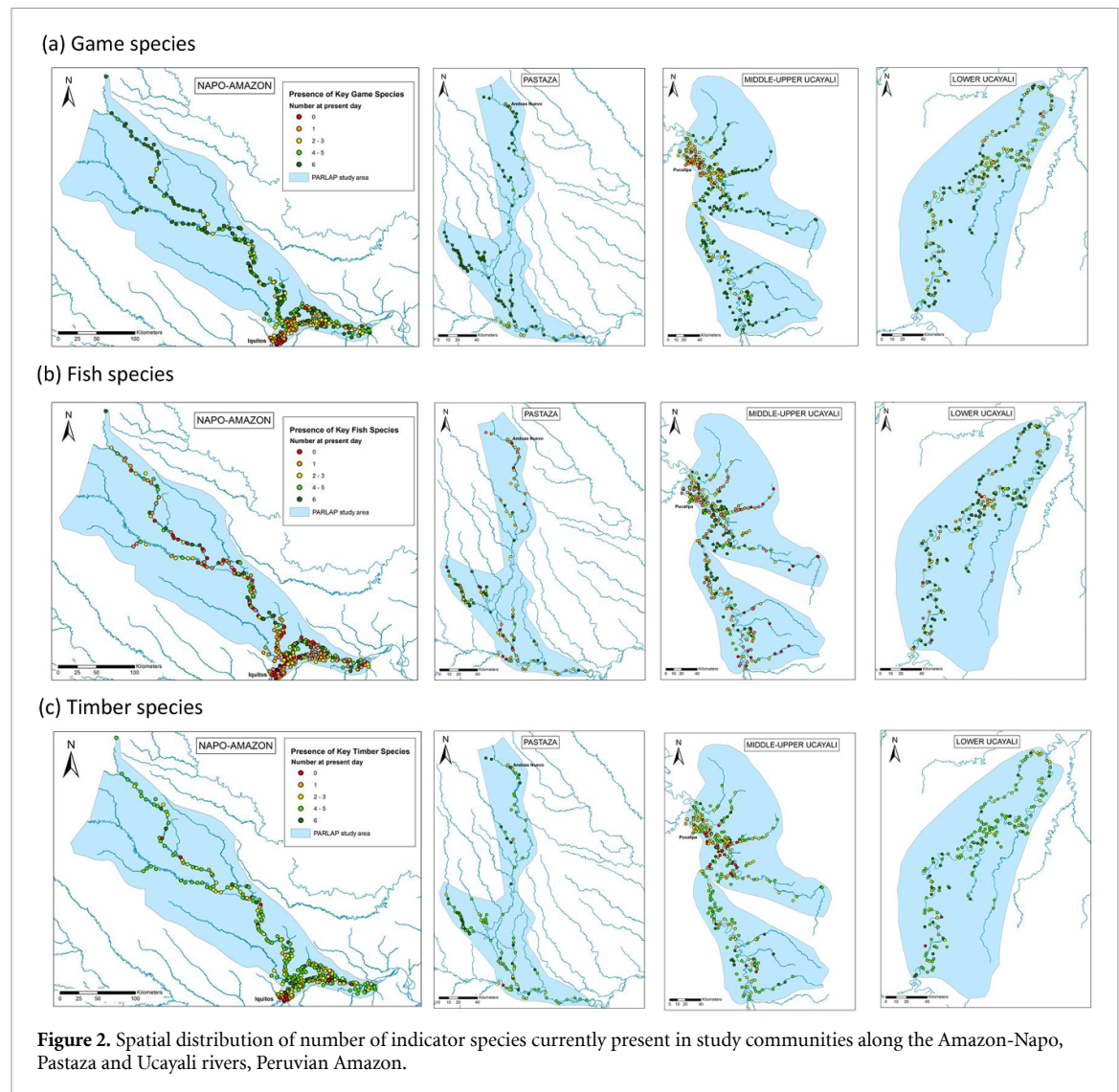
Spanish common name	Scientific name	English common name	Species classification
<i>Game</i>			
Sacha vaca	<i>Tapirus terrestris</i>	Lowland tapir	Large-bodied
Huangana	<i>Tayassu pecari</i>	White-lipped peccary	Large-bodied
Sajino	<i>Pecari tajacu</i>	Collared peccary	Large-bodied
Ronsoco	<i>Hydrochoerus hydrochaeris</i>	Capybara	Large-bodied
Venado	<i>Mazama</i> spp.	Brocket deer	Large-bodied
Mono choro	<i>Lagothrix lagotricha</i>	Woolly monkey	Small-bodied
Mono coto	<i>Alouatta seniculus</i>	Red howler monkey	Small-bodied
Mono maquisapa	<i>Ateles paniscus</i>	Spider monkey	Small-bodied
Majás	<i>Cuniculus paca</i>	Paca	Small-bodied
<i>Fish</i>			
Paiche	<i>Arapaima gigas</i>	Arapaima	1st class
Gamitana	<i>Colossoma macropomum</i>	Tambaqui	1st class
Paco	<i>Piaractus brachipomus</i>	Red-bellied pacu	2nd class
Tucunaré	<i>Cichla ocellaris</i>	Peacock bass	2nd class
Fasaco	<i>Hoplias malabaricus</i>	Wolf fish	2nd class
<i>Timber</i>			
Caoba	<i>Swietenia macrophylla</i>	Mahogany	1st class
Cedro	<i>Cedrela odorata</i>	Spanish cedar	1st class
Moena	<i>Ocotea bofo</i>	Louru	1st class
Tornillo	<i>Cedrelinga cateniformis</i>	Tornillo	1st class
Cumala	<i>Osteophloe platyspermum</i>	Cumala tree	2nd class
Lupuna	<i>Ceiba pentandra</i>	Kapok	2nd class

