ASSESSING THE IMPACT OF WCS'S CONSERVATION PROGRAMS ON JAGUARS


Jaguar cools down during dry season heat in the core of the Selva Maya Jaguar Conservation Unit

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EXECUTIVE SUMMARY

We undertook this exercise to assess the impact of WCS interventions, first, by assessing trends in jaguar populations in WCS sites as compared to non-WCS sites, second by assessing the impacts of WCS interventions on the jaguar population trends. We used jaguar population data from surveys conducted between 2002 and 2016 at 11 sites between 2002 and 2016 in seven WCS jaguar conservation landscapes across seven countries to assess trends. Of these, 10 site trends are based on capture-recapture analyses using densities derived from CAPTURE abundance estimates or spatially explicit density estimates. For Nicaragua, we used a relative abundance estimate based on encounter rates. None of the time series mix analytical techniques. These trends were compared to trends at 13 non-WCS sites across 6 countries, including 9 density trends and 4 relative abundance trends. For interventions we used two different levels: 1) a comprehensive tabulation of management interventions across a ten year period; 2) using financial conservation investment data from four sites and evaluation to examine correlations between jaguar trends and the following classifications of interventions: a) research and monitoring; b) local livelihoods; c) human-wildlife conflict; d) community scout/patrol/SMART; d) education; e) natural resource management.

We recorded a 7.8% average annual rate of increase in the WCS sites as compared to a rate of 2.8% in the non-WCS sites, testimony to the positive impact of the broad categories in interventions we summarized across all the WCS sites. Examining the subset of sites for which we had financial data we found that impacts on jaguar populations were generally positive for natural resource management, education, community scouts/patrols, and local livelihoods. The positive impact of mitigating human-wildlife conflict was less clear, perhaps because jaguar monitoring at our sites has mostly focused on more remote forest interior sites. This is being rectified this year in four sites, but the data are pending.

Relating our findings to our theory of change

Maintain fully functional protected areas

In two areas we considered as WCS sites, the institutions' role was in establishing the protected area. Further intervention data was unavailable, but the positive effect of establishing the protected area was evident. The 7.8% average annual increase in WCS sites and the strong correlations between community scout/patrol are solid evidence of the strong role protected area defense has in maintaining jaguars.

Mitigate unsustainable actions across the larger landscape

We found a strong relationship between sustainable natural resource management (which includes certified timber and non-timber forest extraction, and wildlife management) and jaguar population trends. The ambiguous relationships we encountered between trends and human and wildlife conflict mitigation can be attributed to two factors: 1) we have not frequently measured populations in the exact areas of these interventions, but are now: 2) the site that has been most active in this theme is a recent addition 2012-2017, and their jaguar trend data were not ready for and included in the analyses.

Build constituencies for conservation

Our efforts to improve local livelihoods through a diverse range of locally adapted strategies were tightly associated with positive population trends. We have employed diverse methods to mentor the next generation of conservation leaders and inspire government leaders and civil society to support conservation through programs in schools, radio spots, televised programs, international news blogs, and more. In the case of the latter, we have not yet devised a way to accurately measure the effect of broad publicity on jaguar populations.

Relating the analysis to our 2020 goals

Our 2020 goals are jaguar populations in eight large Jaguar Conservation Units that make a significant contribution to range-wide jaguar conservation will be stable or increasing, with no net reduction in numbers or space occupied by jaguars; human-jaguar conflicts will be reduced to mortality levels that do not cause population decreases; hunting of prey will be at levels that sustain jaguar production and provide abundant natural alternatives to domestic livestock; and in-country funding and law enforcement institutional capacity will be sufficient to prevent habitat degradation and loss in those eight JCUs.

This intellectually stimulating exercise validated the positive value of the range of conservation interventions we conduct for jaguars, where we work, and based upon the scale of those sites, range wide. The tools we use – some directly related to jaguars, and many with broader forest and biodiversity conservation goals – effect jaguar conservation quite nicely. Our analyses lead us to the conclusions and recommendations that investment levels of roughly 75% in effecting conservation (that benefits jaguars) and 25% in assessing the impact of those interventions is a good balance, and jaguar conservation benefits from even higher proportions of intervention investments.

The population trend of an average annual increase of 7.8% in WCS sites compared to 2.8% in non-WCS sites, indicates at least partial success in our goal of achieving stable or increasing jaguar populations, and implies that human-jaguar conflicts have been reduced to levels that do not cause population decreases. The analyses we conducted did not assess jaguar prey status across the sites. Data are in-hand for that in most sites, and merit an analysis. The correlation between patrols and jaguar populations indicate the positive effect of law enforcement, but in this case, as related to WCS facilitated interventions. We were unable to collect data on in-country funding for this analysis, and have to report that progress in that regard represents an as-of-yet unrealized component of our 2020 goals.

In summary, we report success through positive trends in jaguar populations where we work, and note pending information on prey status, as well as the effect of our work reducing human-jaguar conflict. In an overwhelming way, this exercise emphasized the positive value of broad conservation interventions to achieve jaguar conservation, and the need for long term monitoring with repeated measures to assess trends.

INTRODUCTION

The top carnivore of the tropical Americas, the jaguar (*Panthera onca* L), now occurs in approximately 61% of its nearly continuous pre-1900 range between southern United States and central Argentina (Sanderson et al. 2002a, b, Polisar et al. 2014, Zeller 2007). The current range still spans approximately sixty degrees of latitude and a range of biomes from semi-xeric cactus-rich scrub forests to flooded forests of the Amazon. However, the process of jaguars being extirpated through persecution in response to livestock depredation, and habitat loss continues in many areas. The species is now nearly absent from the USA, restricted to the extreme northern limits of Argentina, and has been eliminated in over 77% of its historic range in Central America (Swank and Teer 1989, Sanderson et al. 2002b, Yackulic et al. 2011a, b, Wultsch et al. 2016). In some of the remaining 33% occupancy probabilities are very low (Petracca et al. 2017). Jaguar habitat is rapidly decreasing (Hansen et al. 2013, Thornton et al. 2016, Olsoy et al. 2016). As examples, Paraguay lost approximately 3,500 km² of forest per year for the last 5 years (SEAM, 2017) and Brazil lost approximately 5000 km² per year for the last 5 years (Mongabay, 2016).

