Ecosystem services provided by the habitat of the Jaguar (Panthera onca)

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Executive summary

Jaguars (*Panthera onca*) are declining across their range; the large territories they need are disappearing along with a wide range of ecosystem services, and associated social and economic benefits.

The current project had three aims:
- assess the knowledge level on ecosystem services across the jaguar range
- map the ecosystem services from the jaguar range
- develop a proposal for further work on ecosystem services from the jaguar range

The following report contains a literature review (section 1 produced by Sue Stolton and Nigel Dudley of Equilibrium Research); a mapping exercise of ecosystem service assessment (section 2 produced by Sophia Burke of AmbioTEK CIC and Mark Mulligan, Dept. Geography, King’s College London) and proposal for a larger scale project (appendix 1 produced by Sue Stolton and Nigel Dudley of Equilibrium Research).

Key findings from the report are:
- To date there has been very little research on the links between ecosystem services and jaguars
- The jaguar range encompasses areas of particularly high biodiversity (27.7% of the world’s total)
- The jaguar range provides an array of ecosystem services: in particular carbon storage and sequestration (17% of the world’s provision), hazard mitigation (12% of the world’s provision), and wildlife services (12% of the world’s provision).

This report is a scoping study, investigating current levels of knowledge. The next stage is to build a more complete knowledge base and use this to further develop ecosystem services, to support both human communities and jaguar populations.
Section 1: Literature review

Jaguars are declining across their range (Quigley et al., 2018). Jaguars need large territories; implying that for truly healthy populations to survive landscape scale planning, connectivity and conservation corridors are necessary. This landscape scale matrix provides the opportunity for the jaguar range to include a wide range of ecosystem services, along with associated social and economic benefits. However to date there have been very little research on the links between ecosystem services and jaguars.

Thornton et al. (2016) undertook a quantitative evaluation of the umbrella value of the jaguar for conserving high-quality habitat of co-occurring mammal species in Latin America. The results showed that the jaguar network outperformed random networks in protecting high-quality habitat for co-occurring mammals.

Some research has looked at the management of jaguars in mixed use landscapes. Research in Colombia estimated jaguar density outside protected areas in agricultural regions, which included cattle ranching (the main land use in the country) and oil palm cultivation. Low but important populations occurred in agricultural landscapes, including oil-palm plantations (the highest recorded being 2.52±0.46–3.15±1.08 adults/100 km²). The authors concluded jaguars can utilise areas where natural ecosystems and riparian habitats persist in the landscape and where hunting of both jaguar and prey is limited (Boron et al., 2016). Supporting land management through payments for conservation management based around coexistence of human communities with large predators provides a major conservation opportunity for the survival of wild jaguars. A survey across four countries (Bolivia, French Guiana, Nicaragua and Guatemala) and a range of biomes with Forest Stewardship Council (FSC) or Pan European Forest Council (PEFC) certification found that income generating forest management can be compatible with jaguar and ecosystem conservation, but only where there is efficient control of secondary impacts of access and hunting (Polisar et al, 2017). In Brazil, a study of Formosa military training area in Goia state recorded the presence of jaguars, and many other endangered species, highlighting the possible utility of this form of land use in conservation planning (Arimoro et al., 2017).

A participatory process in Costa Rica investigated human wildlife conflict with ranchers from areas where attacks on livestock by big cats were suspected (Amit & Jacobson, 2018). Community support for payments for ecosystem services (PES) was one of six incentives suggested by stakeholders to increase benefits for rural communities coexisting with large carnivores, specifically jaguar and puma (Puma concolor). There are however very few examples of PES related to jaguars. In northern Belize a conservation payment programme pays local landowners who border protected areas when camera traps record wild cat (including jaguar) presence on their land. A study of this programme found that tolerance to wild cats was associated with gender and participation in the camera trapping programme, whereas intention to kill cats was associated with cultural group (Mennonites vs Mestizos), presence of children in the home and, to a lesser extent, tolerance. Interestingly, tolerance was not significantly related to depredation losses or economic factors suggesting that monetary payments alone are unlikely to affect attitudes and behaviours towards carnivores (Harvey et al., 2017). Similar findings came from a survey of ranch operators in Arizona and New Mexico in the USA which is facing new regulations related to jaguar conservation. The results showed that
although ranchers are interested in wildlife conservation generally, they were unlikely to get involved in PES payments originating from government schemes due to concerns related to increased government involvement in their operations. The researchers concluded that to meet endangered species conservation goals effectively, PES programmes should be voluntary, focus incentives on healthy ecosystems rather than a single species, and use private funding to support incentives (Lien et al., 2019).

Tourism is one of the most obvious and easiest sectors to make links between economic benefits and charismatic species. One study has shown that jaguar ecotourism represents a gross annual income of over US$6 million in land-use revenue across a representative portion the Brazilian Pantanal. The study also considered the costs of jaguar depredation on livestock within the same area and estimated that the resident jaguar population would induce a hypothetical damage of about US$120,000 per year in bovine cattle losses. The study concluded by suggesting a partnership between ecotourism and cattle ranchers, where cattle losses induced by jaguars could be compensated by a system of voluntary donations from tourists, ensuring that both traditional livestock husbandry and ecotourism can co-exist within the same ranches, thus promoting landscape-scale jaguar conservation (Tortato et al., 2017).