in 49% of communities and 39% had access to a public telephone at the time of the community survey. The mean distances along the rivers to the nearest neighbouring settlement, market town, and major urban centre (i.e. Iquitos or Pucallpa) are 4.1 km (std dev: 3.8 km, Euclidean), 81.9 km (std dev: 77.1 km, river network), and 261 km (std dev: 227.2 km, river network), respectively, and were based on the geo-referenced location of each community (see [52]).

In each community, the field teams sought out community leaders and elders to participate in a focus group-based interview, guided by a 9-page structured questionnaire. The interview sought information on a wide range of topics—from community characteristics and history to primary economic activities and local resource availability—paying particular attention to conditions and activities at the time of community establishment. A key element of the questionnaire focussed on accessing local ecological knowledge regarding species status around the community, both at the time of the survey (today) and when the community was established at its current site. Questions were asked to assess the presence of important indicator species; to gauge expected yields; and to determine the relative abundance of high-value species among those harvested. A consensus was sought from focus group members for each response which was generally found to be consistent with reports received in the household survey.

Lists of indicator species using Spanish common names were presented to the focus group that capture a range of market values as well as cultural

preferences and vulnerabilities to harvesting pressure (table 1). Focus group members were asked whether each species could be encountered within one day's travel from the community (by foot for game and timber; by canoe for fish), today and at community establishment in the current site. To assess yields of game, the group was asked to free-list which species (and equivalent weight in kilograms) one can capture on a good night of hunting, less than one day's walk from the community. To assess fish yields, the group was asked to estimate the catch (in kilograms) on a good night of fishing with a gillnet within one day's travel by canoe, currently and at establishment, as for game. Finally, focus group members were asked to identify which economic activities people in the community engaged in from a list of 11 activities (e.g. agriculture, fishing, hunting, logging, non-timber forest product harvesting, tourism, petroleum industry, etc) and then free-list the principal products associated with each, for the two periods of interest. A total of 24 game species, 39 species of fish and 48 species of timber was free-listed. Game was classified into large-bodied mammals, small-bodied mammals, monkeys, birds and reptiles. Monkeys were analyzed as a distinct group because of their cultural importance in local diets, their vulnerability to over-harvesting, and the importance given to them by international conservation NGOs. Fish and timber were grouped into 1st class, 2nd class, and 3rd class species by local preferences and market value (tables 1 and S1 stacks.iop.org/ERL/15/074016/mmedia). By comparing the named products (e.g. species of fish, game and timber), we can assess the change



in mention of high-value species since community establishment.