The jaguar is listed on Appendix I of CITES (www.cites.org) and Near Threatened in the IUCN Red Data List (http://www.iucnredlist.org/). Jaguars are listed as Critically Endangered in Argentina (Ojeda et al. 2012) and Mexico, Endangered in Ecuador (Tirira 2011), Vulnerable in Venezuela (Rodríguez, J.P & Rojas-Suárez 2009) Brazil (ICMBio, 2016) and Bolivia (Aguirre et al. 2009. Despite bold range wide initiatives for jaguar corridor conservation (Rabinowitz and Zeller 2010; Petracca et al. 2017), the challenges of holding ground in significant jaguar conservation units (JCUs)[1] can be high and require a suite of tools to confront direct and indirect threats. A recent range wide analyses indicated that, with the exception of the Amazon, range wide jaguar status may be more dire than previously estimated (De la Torre et al. 2017a) highlighting the importance of maintaining populations in large JCUs critical to range wide population stability and connectivity. In 2016, using knowledge of average density estimates (Polisar et al. 2014a) generated using spatially explicit models in multiple surveys in JCU's, Polisar generated a global abundance estimate of 40,000 to 80,000 individuals with 60,000 as a middle value. De la Torre et al. (2017a) used global JCU maps/areal estimates combined with jaguar densities to publish an estimate of global jaguar population of 64,000 individuals.

[1] Jaguar Conservation Units (JCUs), areas of key importance for jaguar conservation and expected to contain a population of resident jaguars large enough (at least 50 breeding individuals) to be potentially self-sustaining over the next 100 years.

Obtaining confident jaguar abundance estimates is labor and cost intensive, particularly considering the still vast range of the species (Bahaa-el-Din et al. 2016, Boron et al. 2016, Harmsen et al. 2017, Karanth et al. 2011a, Polisar et al. 2014, Royle et al. 2014, Sollman et al 2011, Tobler and Powell 2013). While trends may be elusive for this cryptic secretive forest dwelling species on a global level, they can be analyzed on a site-specific level, and related to management interventions. We present the ecological factors critical for jaguar conservation, the primary threats to jaguar populations, an analysis of population trends in WCS and non WCS conservation sites, and make a cautious evaluation of the impacts of management interventions.

ECOLOGICAL REQUIREMENTS

Habitat fragmentation, prey depletion, and direct killing are the three main threats jaguars face. Which factors dominate in driving declines has varied across time and space. There was still intact jaguar habitat in the southwestern USA when jaguars were consciously eliminated by direct killing (Polisar et al. 2014). In contrast, the Brazilian Amazon and Paraguay have some of the highest deforestation rates in the world (Hansen et al. 2013).

Spatial ecology

Jaguar conservation requires large blocks of continuous relatively intact prey rich habitat or substantial habitat patches linked by areas of safe passage. Morato et al. (2016) reported the following mean home ranges for females and males in square kilometers respectively across biomes in Brazil: Pantanal 52/144; Amazon 68.4/211.6; Atlantic Forest 268/462.8. One male in Cerrado had a home range estimate of 1,268.6km². The Morato et al. 2016 results are similar to previous home range estimates for the prey rich savanna-forest mosaics of the Brazilian Pantanal and Venezuelan Llanos (Cavalcanti and Gese 2009, Scognamillo et al. 2003) and found a positive relationship between jaguar home range and human population size; the more humans, the larger the jaguar home ranges, with the largest home ranges recorded from the relatively fragmented Atlantic Forest biome. Home range estimates of over 300km² for females and over 1,000km² for a male were previously reported from semi-xeric Paraguayan Chaco (McBride 2009). De la Torre et al. (2016) reported a mean female home range of 181.4km² from the humid and well-watered forests of Selva Lacandona in Chiapas, Mexico. Just to the north of Lacandona in Guatemala's Selva Maya, where there is both less rainfall and surface water, home ranges generated during spatially explicit recapture density estimates, generated female and male home ranges of 321 and 535 km² (Tobler et al. in prep).

Densities

Jaguar density estimates are related to an area's intrinsic primary productivity, secondary productivity in terms of natural prey available at the ground level and at shorelines, reduced prey abundance due to over hunting of game, fragmented distribution of prey in deforested areas, and direct killing of jaguars due to their perceived (or actual) roles in livestock losses.

Jaguars occur at naturally low densities even in relatively intact areas where hunting pressure is low. Using spatially explicit recapture and /or telemetry validated models, on the higher end there are estimates of 4.4 adults/100km² in the Peruvian Amazon (Tobler et al. 2013), and 6.6 in the Pantanal of Brazil (Soisalo and Cavalcanti 2006). Both are prey rich well watered habitats. Ramalho (pers. comm) has obtained density estimates of 7.35-10.79 jaguars/100km² in prey rich flooded forest (varzea) ecotones in central Brazil. In contrast, Sollman et al. (2011) estimated 0.29 adults per 100km² in relatively dry Brazilian Cerrado, a figure possibly linked with the enormous Morato et al. (2016) male home range estimate. Noss et al. (2012) generated density estimates of 0.39-1.06 jaguars/100km² in thirteen sampling sites in the semi-xeric Bolivian Chaco.

Boron et al. (2016) reported density estimates outside of protected areas of 2.52 jaguars/100km² in the Magdalena Valley of Colombia and 1.12/100km² in a ranching dominated area in the Colombian llanos. Jędrzejewski et al. (2016) reported density estimates of 4.4 adults/100km² from a ranch in similar habitat in Venezuelan llanos where hunting was prohibited and 50% of the ranch maintained as wild forests. Figel et al. (2016) obtained moderate density estimates of 2.04 jaguars/100km² in a study area in Nayarit, Mexico where human population exceeded 50/km², another reminder that coexistence, while challenging, is feasible. Espinoza (2012) obtained estimates of 1.52, 1.96, and 5.7 jaguars/100km² along a gradient of road access/hunting pressure in the Ecuadorian Amazon. Large areas with adequate prey and freedom from high-levels of persecution are prerequisites for effective jaguar conservation.

Resource selection

. Jaguar diets in homogenous habitats are more opportunistic than in patchy habitats with clumped prey, where jaguars do not capture every prey item encountered (Carrillo et al. 2009, Emmons 1987, Foster et al, 2010, Weckel et al. 2006) which relates to human-jaguar coexistence. When given the option of selection, jaguars will tend to pick medium- and larger-sized prey items (Azevedo 2007a). If livestock are in jaguar habitat, they may become part of that equation (Polisar et al. 2003, Scognamillo et al. 2003). Equally unfortunate for jaguars, their preferred prey items also constitute some favorite game species for humans (Novack et al. 2005, Foster et al. 2014), which can result in reduced prey biomass available for jaguars, with presumed direct effects on jaguar densities, movement patterns, and home range sizes.