Finally, one study in northeast Brazil noted that jaguars were noted as having a role in local “superstition” but no details were given (de Melo et al., 2014).

Methodology
A literature review was carried out in March 2019 using the web of science and other databases available through the University of Queensland’s library database. Reviewed terms were: “Panthera onca” and “ecosystem services” from any field over the last five years (2015-2019) for peer reviewed papers (articles). A wider Google search of material found no additional papers of direct relevance to the subject.
Section 2: Co$ting Nature Assessment of Ecosystem Services

Co$ting Nature (www.policysupport.org/costingnature) is a tool to characterise conservation priority spatially, at scales from local through national to global scale. It uses remote sensing and global databases to map the spatial distribution of 13 ecosystem services and four other conservation-relevant factors such as biodiversity, current human pressure on the land and future threats. The tool was used to produce a range of maps using the Co$ting Nature Policy Support System covering the Species Survival Commission (SSC) data set for the extant range of the jaguar.

Overall the story indicates that the jaguar range encompasses areas of particularly high biodiversity (27.7% of the world’s total) and provides a range of services especially carbon storage and sequestration (17% of the world’s provision), hazard mitigation (12% of the world’s provision), and wildlife services (12% of the world’s provision). Other services, such as fuelwood, fish catch, non-timber forest products etc are important to local people although score relatively low on a global scale mainly because of the low human population levels in much of the region.
Biodiversity

Map: Relative biodiversity priority index
Percent of the world’s total biodiversity within jaguar range: 27.7%
Percent of range total biodiversity that is within protected areas within range: 49%

Story: The extant range of jaguar represents 8.6% of the world’s land surface area but supports nearly 28% of the world’s biodiversity and includes some high biodiversity areas especially in the Andean region. Half of the biodiversity in the range falls within protected areas.

Summary of method: Biodiversity is not a service per se but is important culturally, aesthetically and as a potential supporting framework for ecosystems and the services that they provide. Biodiversity loss is therefore to be avoided wherever possible. Two elements of biodiversity are considered as important for conservation priority: (a) species richness (number) of IUCN sampled Red List species and (b) endemism or range size rarity of species of IUCN sampled red-list species. The data available makes these calculations possible for mammals, amphibians, reptiles and birds. The CoSting Nature biodiversity index thus combines relative species richness of clades: mammals, amphibians, reptiles and birds with relative range size rarity based the C-value (Barthlott et al., 2001). Species richness and endemism are equally weighted in the combined index. For each clade Sampled Red List Index species are corrected for the presence of cropland, pasture and urban areas such that the intensity of these land use types reduces the stacked richness and endemism richness linearly.

Kier and Barthlott (2001) define endemism richness as the “specific contribution of an area to

1 Note that CoSting Nature spatial calculations used in this report assume that the land surface area of the world excludes ice areas.
global biodiversity”. Since it accounts for range size rarity, it is potentially a better measure of conservation value than species richness, which can be dominated by common, wide-ranging species. The contribution of a specific area to the global species inventory is known as its C-value. For the 10 by 10 km (native) raster grids used here the C-value of a pixel for a given species was calculated as 1/G, where G is the global range size (i.e. the number of pixels in which the species occurs). Thus where species have a large range, the C-value is low, and where their range is restricted, the C-value is high, and endemism richness of a site is thus the sum of C-values for all the species for which data are available.

**Pressure**

![Pressure Map](image)

**Map:** Relative pressure index
Percent of the world’s total pressure within range: 5
Percent of the world’s total pressure within protected range: 25

**Story:** The extant range of the jaguar represents 8.6% of the world’s surface area but it includes only 5% of the total anthropogenic pressure, so tends to be less pressured than the average, due to low population. A quarter of this land is protected, but much is still significantly pressured by human activity, particularly outside of Amazonia.

**Summary of method:** The index of current pressure is given as the combination of relative population, relative fire frequency, relative grazing intensity, relative agricultural intensity, relative dam density and relative infrastructural density. Relative population is calculated on the basis of population density from Landscan (2007). Relative fire frequency is based on an analysis of the mean
burn frequency from 2001-2010 from the MODIS burnt area product (Mulligan, 2010). Grazing intensity is calculated according to head of cattle for managed grazing and wildland grazing after Robinson et al. (2013). Agricultural intensity combines the fractions of cropland (Fritz et. al., 2015) and pasture (Ramankutty et al., 2008) in each pixel. Pressure from dams is calculated as the cumulative upstream number of dams using the Global Dams Database (Mulligan et al, 2009). Infrastructural pressure is calculated from the location of dams (Mulligan et al, 2009), mines (Mulligan et al, 2010a), oil and gas (Mulligan et al, 2010b), roads (UN FAO GIEWS, 2010) and urban infrastructure.