Descriptive analyses and mapping were undertaken using STATATM V15.1 and ArcMapTM to assess the status and spatial distribution of the number of indicator species present and the change for each species in the areas surrounding indigenous and folk (*riberaño*) communities established since 1960 ($n = 689$) (we excluded 13 colonist communities) (figure 1). The cut-off year of 1960 corresponds to a reasonable span of living memory among community elders [30, 36, 53]. Multiple ordinary least squares (OLS) regression analyses in STATATM were used to identify the drivers of resource depletion, controlling for reported initial availability of game, fish and timber species. Independent variables were drawn from the literature, theory and field experience. Specifically, we include distance to the nearest city and market; population density; local environmental conditions (flood risk, main channel aquatic habitat, floodplain habitat, soils); other community characteristics (age, ethnicity and initial availability of land); river basin fixed effects (five basins); and, initial

availability of corresponding wild resources (game, fish and timber) (see table S2 for the construction of independent variables; see table S3 for the descriptive statistics of dependent and independent variables, e.g. initial number of indicator game species to predict current number of game species reported). Results point to the influence of distance to urban centres, local environmental conditions, and importantly to the initial availability of game, fish and timber at the time of community establishment.

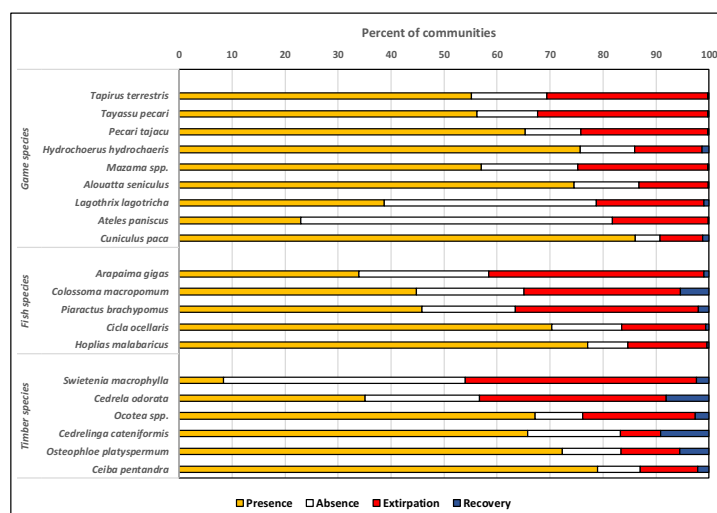
3. Results

The spatial distribution of the number of indicator species present suggests considerable inter- and intra-basin heterogeneity and a strong correlation with proximity to major urban centres (figure 2). Fewer indicator species were reported around the cities of Iquitos and Pucallpa, reflected in a zone or ‘halo’ of lower diversity within about 50–80 km. The urban halo depletion effect is most apparent for game and for fish, and less so for timber where lower diversity is more widespread. The more remote Pastaza and lower

Table 2. Presence of species of wild resources and expected harvest of game and fish in study communities in the current period and at time of community establishment, Peruvian Amazon.