In the Selva Maya of southern Mexico/northern Guatemala, Conde et al. (2010) found that jaguar males and females both preferred tall forest. Scognamillo et al. (2003) found jaguars in Venezuela using habitats (flooding savannas, dry forest, and dry savanna with chaparro, semi-deciduous forest, dry pasture, and evergreen forest) in the same proportion as available within their home range. Ecotones that were productive for prey were preferred, as demonstrated by caiman and capybara taken by jaguars in low stature secondary growth where the primary attraction was prey. Arroyo-Arce et al. (2014) conducted occupancy modeling to determine the habitat characteristics most important for jaguars in Costa Rica's Tortuguero National Park. Seventeen of eighteen jaguar individuals were only detected in coastal habitats where use of nesting green turtle (*Chelonia myda*s) had become common (Guilder et al. 2015). The primary habitat feature influencing jaguar occupancy was easily accessible prey, perhaps in relationship to depleted natural prey due to poaching in the park interior and inland edges (Arroyo-Arce et al. 2014). This pattern of focusing on vulnerable prey is important to consider in managing human-jaguar conflict.

In Mexico's Selva Lacandona, de la Torre et al. (2017a) used telemetry resource selection functions to determine that suitable habitat was large areas of primary forest with long distances from deforested patches. However, jaguars moved through forest strips as narrow as 240 m. Albeit based on a limited number of collared jaguars (5) and one study area, they suggest that width as a minimum for jaguar corridors (de la Torre et al. 2017b). In certain biomes tall intact forest may appear essential habitat. However, forest structure may also be related to low game hunting pressure and security from conflicts and persecution. Jaguars occur from dry scrubby forests in the Chaco through savanna forest mosaics, Amazon flooded forest to mountain slopes, and thus are flexible when it comes to the structural characteristics of habitat. Adequate natural prey and freedom from human-jaguar conflicts are more important than exact botanical composition for functional corridor areas.

Key threats

The primary threats to jaguar populations are three fold : 1) declines in habitat as wild forested areas are converted to human-dominated land uses (Hansen et al. 2013, Thornton et al. 2016, Olsoy et al. 2016); 2) reduction of natural prey (Espinosa 2012, Novack et al. 2005, Foster et al. 2014): and 3 and direct killing, often related to jaguar-livestock conflict.

Ecological components of jaguar-livestock conflict

The spatial distribution of livestock and natural prey are important factors in human jaguar conflicts. In the Maya Biosphere Reserve in Guatemala, Soto-Shoender and Guiliano (2011) found landscape structure including forest cover and distance to forest, as the best explanation of the probability of jaguar predation on livestock. Ranch designs that separate livestock from jaguar habitat will minimize opportunities for jaguars to consider livestock as prey options and learn to take them. Solitary felids can demonstrate individual patterns of food selection (Knopff et al. 2010) and taking certain prey species appears in part to be a learned skill (Ross et al. 1997). Variation in diet among wild cat populations occurs even with natural prey, with prey vulnerability playing a role (Elbroch and Wittmer 2013). In the Pantanal of Brazil, Azevedo and Murray (2007*b*) reported that cattle predation risk was highest for calves, declining for yearlings, and even lower for adults, yet forest proximity was the primary factor explaining livestock mortality, with predation risk increasing as distance to forest cover declined. In the south Pantanal, Cavalcanti (2008) found forest and shrubland used more than their availability, and open field and bare agricultural land generally avoided by jaguars. Shrub-like habitats were selected by 7 of the 10 collared jaguars and open field avoided by 9 of the 10 (Cavalcanti 2008). Jaguars generally prefer forest and shrub-like habitats, but kills can easily be made along ecotones. As Azevedo and Murray (2007*b*) found, maintaining livestock in or near hunting cover for jaguars (which can be shrubs, high grass, or forest edge) leads to increased livestock mortality risk. Separating livestock from forest and natural prey is important. If jaguars are never presented with the opportunity to learn to take livestock, specialization in domestic diets will not become an option, and the lethal control it tends to stimulate can be reduced.

Individual jaguars may develop a preference for domestic animals (Cavalcanti and Gese 2010). When they are removed, livestock losses may cease even if there are other jaguars in the vicinity (Seymour 1989). Wounded jaguars injured by hunters may develop a preference for cattle due to ease of capture (Rabinowitz and Nottingham 1986, Hoogesteijn and Mondolfi 1992), however every radio collared jaguar that preyed on cattle in the Pantanal study area of Cavalvanti and Gese (2010) was in excellent physical condition at time of capture.

The re-emerging threat in jaguar parts

Whereas cessation of the trade in hides of spotted cats when they were elevated to CITES Appendix I in 1975 allowed recovery of jaguar populations in remote and protected areas, in recent years there appears to be an emerging trade in jaguar parts (bones, teeth, skulls) for medicinal or decorative purposes. The clearest examples of these incidents come from the Bolivian and Brazilian Amazon, areas where habitat is intact, but illegal hunting for jaguar parts has started to penetrate strongholds. This will reduce global jaguar populations, unless vigorously prevented, starting now (http://g1.globo.com/pa/para/jornal-liberal-2edicao/videos/v/policia-apreende-cabecas-de-oncas-ameacadas-de-extincao-em-curionopolis/5263906/, http://www.la-razon.com/index.php?_url=%2Fsuplementos%2Finforme%2FMercado-negro-colmillos-informe_0_2254574635.html, http://g1.globo.com/pa/para/noticia/2016/09/ibama-multa-cacador-por-matar-pelo-menos-19-oncas-no-para.html).

Synergies of threats that can lead to local extinctions

The greatest challenge for large scale long-term jaguar conservation is to halt the synergy that occurs when habitats are fragmented, natural prey are depleted, livestock are introduced into former jaguar habitat, and people kill jaguars to either control livestock losses, or to avoid them. Until recently, Jaguars appear to have been essentially one nearly continuous population (Eizirk et al. 2001; Ruiz-Garcia et al. 2013) with the genetic consequences of fragmentation and isolation seemingly remote, but the synergy of factors that drive decline and isolation of sub-populations is increasing (Cuyckens et al. 2017; Haag et al. 2010; Olsoy et al. 2016: Paviolo et al. 2016; Roques et al. 2016: Wultsch et al. 2016). An example of where this can lead is the Atlantic Forest biome where 85% of jaguar habitat has been lost, only 7% remains in good condition, and jaguars occur in 2.8% of an area where they previously were widespread. Habitat loss and fragmentation were the primary causes of decline in the Atlantic forest, and now direct killing is the greatest threat in the remnants (Paviolo et al. 2016). In the face of these threats we prioritize maintaining jaguar strongholds and preserving functional connectivity between JCU's.