**Threat**

![Relative threat index masked where jagzip [uploaded] area is = 1](image)

**Map:** Relative threat index  
Percent of the world’s total threat within range: 10  
Percent of range total threat that is protected: 42

**Story:** The extant range of jaguar represents 8.6% of the world’s surface area but has 10% of its anthropogenic threat. Jaguar habitat is thus more threatened than the average and around 42% of this threat falls in the protected range.

**Summary of method:** Threats are distinct from pressures because pressure refers to current pressure whereas threat is the potential to increase pressure into the future. The Costing Nature relative threat index combines threats of land use change, climate change and infrastructural change. All threats are assumed to be related to accessibility to populations through the roads network. The threat of deforestation is assumed to scale with proximity to existing deforestation
fronts according to MODIS VCF_change (VCF_change is a land use change alert system based on the MODIS Vegetation Continuous Fields tree cover product (Collection 4, release 3)) and Global Forest Change, threats from infrastructure are assumed to scale with projected change in GDP and threats from population to scale with projected population change. Threats from climate change are assumed to scale with 17 GCM ensemble projected IPCC AR4 A2a temperature and precipitation change to the 2050s. Finally remote threats such as mining and oil and gas (that may be distant from populations, urban areas and roads) are assumed to be greater in proximity to existing night-time lights. All of these threats are given equal weight and scaled from 0-1 in the final threats map.

**Bundle of ecosystem services**

![Map: Bundle of ecosystem services](image)

**Percent of the world total within range:** 11
**Percent within range that is protected:** 37
**Number of people benefitting within area (millions):** 53

**Story:** Jaguar habitat provides a greater proportion of Costing Nature's 13 ecosystem services than the average (11% of total services provided in only 8.6% of the world’s surface area). This reflects provision across a range of services and proximity of some jaguar habitat to human populations. Some 37 million people within this range benefit directly from these services.

**Summary of method:** The model produces a series of summary metrics as maps which combine the outputs of many of the modules described below. This is total realised services including: timber (softwood, hardwood), fuelwood (softwood, hardwood), grazing/fodder, non-wood forest products,
water provisioning (quantity, quality), fish catch, carbon, natural hazard mitigation (flood, drought, landslide, coastal inundation), culture-based tourism, nature-based tourism services, environmental and aesthetic quality services, wildlife services (pollination, pest control), and wildlife dis-services (crop raiding, pests). All are combined here on a scale of 0-1 (lowest to highest) with equal weighting for each service.

**Greatest service per pixel**

**Map**: Greatest relative total realised bundled service

**Story**: Throughout most of the jaguar range the per-pixel greatest service provision is carbon storage and sequestration (reflecting low nearby populations and thus few beneficiaries for more localised services). There are, however, parts of the range in which hazard mitigation, wildlife services or commercial fisheries (in the Amazon) are the greatest services provided.

**Summary of method**: Greatest relative total realized bundled service gives whichever is the greatest of the component services in each pixel e.g. timber (softwood, hardwood), fuelwood (softwood, hardwood), grazing/fodder, non-wood forest products, water provisioning (quantity, quality), fish catch, carbon, natural hazard mitigation (flood, drought, landslide, coastal inundation), culture-based tourism, nature-based tourism services, environmental and aesthetic quality services, wildlife services (pollination, pest control), wildlife dis-services (crop raiding, pests). Note that greatest service may not be high but is higher than all other services in that pixel.

Ecosystem services in the jaguar range
**Timber (softwood, hardwood)**

**Map**: Relative realised commercial timber services index
- Percent of the world total within range: 10.5
- Percent within range that is protected: 32
- Number of people benefitting within area (millions): 17.4

**Story**: Jaguar habitat has higher than average potential for realised commercial timber provision (10.5% of total services in 8.6% of the world’s surface area) which reflects the jaguar habitat located in forested areas; but values are not universally high across the range due to the low road accessibility in the jaguar range. The areas with high values are where there are both high densities of timber and also access to markets.

**Summary of method**: Timber provision is used for house building, furniture and in food storage, water and agricultural infrastructure. At low extraction rates it is sustainable and can continue to be provided at the rates consumed. At high extraction rates it is consumptive of the ecosystem and may damage the co-benefits for other services provided by forests. Realised timber services thus need to be considered carefully in this regard. Timber is separated into commercial timber and domestic timber. Commercial timber contributes value to national beneficiaries, whereas domestic timber contributes value to local beneficiaries. Softwood and hardwood are also considered since these have differing economic values.

**Commercial timber**: First, the potential mass of timber (the potential service) is estimated from the above ground carbon stock map (Ruesch et al, 2008; Saatchi et al, 2011). The sustainable harvest is
considered to be the reciprocal of the number of years taken to develop the stock at the annual sequestration rate, according to the dry matter productivity data of Mulligan (2009) based on a 10 year climatology of SPOT VGT data.