	Current			Initial			Difference of means
	Mean	Std dev	n	Mean	Std dev	n	
<i>Game</i>							
No. Indicator species	5.46	2.84	689	7.20	2.18	689	−21.9***
No. large-bodied mammals	3.14	1.85	689	4.35	1.28	689	−20.3***
No. small-bodied mammals	2.32	1.22	689	2.85	1.13	689	−15.4***
No. species free-listed	1.97	1.65	689	2.27	1.70	689	−4.5***
No. species captured on a good night	1.99	1.08	689	2.70	1.19	689	−17.2***
Expected harvest on a good night (kg)	40.4	43.4	689	145.3	127.9	689	−12.5***
% Weight as large -bodied mammals	48	39	619	78	27	619	−18.1***
% Weight as small-bodied mammals	38	38	619	19	25	619	12.1***
% Weight as other species	14	28	619	3	9	619	10.3***
<i>Fish</i>							
No. indicator species	2.81	1.68	689	4.07	1.54	689	−24.7***
No. 1st class species	0.85	0.87	689	1.49	0.78	689	−19.6***
No. 2nd class species	1.96	1.04	689	2.59	0.87	689	−19.0***
No. species free-listed	3.18	1.15	689	3.29	1.07	689	−2.3**
Expected harvest on a good night (kg)	21.4	56.1	681	70.6	135.2	685	−12.7***
<i>Timber</i>							
No. indicator species	3.57	1.58	689	4.57	1.61	689	−17.7***
No. 1st class timber species	1.98	1.11	689	2.84	1.24	689	−18.4***
No. 2nd class timber species	1.59	0.70	689	1.73	0.60	689	−6.0***
No. species free-listed	1.78	1.67	689	2.37	1.80	689	−8.6***

The analysis sample is 689 communities. The current period is the time of the community survey; the initial period is the time of community establishment at the current site. The expected harvest includes all communities. %Weight of game calculated only for communities where current and initial total harvest of game > 0. Difference of means shows t value of the paired t-test for the null hypothesis that the means at the current period and the initial period are the same. **p < 0.05, ***p < 0.01, based on the two-sided significance of the t-test. The degrees of freedom are the number of total observations minus 1 (e.g. 688 for No. Indicator species).

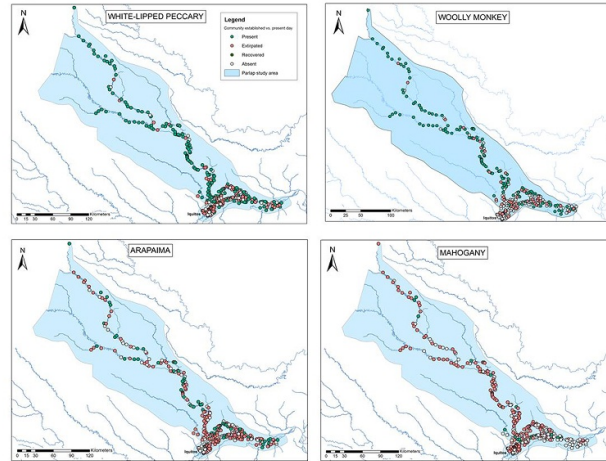
**Figure 3.** Change in status of indicator species of game, fish and timber in study communities between community establishment and the current period, Peruvian Amazon. Presence (or absence) of species at both the time of community establishment and community survey. Extirpation refers to absence of species at time of community survey but presence when community first established. Recovery refers to species presence at time of survey but absence at community establishment.

Ucayali rivers have more indicator species present around communities relative to other river basins. The urban-rural gradient in number of indicator fish species present is less sharp than for game with many communities far from urban areas reporting relatively fewer fish species. The lower Ucayali river is relatively species 'rich' for fish as the Pastaza

basin is for game. The presence of the oil town, Andoas Nuevo, on the upper Pastaza river (Figure S2 (stacks.iop.org/ERL/15/074016/mmedia)), is evident by local depression in the number of fish and game species.

Comparisons between the current and initial species presence for communities established since 1960

(a) Napo-Amazon rivers



(b) Middle-Upper Ucayali river.