Life history recovery times when threats are abated

Jaguars can live up to 20 years (McDonald 1984), but in the wild, an individual of 10-12 years may considered old (Seymour 1989). Females are reproductively active between 2 and 13 years of age, whereas males become sexually mature at 3-4 years (Seymour 1989). The number of cubs ranges between 1 and 4, and average is 2. Gestation period averages 101 days and the interbirth interval for jaguars is 2 years. Survival rates for males and females >2 years of age are high, averaging 0.78/year for both sexes and cub survival is estimated at 0.85 (Watkins et al. 2014). A crude summary of these parameters is that a jaguar generation length is about two and a half to three years. Based upon a 1:1 sex ratio, in optimal conditions, a jaguar population at best might replace every two and half to three years. Although jaguars have the potential to double the population in approximately 10 years, emigration and high mortality may slow population growth.

How to track population trends

Wildlife surveys tend to be exploratory (Williams et al. 2002, Long and Zielinski 2008). When done well they provide the material for repeated measures, allowing inferences about trends in abundance, and/or distribution, and the relative importance of management or ecological attributes. Evaluating management impacts can include trends in direct and indirect responses to management interventions (Jones et al. 2013) and social factors such as the efficacy of outreach intended to change the livelihood options, attitudes and practices of the people who coexist with the species. The hierarchical spectrum of jaguar monitoring rigor and cost includes capture-recapture studies, occupancy (presence-absence), and presence. Long-term capture-recapture (CRC) studies using camera traps can assess the influence of environmental and management factors on density, distribution, survivorship and numerical trends of female and male jaguars, but require considerable investments of expertise and resources (Bahaa-el-Din et al. 2016, Boron et al. 2016, Harmsen et al. 2017, Karanth et al. 2011a, Polisar et al. 2014, Royle et al. 2014, Sollman et al 2011, Tobler and Powell 2013). Range-wide monitoring of jaguars implies an immense scale that includes JCU's which function as sources, and the matrix of secondary and peripheral areas which connect JCUs and can be used as corridors by dispersing individuals. The cost and emphases of monitoring needs to be considered in the context of the value of the improved decision making it enables (Jones et al. 2013).

Despite an abundance of one-off- jaguar population estimates (i.e. Alfaro 2007, Boron et al. 2016, Chavez and Ceballos, 2006, de la Torre & Medellín 2011, De Thoisy, 2010, Diaz Santos et al. 2010a, Diaz Santos et al. 2010b Espinoza 2012, Faller et al. 2007, Figel et al. 2016, Foster et al. 2013, Gonzalez-Maya et al. 2008, Jedrezejweski 2016, Kelly 2003, Maffei et al. 2004, McCain and Childs, 2008, Medellin et al. 2016, Moreno 2006, Núñez y Saracho, 2010, Perera –Romero et al. 2011, Portillo and Hernández 2011,Silveira et al. 2009, Soisalo & Cavalcanti 2006, Salom Pérez et al. 2007, Sollman et al. 2011, Tobler et al. 2013), time series analyses of population trends across time are uncommon (Harmsen et al. 2017).

The next level down in cost is detection probability based presence-absence occupancy modeling (OM) of jaguars and prey (Karanth et al. 2011b; Polisar et al. 2014; Sollman et al. 2012; Sunarto et al. 2012; Tobler et al. 2015). Some occupancy models will give an estimate of local abundance as well (Royle and Nichols, 2003; Royle 2004). At the lowest level of complexity and rigor (Tobler et al. 2008; Polisar et al, 2014; Sollman et al. 2013) are encounter rates with camera traps (relative abundance estimates RAI, O'Brien 2010). Detailed population parameters of the target species (spatial distribution, density, population size, survival, and recruitment) are the best measure of responses to management interventions. Optimally CRC studies in core areas embedded nested in much larger OM sample areas would be a desirable goal in priority conservation areas (Polisar et al. 2014). In this paper we draw in a suite of surveys across a number of countries, drawing from the entire range of data described above to evaluate trends.

METHODS

Trend Analysis

We follow the approach of Buckland et al (2005, 2011) using the geometric mean of relative abundance indices as a composite indicator for jaguar trends at WCS and nonWCS sites. The relative abundance index is calculated for time t as N_t/N_1 where N_t is a measure of abundance, density or distribution at time t and N_1 is the same measure at the start of the time series. The initial scaled value is $N_1/N_1 = 1$ for the first year of the time series. When there are gaps between consecutive surveys (e.g. N_1, N_2, ND, ND N_5) we use log linear interpolation (Collen et al. 2008) to estimate missing values. The Time series index I for any year j is then calculated as:

$$I_j = \left(exp\left(\frac{1}{S} \sum_{i=1}^{S} log \frac{n_{ij}}{n_{i1}} \right) \right)$$

where n_{ij} is the abundance at site i and time j and n_{i1} is the initial abundance at site i and S is the number of sites. The index has an initial value of 1 but can be scaled to an initial value of 0 by subtracting 1 from each index value. The index records the percent change from initial conditions. A value of 1.05 in year 2 indicates a 5% increase over year 1. A value of 0.95 indicates a 5% decline over year 1.

The use of within site trends standardized to a baseline year offers two advantages. First, it makes no difference what the measure is used – density, abundance distribution, fish biomass – as long as there is no within species trend co-occurring with the measure. Buckland et al (2011) cite a downward trend in fish weight in heavily exploited fisheries that might affect index estimates compared to indices based on number of catch. Second, we can combine and compare trends from different surveys. For example, the Wildlife Picture index (O'Brien et al. 2010) combines trends for 244 species in 511 populations at 15 sites globally. The structure of the index allows us to create an index at each site we monitor and aggregate up from the site index, to country, region and global index for each species.

Often time series are incomplete with some time series starting at time t>1 or ending before the longest time series. Suppose we have a time series composite that covers 2000 through 2017. We want to add a time series starting in 2010. We scale the 2010 time series by the composite value for 2010 such that the new index does not affect the composite for 2000-2010 but does have an effect going forward. A similar process is used for time series that end before the final date of the composite. In this manner time series of uneven lengths can be combined into the composite index (Buckland et al 2011).

To generate confidence intervals, we use a bootstrap simulation in R with 1000 repetitions to estimate the values in the time series composite index and consider the 2.5% and 97.5 percentile values as the 95% confidence interval.