The realised service (the timber accessible) is calculated as potential timber within 6 hours travel time of a population centre of >50K people (Uchida and Nelson, 2009) and on slope gradients <31.5 degrees (70%) (Lehner et al., 2008) considered to be workable for logging (Greulich, 1999). This accessibility requirement represents the availability of transport infrastructure for timber. Co$ting Nature also allows the specification of forest management units or timber concessions (as an area of interest) to restrict timber within specific zones. In both cases, timber mass defined as accessible is constrained by slope to reflect the higher cost of removal (and increased wastage) on steeper slopes using a linear decrease in timber availability (from the potential availability to zero) as slope increases from 0 to 90 degrees. The product of the potential services and these accessibility constraints is the realised timber service in tonnes.

**Domestic timber:** This differs from commercial timber in that it is not permitted in areas where commercial timber extraction is present or urban areas and the conversion from potential to realised service depends on a population dependent demand (assuming one tonne dry weight person per year) that also scales with slope gradient (reaching zero at 90 degrees). The realised domestic timber service is thus the domestic timber demand (where demand < supply) and the supply (if demand > supply), with unmet demand supplied via markets.

**Fuelwood (softwood, hardwood)**
Map: Relative realised fuelwood provision services index
Percent of the world total within range: 3.5
Percent within range that is protected: 27
Number of people benefitting within area (millions) 24.6

Story: Low local human populations in much of the jaguar range means that the fuelwood provision service is lower than average for the world, though some 24.5 million people still benefit (3.5% of total services provided globally but in only 8.6% of the world’s surface area). Areas with higher fuelwood ecosystem services are small areas in eastern Brazil, northern Peru and northern Colombia, and parts of Central America.

Summary of method: Fuelwood is a provisioning service that is fundamental to the energy security for cooking and heating, particularly of the poor. Domestic fuelwood only is considered. As with timber, all above ground carbon stock represented by tree cover is considered a potential fuelwood service or supply, so the potential fuelwood service is the product of above ground carbon stock (Ruesch et al, 2008; Saatchi et al, 2011) and fractional tree cover (di Miceli et al., 2011) for rural areas (Schneider et al., 2009) only (urban trees are considered not to be usable for fuelwood). Fuelwood demand is considered to scale with rural population (Landscan, 2007) and per-capita use of 3.65 tonnes/person/year (OECD, 2006) but also with slope gradient using a linear decrease in fuelwood demand (from baseline demand to zero) as slope increases from 0 to 90 degrees. The realised fuelwood service (tonnes) is thus equal to the fuelwood demand (where supply >= demand) or is constrained to the supply where (supply < demand). Fuelwood is considered only for domestic uses and is not considered a commercialised ecosystem service. Fuelwood thus benefits local beneficiaries.
Grazing/fodder

**Map**: Relative realised grazing and fodder services index

- Percent of Word total within range: 4.9
- Percent within range that is protected: 20
- Number of people benefitting within area (millions): 47.7

**Story**: Grazing is lower than average in jaguar habitat because of lower livestock densities and lower overall grassland productivity (4.9% of total services in 8.6% of the world’s land surface area). There are some notable exceptions with high values in northern Colombia and Venezuela and parts of Brazil and some 47.7 million people still benefit from this service provided within the jaguar range.

**Summary of method**: The grazing and fodder service is a provisioning service that is fundamental to pastoralists who work with wildland grazers (cows, sheep, goats etc who graze in the natural environment). The potential grazing and fodder service is calculated as the tonnes of dry matter productivity for the non-cropland cover fraction (i.e. including pastures, forests and other non-cropland uses). The dry matter productivity data used is that of Mulligan (2009) based on a 10 year climatology of SPOT VGT data. The realized grazing and fodder index must account for the consumption by livestock and does so by assuming that wildland grazers consume some 12 kg dry matter per day so consumption is calculated as the wildland grazer headcount (Robinson et al., 2013) multiplied by the average consumption in tonnes. The realized grazing service is thus the minimum of the livestock consumption and the potential service. Where the potential service is lower than the livestock consumption, the difference is considered to have to be supplied through feed. The grazing and fodder is service considered to benefit local beneficiaries.
Non-wood forest products

**Map:** Relative realised non-wood forest product services index
Percent of the world total within range: 2.9
Percent within range that is protected: 30.9
Number of people benefitting within area (millions) 24.6

**Story:** Again because of the relatively low levels of rural population over much of the jaguar habitat, this produces less than average service provision for NWFPs (2.9% of total services in 8.6% of the world’s land surface area). Still nearly 25 million people benefit from this service within jaguar habitat. The geographical spread is fairly even with one or two hotspots of service provision in Central America.

**Summary of method:** Non-wood forest products (NWFPs) are a wide range of forest fruits, nuts, fungi, animals and plants sourced from forests. NWFPs exclude timber and fuelwood. NWFPs are thus a provisioning service. Though they may contribute to domestic subsistence or be sold in markets, they are considered to benefit local beneficiaries and are calculated as a single service without separation between commercial and domestic since collectors are artisanal, not large scale commercial. The potential service is calculated as the fractional tree cover (di Miceli et al., 2011) for rural areas (Schneider et al., 2009) only (urban trees are considered not to be usable for NWFPs) on the basis that all forests can potentially provide NWFPs. The realised service is the product of the potential service and the normalised population considered poor (Elvidge et al, 2006) on the basis that NWFPs increase in use and importance with poverty.