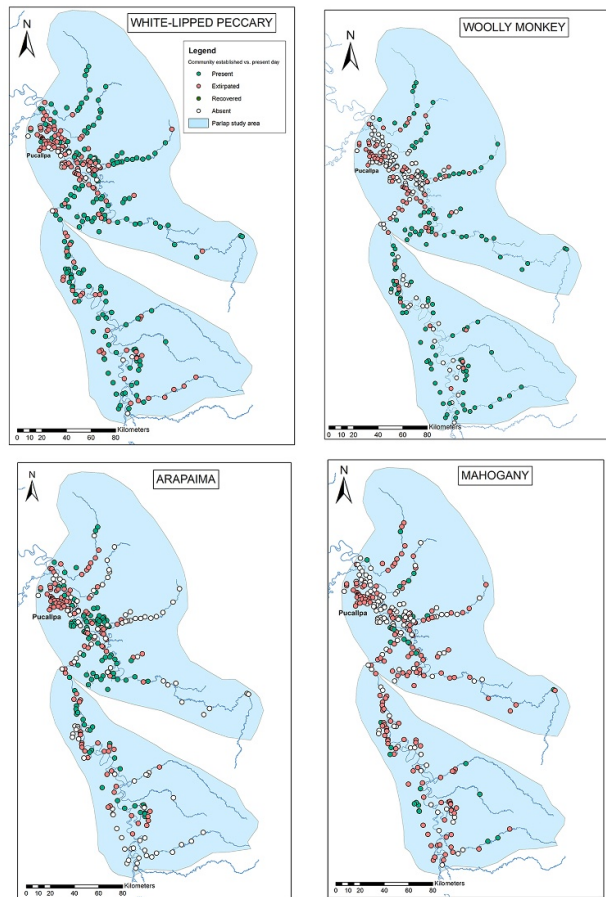


Figure 4. Presence and loss of selected vulnerable species along the Napo-Amazon and Middle-Upper Ucayali rivers.

($n = 688$; mean community age is 26 years, see figure S1) suggest a significant decrease in important local wild resources around communities. The mean number of indicator species fell consistently for game (7.2 to 5.5 species), fish (4.1 to 2.8) and timber (4.6 to 3.6) between the time of community establishment and today (table 2). The mean number of free-listed species also fell for game, fish and timber. Today, nine

of 20 key species are found in 30% + fewer communities than at the time of community establishment. Local depletion is highest for valuable timber (mahogany 84%; cedar 50%), then fish (arapaima 55%; pacu 43% and tambaqui 40%); and then game (spider monkey 44%; collared peccary 36%; tapir 36%) (figure 3). The disappearance of vulnerable species such as white-lipped peccary, arapaima and

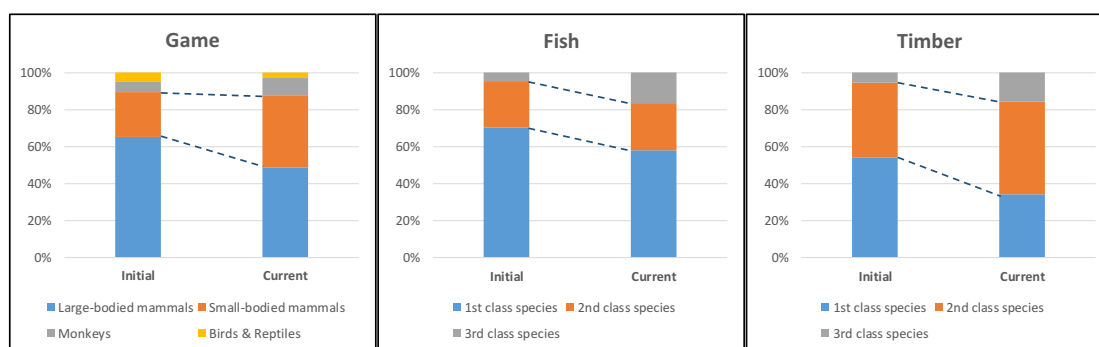


Figure 5. Percentage of free-listed species of game, fish and timber by class in study communities, at community establishment and the current period, Peruvian Amazon.