We used data from surveys conducted between 2002 and 2016 at 11 sites (10 CRC, 1 RAI) between 2002 and 2016 in seven WCS jaguar conservation landscapes across seven countries to assess trends and compared those trends to surveys conducted at 13 non WCS sites (9 CRC, 4 RAI) across six countries

Impact of interventions analysis

WCS jaguar programs have operated since 2001 and have a range of tenures. We were able to determine time series estimates for Bolivia's Madidi-Tambopata landscape at two sites, 2002-2014 and 2004-2015, for a combined 14 year time series. We have financial investment by intervention for the landscape from 2000-2015. For Guatemala, we have time series data from 2001-2009 for 2 sites, a landscape level time series for 2002-2013 and financial investment for the landscape for 2002-2013. For Nicaragua, we have time series data for 2006-2016 and financial information for 2007 and 2009-16. For Ecuador, we have time series data for and financial data for 2007-2010. The financial data for Kyaa Iya Gran Chaco NP were presented as lump sum investment over time and could not be broken down; these were dropped from the analysis. We have no financial data for the Cockscomb Basin, Belize and Mamiraua Reserve Sustainable Development Reserve, in Brazil.

We use a correlation analysis for all countries and landscapes, and a partial correlation analysis for Bolivia, Guatemala, and Nicaragua which have the most data on intervention costs. The correlation analysis gives results to simple linear regression and ARIMA(0,0,0) models.] Partial correlation is a measure of the strength and direction of a linear relationship between two continuous variables while controlling for the effect of one or more other continuous variables (also known as 'covariates' or 'control' variables). Although partial correlation does not make the distinction between independent and dependent variables, the two variables are often considered in such a manner (i.e., you have one continuous dependent variable and one continuous independent variable, as well as one or more continuous control variables).

We assessed interventions that contribute to jaguar conservation on two levels. First we generated a summary across seven WCS country programs and sites where we currently conserve jaguars, using the following categories of: interventions: a) protected area and wildlife law enforcement in large protected area complexes (law enforcement); b) community conservation and livelihood benefits with local people; c) Natural resource management (which included wildlife management and timber and non-timber forest products); d) education and training of public, ranchers and government on jaguar ecology and human-jaguar coexistence (education); e) working directly with ranchers to reduce human-jaguar conflicts on the edges of reserves (human-wildlife conflict). Second, for landscapes in which we had adequate data, we generate summaries of year specific interventions in the above categories.

Study Areas:

We used data from surveys conducted between 2002 and 2016 at 11 sites between 2002 and 2016 in seven WCS jaguar conservation landscapes across seven countries to assess trends. Of these, 10 site trends are based on capture-recapture analyses using densities derived from CAPTURE abundance estimates or spatially explicit density estimates. None of the time series mix the two analytical techniques. For Nicaragua, we used a relative abundance estimate based on encounter rates. These trends are compared to trends at 13 non-WCS sites, including 9 density trends and 4 relative abundance trends across 6 countries.

Management Interventions in WCS Jaguar Conservation Landscapes:

We assessed interventions that contribute to jaguar conservation on two levels. First, as preparation, we generated a ten year summary 2008-2017 across seven WCS country programs and sites where we currently conserve jaguars, using the following categories of: interventions: a) protected area and wildlife law enforcement in large protected area complexes; b) community conservation with local people; c) working with ranchers to reduce human-jaguar conflicts on the edges of reserves; d) education and training of public, ranchers and government for human-jaguar coexistence; e) national and regional policy and planning. Second, we extracted summaries of year specific intervention investments using the categories of Community Assistance, Natural Resource Management (which included certified timber and non-timber forest product extraction), Law Enforcement, Education, and Jaguar-Livestock Conflict Mitigation and related that specifically to jaguar population trends where adequate information made that possible.

Parks and other protected areas where WCS and partners have worked

Figure 1. Study areas used to assess jaguar trends where WCS has worked and currently works.

Bosawas Biosphere Reserve, Nicaragua): (Long: -85.144; Lat: 13.443). Bosawas Biosphere Reserve (~20,000 km^{-2}) is the second largest rainforest in the Neotropics, after the Brazilian Amazon. Straddling the northern part of the Department of Jinotega and the Autonomous Regional of the North Atlantic Coast, and bordering Honduras, the reserve has an elevation gradient ranging from 20 m asl on the Caribbean coastal plain to 1745 m in the west (Ineter 1988). Rainfall varies from 1440 to 3000 mm/yr (Ineter 1988) with the majority falling during a June-November rainy season resulting in wet and moist forest types (Holdridge 2000). Established in 1997, the Bosawas Biosphere Reserve includes five protected areas overlapping indigenous territories and an extensive buffer zone surrounding the reserve. Much of the buffer zone is degraded/deforested by livestock use (Stocks et al. 2007) and the best preserved forest remains in the indigenous territories, which have designated discrete land use types, the most significant being agriculture, extraction (including hunting), and conservation (Stocks 2007). The core conservation areas total ~ 8,000km^2. As in Guatemala, extensive linear foot transect and hunting offtake studies (2001-2005) preceded camera trap surveys.

WCS interventions in Bosawas began in 2006 with a series of camera trap surveys in 2006-07, 2009, and 2011-2016. In 2007, WCS instituted a community-based wildlife management program. In 2009 we began addressing human-jaguar conflict, supporting 3 releases of technical manuals on human-jaguar co-existence (2009, 2015-16). In 2010 and 2013, we tested methods to reduce jaguar attacks, mainly focused on protecting pigs and calves, and in 2010 and 2017 we worked with ranchers to improve space-efficient methods of managing livestock. Also in 2009, we supported development of community based foot patrols continuing support in 2015 and 2016. Also in 2016 we initiated a SMART training program. In 2016, we administered a baseline Basic Necessities Survey, and in 2017, we developed a Community Conservation Agreements for jaguar prey conservation. Currently, livestock management systems are being improved on reserve edges in western Bosawas, an effort reflected in adjacent Biosphere Reserves in Honduras (Tawahka Asangni and Rio Platano). Primary alliances in these areas are with indigenous leaders and para-biologists who have been engaged since 2004, but also working with the Ministry of Environment and Natural Resources (MARENA) and two universities in Nicaragua. In Honduras adjacent working alliances are with indigenous leadership in Miskitu and Tawahka territories but also engaging Honduran national protected area agencies such as Instituto Conservacion Forestal, Areas Protegidas, y Vida Silvestre (ICF) . We collaborate with the National Agricultural University which is currently installing camera traps along gradients from livestock management systems to reserve interiors.