Ecosystem services in the jaguar range
**Water provisioning (quantity, quality)**

Map: Relative realised water provisioning services index
Percent of the world total within range: 1.6
Percent within range that is protected: 36.8
Number of people benefitting within area (millions) 46

**Story:** The jaguar range provides around only 1.6% of the world’s water ecosystem services in some 6.8% of the world’s land surface area, due to low population density locally and downstream in these areas, with significant inputs in some key basins such the agricultural belts southeast of the Amazon in Brazil. The areas upstream of major cities are very important for the ES, and there are high values in parts of Brazil and Mexico. Some 46 million people benefit within the range, many more downstream also.
### Commercial fisheries

**Map:** Relative realised commercial aquatic fisheries services index  
Percent of world total within range: 9.8  
Percent within range that is protected: 41  
Number of people benefitting within area (millions): 2.2

**Story:** The jaguar range provides around 9.8% of the world’s commercial fisheries services in some 8.6% of the land surface area. Fisheries are difficult to visualise at a national scale but you can see elements of them along the rivers, particularly in the Amazon and on the coast in Central America. Some 2.2 million people close to these fisheries benefit and many more further away will also do so (through market access).

**Summary of method:** The provisioning service of fish catch considers commercial and artisanal fisheries separately. Commercial fisheries tend to support national beneficiaries, whereas artisanal fisheries support local beneficiaries. Fisheries are estimated according to the water bodies that provide habitat. First water bodies are mapped and the volume per square km of each estimated according to water body. Viable stocks are not considered to exist at mean annual temperature <=13 degrees C. Above 13 degrees C stock is assumed to be 1000 tonnes of fish per cubic km of water. The potential commercial fisheries service is calculated as the product of stock (tonnes per km²) for non urban areas only (commercial fisheries are not considered viable in urban areas) and water quality. The sustainable serviceable stock is considered to decline linearly as the potential contamination increases. Potential contamination is calculated using the Human Footprint on Water Quality HFWQ (Mulligan 2009, Fink et al., 2018). HFWQ calculates the percentage of precipitation in each pixel that
falls on potentially polluting land uses (cropland, pasture, urban, roads, mining) upstream and how its impact flows and is diluted downstream. One third of the available stock is made available to take on an annual basis.

These stocks are considered viable for commercial fisheries where stocks are >500 tonnes. The realised commercial fisheries service is calculated as the product of the potential service in areas of commercial viability and accessibility (the service is only realised commercially if the potential service is within six hours travel time to the nearest town according to the agglomeration index of Uchida and Nelson (2009).

Artisanal fisheries are also possible in areas of commercial fishing but are demand controlled rather than supply controlled. Commercial fisheries are assumed to be supply controlled, so fisheries are not affected by the population levels. So if the population is low, the amount of fish may far exceed the need of the local population. The only limit for commercial fishing is the supply of fish itself. On the other hand, artisanal fishing is related to the demand from the local population, and if the population is low then only a fraction of the supply will be taken, as it is locally demand driven not supply driven. Demand is assumed to be 100g per person per day for poor (Elvidge et al., 2009), non-urban (Schneider et al., 2009) persons adjacent to (upstream of) the water bodies only. Fish to urban populations and those away from water bodies is assumed to be supplied through the market from commercial fisheries. The realised artisanal fisheries service is the minimum of the potential supply and the calculated demand.

**Carbon**

![Map of carbon values](image.png)
**Map**: Relative potential and realised carbon services index
Percent of the world total within range: 17.3
Percent within range that is protected: 45
Number of people benefitting within area (millions): 53

**Story**: The jaguar range provides over 17% of the world’s carbon storage and sequestration in some 8.6% of the world’s surface area. This is a key ecosystem service across most of the range since beneficiaries do not need to be close to realise the benefits of Carbon. The service is high across almost all the range.

**Summary of method**: Carbon storage and sequestration are distinct regulation services that benefit all humanity and may also provide opportunities for carbon finance to support national or local beneficiaries. Carbon stored in vegetation and soil is locked out of the atmospheric system for a period and this contributes to there being less carbon in the atmosphere. Carbon storage is not an active service of the ecosystem but rather a consequence of carbon sequestration and of the ecosystem remaining intact so that carbon accumulates (so a passive service). Carbon sequestration is determined by photosynthesis and accrues continuously so the magnitude of the service increases over time, contributing to carbon stocks in the process. The total carbon service is thus the combination of carbon stocks and carbon sequestration and the balance between the two clearly depends on the time period over which sequestration is calculated. Carbon sequestration is calculated here from the dry matter productivity (DMP) analysis of Mulligan (2009b) in which SPOT-VGT DMP1 calculated every 10 days at 1km resolution on the basis of change in NDVI, was averaged over the period 1998-2008, globally. DMP (t biomass/ha/yr) is multiplied by 0.42 (Ho, 1976) to convert to units of tC/ha/yr. Above-ground carbon stock is calculated from Saatchi et al (2011) for the areas in which data are available and Ruesch and Gibbs (2004) elsewhere. This is combined with soil carbon calculated from the map of Scharlemann et al. (2012) to produce total above- and below-ground carbon stocks. The potential (Cp) and also realised(Cr) carbon service is thus the mean of normalised carbon sequestration (Cs), normalised above-ground carbon stocks (Ca) and normalised below-ground carbon stocks (Cb) (eq 1 and 2). The potential and realised services are the same because all Carbon sequestered and stored benefits the global community irrespective of their location relative to the site of service provision (i.e. beneficiaries do not need to be nearby or downstream)