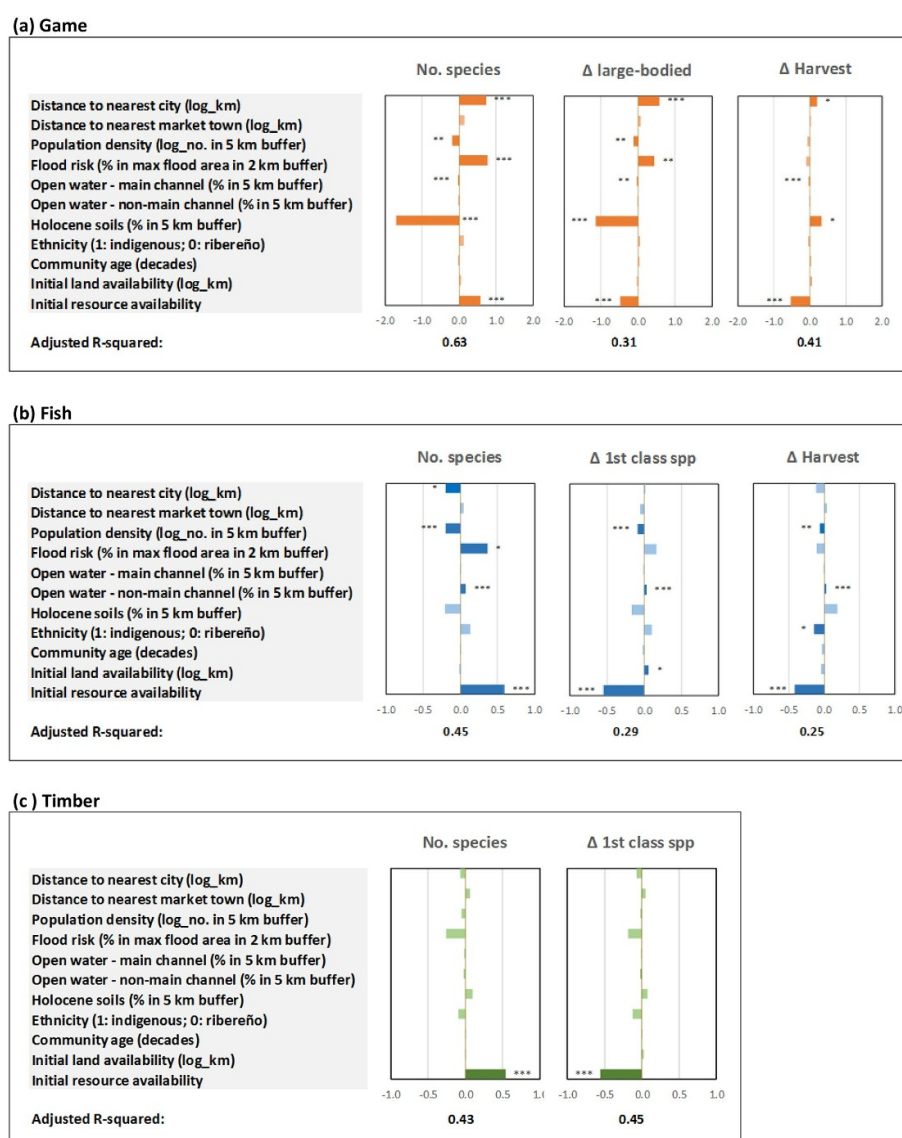


Figure 6. Results of OLS regression analyses of the number of indicator species present, the change in class of species, and expected harvest (game and fish) between community establishment and the current period on community and environmental characteristics. The sample for analysis comprises 689 communities. Each set of bar graphs shows the estimated coefficients of selected independent variables in OLS regression. Darker bars indicate coefficients that are statistically significant (* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$). Basin fixed effects (5 basins) are not shown. See Supplementary information, Table S3, for definition of explanatory variables; Table S4 for test statistics and coefficients.

mahogany is apparent in communities near the cities but also, in the case of mahogany, in remote regions (figure 4). Importantly, for many communities, certain vulnerable species were absent at the time of community establishment; game: woolly and spider monkeys (35 and 59%, respectively); fish: arapaima (25%) and tambaqui (20%); timber: mahogany (46%) and cedar (22%) (figure 3). Evidence of recovery, however, is found for some species across groups, especially timber (tornillo 12.5%; cedar 11.5%) and fish (tambaqui 7.2%) but less so for game species (<2% of communities report presence today but absence at outset).