Bolivian Chaco – Kaa-Iya del Gran Chaco National Park, *Bolivia*: (Long: -61.25; Lat: -19.067) This is the largest dry forest protected area in the world with 34,411 km^2, located in southeast of Bolivia on the border with Paraguay. Altitudes range from 100 to 859 m asl and the main vegetation is Chacoan dry forest, but there are also areas with Chiquitano semi deciduous forest, savanna and some rocky hills and wetlands. The mean annual precipitation is mainly between 400 and 1400 mm and the temperature averages 25°C. As this is a National Park with 25 park rangers and seven park camps, the area is well protected, so hunting pressure inside the park is low. Main threats are cattle ranching and agricultural mega-projects bordering the park, new roads and hydrocarbon projects and some mining projects in the park.

WCS was involved in the creation of Kaa Iya del Gran Chaco National Park in 1995, and worked on conservation between 1997 and 2007. The primary interventions were protected area management and law enforcement ($2 million), community based conservation ($2.3 million), policy and land use planning ($2 million), environmental education ($1.5 million) and working with ranchers to mitigate jaguar-cattle conflict ($0.3 million). WCS ultimately closed the project when the primary sponsor USAID was ordered to leave Bolivia by the Bolivian government.

Cockscomb Basin Wildlife Sanctuary, Belize: (Long: -88.583; Lat: 16.473). The Cockscomb Basin Wildlife Sanctuary (CBWS) is known as the first jaguar preserve, set up with assistance of WCS. It is located southern Belize, considered part of the greater Selva Maya with an area of 425 km². It was heavily logged during the 1980s, but has been protected since 1990. The main vegetation is dense subtropical wet secondary forest with altitudes from 0 to 600 m asl. The average precipitation is 2500 mm per year with a brief dry season from March to June. Main threats of the area are hurricanes and selective timbering.

WCS maintained an active presence in CBWS between 2002 and 2007, working with Belize Audubon Society which carries primary management authority and responsibility. Today, Belize Audubon manages the reserve and Panthera conducts research there. Interventions under WCS were restricted to research and monitoring and a jaguar-cattle conflict mitigation workshop. Overall, threat level in Cockscomb Basin has been low since the logging in the 1980's.

Greater Madidi-Tambopata Landscape (GTML), Bolivia and Peru: (Long: -68.215; Lat: -14.001. The Madidi National Park and Integrated Management Natural Area (PNANMI Madidi) bridges a 6,000-meter altitudinal range in the northwestern Bolivian Andes and is the centerpiece of the Greater Madidi-Tambopata Landscape, which is made up of 140,000km² spanning Bolivia and Peru, eight PAs, and the respective territories of eight indigenous groups. Approximately 65% of the GMTL is considered jaguar habitat, composed of Amazonian rainforest, natural grasslands and Andean foothill tropical forest. Management of the landscape is divided among National Protected Areas, Municipal Protected Areas, Indigenous Territories, Forest concessions and Private Lands. Major threats to Jaguar in the GMTL are associated with development projects in the region including road construction, sugarcane agriculture development, unsustainable extraction of timber, gold and other natural resources, hydrocarbon exploration, and a proposed hydro-electric dam. Other threats include prey depletion through over-hunting and killing of jaguars in jaguar-cattle conflicts. An emerging threat appears to be trade in jaguar teeth and other wildlife parts to Chinese workers on development projects.

WCS has a long history of sustained conservation interventions in Bolivia. WCS was peripherally involved in the creation of Madidi National Park in the early 1990's and has worked with national authorities and local organizations to preserve the long-term viability of the area. We have embraced a landscape conservation vision that plans for the ecological needs of wide-ranging wildlife, while also developing sustainable natural resource management initiatives to meet the development needs of the roughly 300,000 people who live in the rural landscape. We have also implemented a rights-based conservation program that focuses on strengthening local capacity for territorial management while building a constituency for conservation. Jaguar conservation activities began in 1999, focused on strengthening the rights and abilities of indigenous communities to manage their resources, with the development and annual support of community conservation agreements for jaguar prey conservation. In 2000, WCS initiated an annual program to reduce pressure on wildlife and forest products by introducing strategies to improve livelihoods. In 2014 and 2015 we introduced Basic Needs Surveys. In 2000, we started annual support for community-based wildlife management activities, and in 2002, we expanded that program to include management of non-timber forest products and timber management. In 2002, we also started an annual program of community-based patrolling to protect their territory and resources, including annual training in SMART since 2011. Since 2001, WCS has run extensive education programs including training programs alternative education programs and Identidad Madidi, a program to teach the importance of biodiversity a Center of the landscape

Mamirauá Reserve, Brazil: (Long: -65.700; Lat: -2.26). WCS helped to establish the Mamirauá Sustainable Development Reserve is located in the State of Amazonas, Brazil in 1996. It has an area of 11,240km² and is covered by varzea flooded forest (inundated seasonally by white water). This is the largest reserve fully dedicated to the conservation of the central Amazon floodplain ecosystem. The climate is tropical humid, with an average annual rainfall of 2373 mm. Mamiraua is a development reserve that allows some management and harvest of resources. One of the threats is overexploitation of natural resources, especially timber. Another is a high rate of jaguars killed in response to attacks on livestock adjacent to the some of the communities in the reserve.

Maya Biosphere Reserve (MBR), *Guatemala*: (Long: -89,920; Lat 17.76) The 21,150km² MBR in the Petén of northern Guatemala, is the most ecologically intact and archeologically important region of Guatemala and one of the most important conservation areas in the western Hemisphere. It was created in 1990 to improve local livelihoods while conserving biological and cultural heritage. With 20,000km² representing 19% of Guatemala's land surface, the MBR has more than 180,000 human inhabitants (10% indigenous to the Petén) and a 7% population growth rate. This largest and most intact portion of the tri-national Guatemala-Mexico-Belize Maya Forest is a centerpiece of sustainable development strategies.

The MBR provides over 90% of national petroleum, timber and non-timber forest resources exports, and features Tikal National Park (a UNESCO World Heritage Site), one of Guatemala's main tourist attractions. The MBR also contains the ancient Maya site of El Mirador, soon to be nominated as a second World Heritage Site and a powerful magnet for tourism. The MBR has great economic potential from environmental service payments for carbon offsets, and contains a massive fresh water recharge zone in a Ramsar site.

The MBR includes zones for agro-pastoral development (Buffer Zone), sustainable forest product extraction (Multiple Use Zone) which includes Forest Stewardship Council (FSC) certified timber extraction, and biodiversity protection (Core Zones, consisting of parks and "biotopes"). Thirty-six percent of the reserve is designated as Multiple Use Zone managed by local communities, much of it in ecologically and economically successful forest management concessions, with some Core Zones administered by national NGO's.