\[ \text{Cp} = \frac{(\text{Cs} + \text{Cb} + \text{Ca})}{3} \]
\[ \text{Cr} = \text{Cp} \]
Natural hazard mitigation (flood, drought, landslide, coastal inundation)

**Map**: Relative realised natural hazard mitigation index  
Percent of world total within range: 12  
Percent within range that is protected: 34  
Number of people benefitting within area (millions): 38

**Story**: The jaguar range provides around 12% of the world’s natural hazard mitigation in some 8.6% of the world’s land surface area. This is a key service of these habitats supporting beneficiaries downslope and downstream. Much of the range is high for this service but there are some key hotspots in Central America and in the Andes. Some 38 million people within the range benefit from this service and many more downstream and downhill will also do so. Only 38% of the hazard mitigation service within the range is protected.

**Summary of method**: The mitigation of natural hazards by so-called green infrastructure is an important regulating service. In Co$ting Nature we first calculate the environmental potential for hazards as an index varying from 0 to 1. We then calculate human socio-economic exposure to this hazard potential and combine this with a measure of vulnerability to hazard in order to calculate risk where risk is the product of exposure to hazard and vulnerability. Potential hazard mitigation services provided by nature are then calculated for coastal inundation, floods and landslides/soil erosion. These are then combined with the map of risk to calculate realised hazard mitigation services as the minimum of the risk and potential hazard mitigation services indices in each pixel.

We calculate an index of potential hazards taking into account cyclones, coastal inundation,
landsides and soil erosion, floods. The potential cyclone hazard is calculated as the relative cyclone hazard frequency of Dilley et al. (2005). Potential flood hazard is calculated as proportional to the available water in each pixel (downstream cumulated rainfall minus actual evapotranspiration). Coastal inundation hazard is considered to be inversely proportional to elevation in the range 0-30m above sea level and in coastal areas (that is to say within 2000m of the coast), scaling 1 to 0 from sea level to 30m above sea level. The coastal inundation hazard index (0-1) is comprised of sea level rise hazard (assumed to be uniform globally but interacting with terrain elevation, global relative Tsunami hazard (mapped by Mulligan, 2011 based on NGDC data) and global relative cyclone frequency (Dilley et al., 2005). Potential hazards from landslides are assumed to scale with relative mean upstream slope gradient. Hazard potential is then calculated as the mean of the cyclone hazard index, coastal inundation hazard index, landslide hazard index and flood hazard index.

Socio-economic exposure to hazards is considered to scale with the relative human population (Landscan, 2007); relative infrastructure including dams (Mulligan et. al., 2011), mines (Mulligan, 2010a), oil and gas (Mulligan, 2010b), urban (Schneider et al., 2009), roads (UN FAO GIEWS, 2010); relative agriculture (Fritz et al, 2015 and Ramankutty et al., 2008) and relative GDP (Ghosh et al., 2010) indices. Hazard exposure is then the product of hazard potential and socio-economic exposure. Vulnerability is assumed to scale inversely with combined GDP and infrastructure such that high GDP and infrastructure leads to lower vulnerability (even though they may also contribute to higher exposure). High GDP and infrastructure are considered less vulnerable because they indicate economic and infrastructural potential for disaster preparedness and recovery. Risk is the product of exposure and vulnerability.

Ecosystems provide a range of potential hazard mitigation services. These can derive from ecosystem processes in situ at the sites where risk occurs or elsewhere (e.g. upstream). The hazard mitigation services currently considered by Co$tingNature are landslide/erosion control, coastal protection, flood storage/mitigation, flow regulation). Landslide/erosion control is considered to be provided by the presence of vegetation, especially trees and by regulated land use. Therefore the landslide/erosion control service is assumed to scale with the proportion of upstream land that is tree-covered (di Miceli et al., 2011) or protected (WDPA, 2016). The upstream tree cover index is also assumed to control the flow regulation service at a point. Flood control is assumed to be provided by the upstream fractional cover of water bodies (Mulligan, 2010), wetlands (Mulligan, 2010), floodplains (Mulligan, 2010) and tree canopies (Mulligan, 2010), all of which provide storage capacity for flood waters. Coastal protection is assumed to be provided in coastal areas (within 2000m of the coast and from 0-30m above mean sea level) by the cover of mangroves (Spalding et al., 1997) and by wetlands (Lehner et al., 2004) in those areas. Total potential hazard mitigation services is thus the sum of coastal protection, flood protection, flow regulation and soil erosion/landslide control mitigation services.