Expected harvests of game and fish on a good night decreased markedly for communities between today and establishment (table 2). For game, expected harvests fell both in terms of the number of species captured (2.7 to 2.0 species) and the capture weight (145 kg to 40 kg). Although large-bodied mammals contribute most by weight to expected harvests in both periods, the share of their contribution fell from 78% to 48% while the contribution of small-bodied mammals and other species, including monkeys, reptiles and birds, rose to 38% and 14%, respectively. Qualitatively the same results hold for number of free-listed game species (figure 5). For fish, expected harvests today are about 30% of initial expected harvests (i.e. 21 kg vs. 70 kg) on a good night of fishing (table 2). The numbers of indicator and free-listed species were also lower. Of the free-listed species, 1st class species remained the most commonly cited, though falling from 73% to 60%, but the share of 3rd class species rose from 4% to 16% (figure 5). For timber, fewer indicator and free-listed species were reported (table 2), and whereas 1st class timber species were most commonly mentioned at establishment (52%), 2nd class species were most mentioned for today (53%). Reports of 3rd class timber species rose from 5% to 16% (figure 5). These results suggest a general trend of ‘harvesting down’ of local wild resources, from large-bodied to small-bodied mammals and other species, and from highly- to lesser-valued fish and timber.

Multiple regression analyses were conducted to predict the reported current number of indicator species present, the change in the share (percentage) of important species (large-bodied mammals and 1st class species of fish and timber), and the change in expected harvest of game and fish from community establishment to today (current value – initial value). Regression models explain between 25%–63% of the observed variance in the dependent variables (figure 6; table S4). In all models, initial resource availability is an important predictor as are the basin fixed effects (indicating heterogeneity across basins). Communities beginning with more indicator species have more species today; those beginning with higher share of valuable species experienced a greater

decrease in their share of valuable species. Communities with initial higher yields experienced larger decreases in expected harvests. Community age and ethnicity were not significantly related to most outcomes (with an exception for fish discussed below). For game, access to the city rather than to market towns predicts lower numbers of indicator species, a greater decrease in the number of large-bodied mammals and greater losses in harvest reported. Higher local population density is related to lower number of species and a larger decrease in the share of large-bodied mammals. Environmental conditions are also influential; higher species diversity and lower decrease in share of valuable species are encountered on older (poorer) soils. For fish, local population density is more important than access to the city or market towns in predicting a decrease in fish indicator species, including 1st class species. Communities with more floodplain habitat (non-main channel open water) had more species, including 1st class species, and lower yield losses; communities at higher risk of flooding also have more species. Older and indigenous communities had greater decreases in reported yields. For timber, only initial availability contributes significantly to yields. Repeating the analyses without controlling for initial availability yields different statistical results for some of the predictors for game, fish and timber, as discussed below (Table S5). Further analysis to predict availability of resources at the time of community establishment shows that newer communities face lower initial availability, suggesting general impoverishment over time within river basins (Table S6).

4. Discussion and conclusion

Our findings from a large-scale, systematic survey of local ecological knowledge suggest that local wild resources are being impoverished around riverine communities along four major rivers in the Peruvian Amazon. Communities founded over the past 50 years report a significant decline in game, fish and timber species, especially large-bodied mammals (tapir, white-lipped and collared peccaries, deer and woolly and spider monkeys), high quality fish (arapaima, tambaqui and pacu), and valuable timber species (mahogany and cedar). Declines in species presence are spatially concentrated, near major urban centers and an oil extraction site, creating a ‘halo’ of defaunation within 50–80 km; the loss of valuable timber species is spatially more pervasive and likely occurred in many areas prior to the 1960s [54]. Expected yields are falling, and people are taking species of progressively lesser value, i.e. harvesting down. Local decline of valuable species is common and newer communities face lower initial availability of game, fish and timber, suggesting widespread

species depletion rather than local repulsion (cf [24]). Some recovery is observed among certain timber and fish species but rarely for game.