WCS started research in the MBR in 1991, focused on game species, an effort that eventually led to over 6,000km of linear foot transects by 2004, 76 months of game offtake data from villages, and 18 months from non-timber forest product camps – and in the process, a deep understanding of cultural norms and conservation priorities. WCS involvement in conservation interventions began in 1998. The MBR has evolved into a showcase of varied conservation strategies for Mesoamerica that now includes >5,000km² of community managed timber and non-timber forest extraction concessions, >1,800km² in community conservation agreements, and 744km² in improved farms, Between 2010 and 2014 there were 2,435 terrestrial foot patrols in the reserve. Between 2008 and 2015 there were 244 overflight patrols to assess illegal activity in protected areas, totaling >90,000km. SMART capacity building in 2015-2017 resulted in 283 foot patrols covering > 12,400km. Between 2009 and 2014, legal prosecution of protected area invasions resulted in 135,200km² reclaimed to conservation. Jaguar camera trap surveys started in 2005 and continued until 2013. Due to resource limitations there have been no subsequent surveys until the current one in the biosphere's buffer zone.

Yasuni Biosphere Reserve, Ecuador: (Long: -77.35; Lat: -1.015). The Llanganates-Yasuni landscape stretches from the Amazonian lowlands to the Andean paramo grasslands encompassing 42,252 km². The landscape includes the Yasuni Biosphere Reserve (16,820km² , established in 1989), Yasuní National Park (10,227 km², established in 1979), the Waorani Ethnic Reserve (7,672km², established in 1990), and the Sapara and Kichwa Indigenous Territories (3,778km² and 4,115km², respectively). WCS has worked in the Yasuni lowlands since 2001 and in the Llanganates highlands since 2014.

The Yasuni climate is very humid with an annual rainfall close to 3,000 mm and mean monthly temperatures of 24-27°C. Vegetation cover is dominated by tall-evergreen *terra firme* tropical forest with canopy height between 25-40 m some flood-plains and swamps occur along the margins of the main rivers. Management of this landscape is divided between national park, Indigenous territories and ethnic reserves.

Threats include colonization and illegal logging, but the most important one is oil exploitation and associated road building, unsustainable subsistence hunting, illegal commercial hunting, wildlife trafficking, human-wildlife conflicts, illegal mining, and large-scale infrastructure projects. WCS interventions have included community-based wildlife management, reduction of human-wildlife conflicts, landscape management to increase functional connectivity, conservation education, technical support to Ministry of the Environment to control illegal hunting and wildlife trafficking, and to implement the mitigation hierarchy to reduce environmental impacts of infrastructure projects.

RESULTS

Observed trends

Between 2002 and 2016, jaguar populations remained stable or grew steadily at all WCS sites (Figures 1, 2). By 2004, the abundance index was significantly higher than the 2002 initial value, indicating rapid population following interventions. Between 2002 and 2016, the population growth rate averaged 7.8%/yr across sites. Only two WCS site showed significant declines in jaguar populations during monitoring: Mamiraua Reserve jaguars declined by 39% and Yasuni NP Jaguars declined by 32%. Central American sites in Guatemala and Nicaragua experienced the highest annual variation, though the trend is positive at all 3 sites (Figure 2).

Comparing WCS jaguar sites to 13 non-WCS sites in Belize, Brazil, Ecuador, Mexico, Peru and Suriname (Figure 3) we see that non-WCS sites experienced stability over the same time period, but did not show increasing trends. We note that, based on this analysis, jaguar populations are doing well at sites where they have been monitored over time.

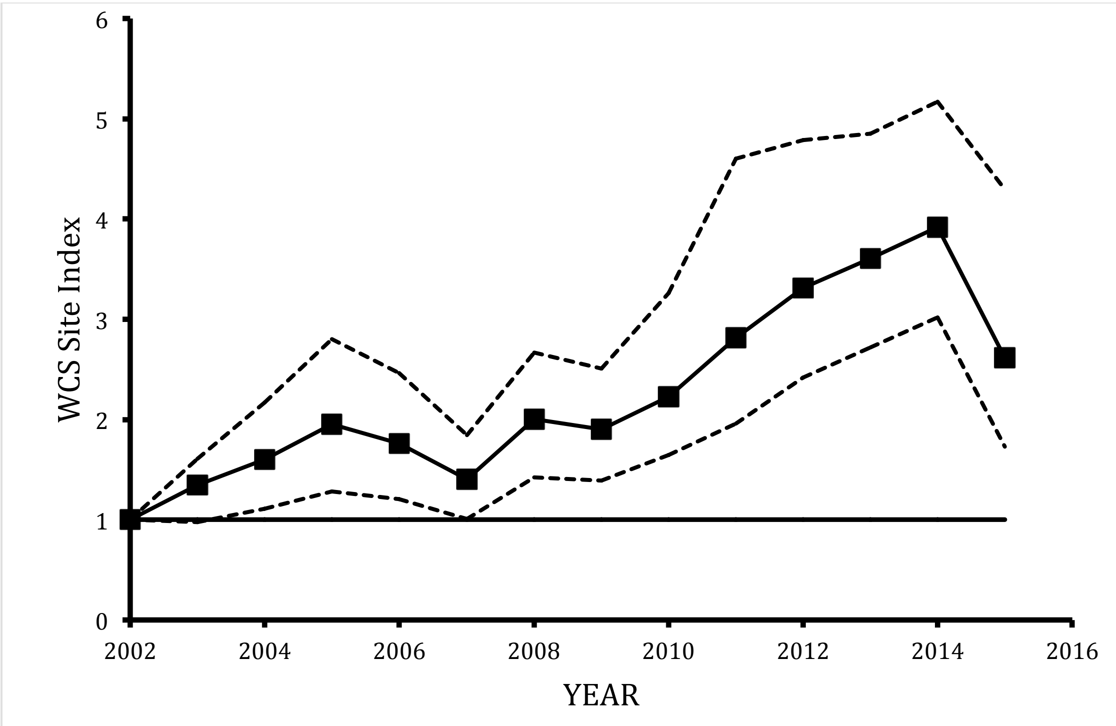

Figure 2. Jaguar Index for 11 WCS jaguar conservation sites in Belize, Guatemala, Nicaragua, Ecuador, Brazil, and Bolivia.