Of course, not all potential hazard mitigation services are realised since in many places either the potential hazard or the actual risk are low. Thus the realised hazard mitigation services are calculated as the minimum of the potential hazard mitigation services provided and the actual risk existing.
**Culture-based tourism**

**Map:** Relative realised culture-based tourism services index

- Percent of the world total within range: 2.2
- Percent within range that is protected: 41
- Number of people benefitting within area (millions): 36.6

**Story:** The jaguar range provides around 2.2% of the world’s culture based tourism in some 8.6% of the world’s land surface. Some 36.6 million locals may benefit. 41% of the culture based tourism within the range is protected.

**Summary of method:** Nature-based and culture-based services are tightly linked. Both can be classed as cultural services are often considered together as recreational services. We separate them because of their very different spatial distributions and potentially different economic valuations. Potential recreational services are calculated according to the potential natural attraction of an area (defined according to its conservation priority index, slope steepness, lack of human land use and water quality), with its accessibility to populations. Areas that are high in natural attractiveness and accessible to significant populations and urban centres receive higher potential recreational services values (for both local and international tourism) than low natural attractiveness areas or areas that are less easily accessible. Potential recreational value is first as a supply if potential tourists calculated as population (Landscan, 2007) weighted accessibility from each urban centre outwards. Accessibility is defined using the agglomeration index of Uchida and Nelson (2009). A recreational attractiveness index is calculated as the mean of the Co$tingNature conservation priority metric, the slope gradient, the lack of human land use and the fraction of water bodies with high water quality.
These are calculated outside of urban and densely populated areas only as we are only interested to account for culture-based tourism that links with nature based tourism, which may not be the relevant in the densely populated urban context. Where accessibility to large populations and/or natural attractiveness are high the potential recreation index is higher.

Realised recreational services will only be a fraction of the potential services because many potentially good recreational sites will not be realised because of infrastructural, market, development and political or security barriers to tourism. We produce an index of realised recreational services using the online georeferenced photographic database of Panoramio which at the time of analysis (2006) contained more than 5 million georeferenced photographs. Photographs uploaded to this database are considered to represent evidence of high value urban-rural or international tourism having taken place. The Panoramio database has been ‘scraped’ for the number of georeferenced photos by different users (i.e. the number of tourists having taken photos) per 25km. These are interpolated to the standard Co$tingNature grids at 1km or 1 hectare resolution. To separate nature and culture based services this realised index is split between areas considered as urban or road for which the realised index is attributed to culture-based tourism vs. areas not urban or road in which the index is attributed to nature-based tourism. For the latter the index is scaled to the maximum of conservation priority, slope steepness and high quality water bodies in order to disaggregate the relatively spatially course metric to the areas which generate the interest in photography (i.e. the service) even if those areas are distance from where the photographs are geolocated (i.e. taken). As always the final index is expressed 0-1.
Nature-based tourism services

Map: Relative realised nature-based tourism services index
Percent of the world total within range: 7.9
Percent within range that is protected: 58
Number of people benefitting within area (millions): 5

Story: The jaguar range provides around 8% of the world’s nature based tourism in some 8.6% of the world’s surface area. Some 5 million local people benefit and many more do also, throughout the tourism supply chain. 58% of the realised nature based tourism within the range is protected.

Summary of method: There are a number of scattered peaks in the ES around some of more accessible parts of protected areas, and natural environments around key cities such as Rio de Janeiro and Sao Paolo. Values are lower in the parts of the range where there are less tourists.
Environmental and aesthetic quality services

Map: Relative realised environmental and aesthetic quality services index
Percent of the world total within range: 4.7
Percent within range that is protected: 37
Number of people benefitting within area (millions): 0.43

Story: Hedonic value is realised where areas that are highly accessible to high value urban land are in close proximity to natural beauty. Some 4.7% of the world’s realised environmental and aesthetic quality services index derives from the 8.6% of land within the range. 37% of the culture based tourism within the range is protected.

Summary of method: Environmental and aesthetic quality is a cultural service intended to capture the hedonic value that may be reflected by increased property prices of good environmental and aesthetic quality. The potential services are calculated as the mean of five indices of aesthetic quality for non built land uses only (i.e. not urban or roads): the presence of wetlands, conservation priority, steep slopes, low human footprint and lack of cropland. Realised environmental quality is then the product of potential environmental quality and accessibility. Accessibility is defined using the agglomeration index of Uchida and Nelson (2009). Areas that maintain high environmental quality whilst still being accessible to populations have a high RREAQ index. Areas more than 2 hours from a population centre of 50K people have RREAQ set to zero because of the accessibility constraint.
Wildlife services (pollination, pest control)

Map: Relative realised wildlife services index
Percent of the world total within range: 11.7
Percent within range that is protected: 26.5
Number of people benefitting within area (millions): 19.6

Story: Wildlife services to cropland and livestock are very high in the more agricultural areas of the jaguar range, with some 11.7% of the world’s wildlife services being realised within the 8.6% of land that represents the range. These are particularly high where productive natural land is close to farmland, thus providing pollinators and pest control. Almost 20 million people benefit locally.