The impoverishment of local wild resources in the Peruvian Amazon is driven primarily by market demand emanating from the rapidly growing cities of Pucallpa—with its road connection to Lima and the coast—and Iquitos, as well as the secondary towns of the region. Access to urban centres is the key driver for game depletion whereas local demand for fish is more important, except for 1st class species such as arapaima, tambaqui and pacu which are sent to the city. Valuable mahogany and cedar for export and domestic use have been extensively removed. Market-driven demand rather than subsistence needs drives both local people and outsiders to put pressure on local resources. Residents finance rural to urban migration with the proceeds of resource harvesting [55] and newcomers to the city bring with them rural tastes for fish and game [56]. The oil industry puts considerable pressure on local resources as reflected in the depletion zone around Andoas Nuevo. Urban-based outsiders seek out game, fish and timber either directly or through contracting local people (*habilitación*), often contesting claims by riverine communities over access to local resources [57]. Communities have sought to secure land rights as well as to protect their wild resources through the creation of communal lakes and forest reserves, and the implementation of management programs [58–60], albeit with mixed success. Recently formed communities face an impoverished forest, and this may explain a trend away from forest resource harvesting towards agriculture in local livelihoods in Amazonian Peru [61] and nearby Ecuador [62].

Our findings are generally consistent with patterns of defaunation in the Brazilian Amazon (see [14, 24–26, 35, 36, 63]) as well as results from studies of wildlife, fish and timber in the Peruvian Amazon (see [18, 55, 64–69]). Where our findings diverge from reports from Brazil appears to be due to the inclusion of initial availability in the analysis. A sizable share of communities at their establishment lacked at least one indicator species (e.g. game, 62% of communities lacked at least one indicator species; fish, 34%; timber, 57%). As such the potential for bias in the estimations of the drivers of resource stocks, of their change, and of change in expected harvest is likely to be high. Indeed, in the regression models run excluding initial resource availability we found that community age became a significant driver of depletion for game and timber (table S5); the effect disappears when controlling for initial resource availability (figure 6; table S4). Since community age is a strong predictor for initial resource availability (table S6), the former significant estimates are biased due to omitted initial resource availability. By considering initial conditions, based on interviews

with community leaders and elders during which current conditions were discussed in the context of conditions at establishment, our analyses minimize potential shifting baseline bias. The powerful influence of initial conditions on current presence/absence of indicator species and expected yields points to the importance of considering historical baselines in analyses meant to guide conservation policy and management strategies.

Like other synoptic, inter-temporal studies that rely on local ecological knowledge, our results are potentially limited by the cognitive bias referred to as ‘rosy retrospection’, i.e. conditions in the past are consistently recalled as being better than today [45, 46]. This may be particularly true for the expected yields of game and fish at community establishment and yield losses between community establishment and today are likely to be biased upwards. Importantly, however, our interest lies in *relative* contrasts across communities over *absolute* changes in yields of game and fish. The simple presence/absence of indicator species is less likely to be affected by retrospection bias. Although historical data drawn from memory may not be precise, it is useful to signal ongoing resource declines. Indeed, our findings are consistent when compared to household-level data for validation, spatial patterns observed in Brazil and the relative vulnerability of species known, and we observe recovery as well as species loss, buttressing the credibility of our measures.

Clearly, our study is a first step—a precursor to studies using classic methods such as line-transect and capture censuses, that would assess the validity of our findings in Amazonian Peru. Over such large areas and with relative rapid rates of impoverishment, however, field-based studies will take considerable time and resources to complete. In the meantime, researchers need to consider what are the implications of wild resource impoverishment for forest-dwelling people and what can be done now to enhance local efforts through on-going community-based resource management to protect game, fish and timber resources around their communities.

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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