Summary of method: Wildlife services are regulation services and include pollination and pest control by wildlife. These are very important to agriculture and are assumed to benefit local beneficiaries above others. Potential wildlife services in a pixel are calculated (for non urban areas only) as the product of the fraction of non-cropland and its relative productivity (Mulligan, 2009) on the basis that natural lands of higher productivity will produce more birds, small mammals and other pollinators and insectivores that could provide wildlife services to cropland. Note that wildlife services to croplands can also be produced by pasture lands in this metric. For this service to be realised, there needs to be non-cropland to produce it and cropland nearby to make use of it. Thus the realised service is zero for pixels in which there are no non-cropland to provide the service and scales from the potential service value to zero as the distance to the nearest cropland increases. A power decay function is used over 5000 metres with a decay constant of 0.2 so that a steep decline is observed between 0-500m from cropland and a more shallow decline after that (see Figure 1).
Nature's contributions to the SDGs in the extant range of the jaguar

Map: Nature's overall contribution to the SDGs index
Percent of the world total within range: 12.4
Percent within range that is protected: 41
Number of people benefitting within area (millions): 53

Figure 1 Decay of wildlife services and dis-services multiplier with distance from agriculture.

Ecosystem services in the jaguar range
**Story:** Some 12.4% of nature’s contribution to the SDGs falls within the 8.6% of land that represents the jaguar extant range, directly benefiting 53 million people. 41% of this 12.4% is protected. Nature’s contributions to the SDGs are particularly high in areas of Central America, Mexico and on the edge of Amazonia where nature and human populations are in close proximity. The SDG to which nature in the range of the jaguar contributes most is shown for each polygon of the range. For those areas furthest from populated areas, responsible consumption is the greatest contribution because all others are very low. Elsewhere contributions to equality and climate action (through carbon sequestration and storage) are extensive, with contributions to life on land, zero hunger and other of the SDGs also being important in certain areas.

**Methods:** The SDGs index allocates each ecosystem service into one or more of the SDG goals and, for each of the goals, sums the ecosystem service provision across these services into a normalised index of those services serving the goal. A high index means a high contribution of nature towards that goal. The map above shows the magnitude of service across 14 of the 17 goals (i.e. SDG 1,2,3,6,7,8,9,10,11,12,13,15; the remaining goals being considered as beyond Nature).
References


Ecosystem services in the jaguar range


World Database on Protected Areas (WDPA) Annual Release 2016 (web download version), Dec 2016. The WDPA is a joint product of UNEP and IUCN, prepared by UNEP-WCMC, supported by IUCN WCPA and working with Governments, the Secretariats of MEAs and collaborating NGOs. For further information protectedareas@unep-wcmc.org
Appendix 1: Benefits from Jaguar landscapes – outline proposal for UNDP

The following memo outlines first thoughts on a project looking at ecosystem services within “jaguar landscapes”. This will be the third study of ecosystem services from the ranges of large cats, following reports on tigers (for WWF in 2016-17) and African lions (for the Wildlife Conservation Network in 2018-19), and draws on lessons learned from these two projects.

Objective: to identify and describe the wider ecosystem services within “jaguar landscapes”.

Study area: the current range of the jaguar (Panthera onca) in Central and South America (possibly also including the potential range where suitable habitat still exists to support reintroduction).

Timing: main research and writing during 2020, building up to input to the post-Aichi target discussions in late 2020.

Team: Sue Stolton and Nigel Dudley; we would also like to hire someone from the region, at least part time, to help coordinate work, build local contacts and be in place to carry forward the results.

Methodology: a several stage process including the following:

- Identifying case studies for all the benefits described, and building these through desk-based research, field research and interviews
- Application of the Protected Area Benefits Assessment Tool (PA-BAT) in selected protected areas to gain in-depth knowledge of how local stakeholders perceive benefits from conservation
- Application of a new tool, Benefits Readiness, on a national level to look at how well countries in the region are set up to take advantage of ecosystem services from jaguar landscapes

Outputs: to be discussed, but we suggest the following:

- An overview report, soft-cover and PDF, designed for maximum input and published by UNDP, ideally this would need to be in Spanish, Portuguese and English
- Peer-review paper in a reputable journal, outlining the main results, to build confidence
- More in-depth country or sector briefings about ecosystem services from jaguar landscapes, ideally headed by a high profile politician, corporate player or similar as appropriate
- Toolkit of back-up material to support the launch including:
  ✓ Press release and video press release
  ✓ PowerPoint presentations that can be used by UNDP and partners
  ✓ Webinar or MOOC outlining the results, available in Spanish, Portuguese and English
  ✓ One-page talking point information sheets on key case studies or benefits
  ✓ Short video of highlights and interviews if budget allows
- Briefings for the 2020 post-Aichi CBD meeting including possible a paper on benefits from the ranges of all three cats in tropical continents