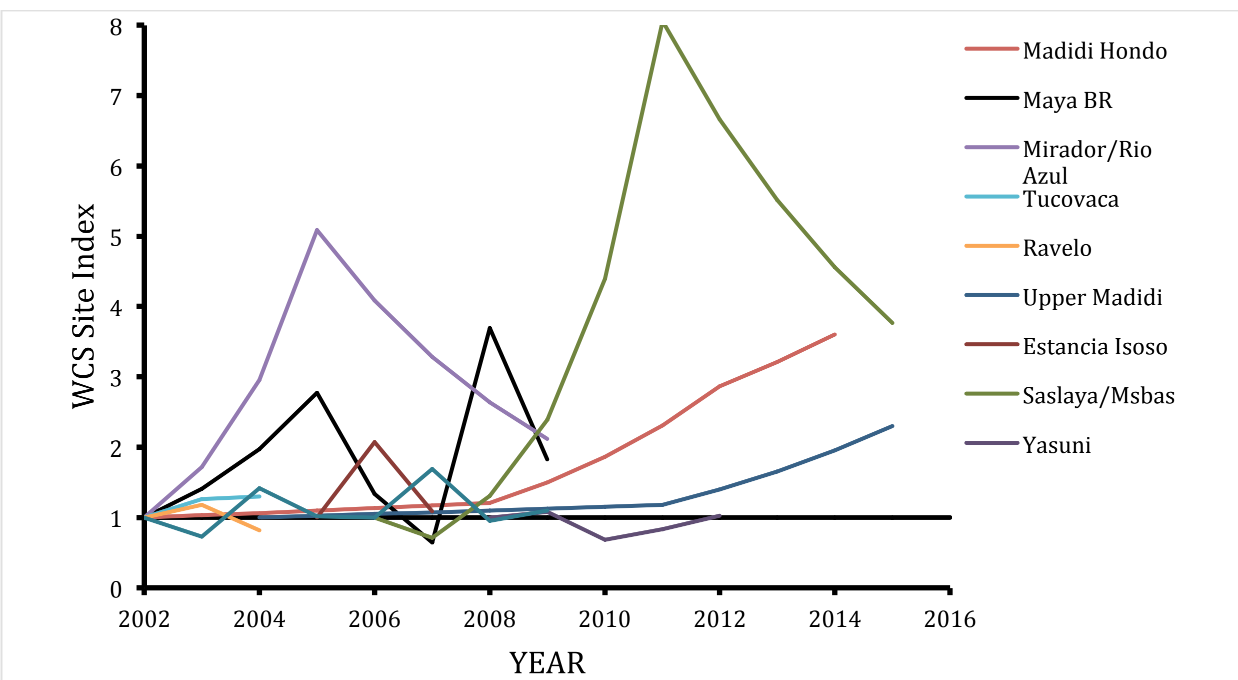

Figure 3. Spaghetti chart trends by individual sites 2002-2016

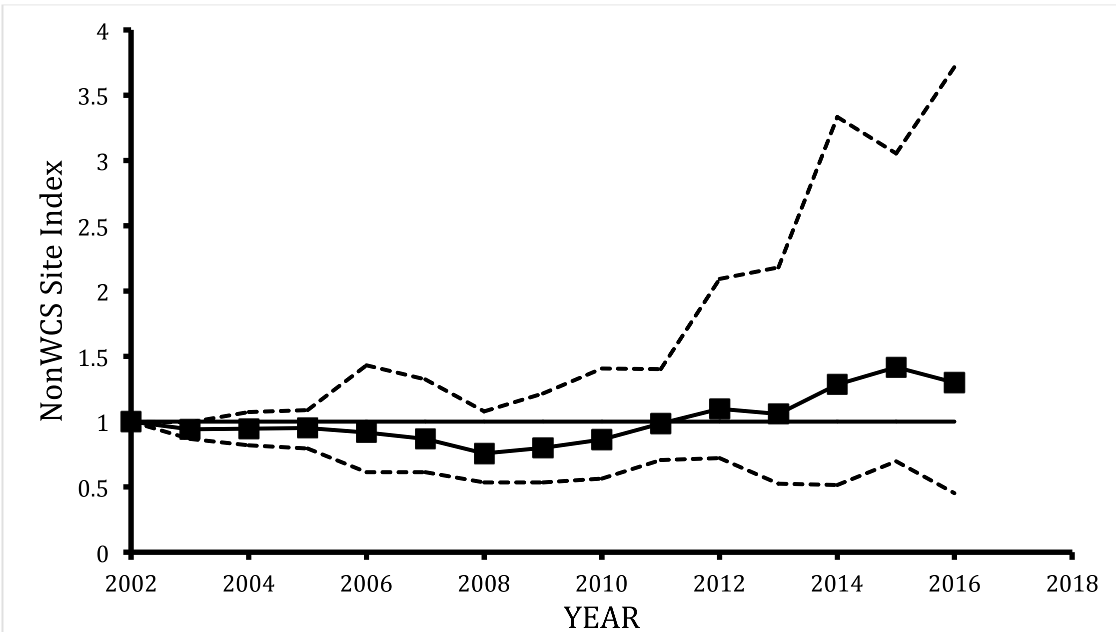

Figure 4. Jaguar Index for 13 non-WCS jaguar conservation sites in Belize, Brazil, Ecuador, Mexico, Peru and Suriname.

Potential causes of trends at WCS sites

Several of the intervention time series at WCS were too short to draw meaningful conclusions and three sites had no WCS interventions other than being established by WCS. The Cockscomb Basin was protected by the Belize Audubon Society in 1990 after work by Alan Rabinowitz established that the area had high jaguar densities. Scott Silver worked in Cockscomb monitoring jaguars and re-introducing black howler monkeys (*Alouatta pigra*) to the reserve. J. Marcio Ayres established the Mamiraua ecological station in 1990 and a sustainable development reserve in 1996. The trend data we have comes from Instituto Mamiraua and we received no additional data on interventions.

We classified our interventions into four broad categories: Community Assistance, Natural Resource Management, Law Enforcement, Education and Human-Wildlife Conflict. Community assistance included development and support of community conservation agreements to support jaguar and prey conservation, and assistance to improve local livelihoods to reduce reliance on wildlife and forest products. Natural resource management included assistance for wildlife management, non-timber forest product management, and certified sustainable timber management. Law enforcement included aerial patrols in Guatemala, support for community patrols to protect territories, and training in SMART. Education consisted mostly of developing jaguar-friendly curricula “Jaguars Forever” and “Identidad Madidi”, and distributing a technical manual on living with jaguars. Jaguar-cattle conflict mitigation involved testing methods to reduce jaguar attacks on livestock and working with ranchers to improve livestock husbandry.

Maya Biosphere Reserve, Guatemala

WCS began working in the Maya Biosphere Reserve in 1991, but major jaguar focused activities were initiated in 2005, with 11 jaguar surveys 2005-2013 in many parts of the reserve. We used 11 years of financial investment (2002- 2013) for these specific areas as an index of interventions and correlated the investment with the jaguar trend during that time period. WCS invested $5,675,467 in MBR between 2002 and 2013 for an average of $472,955/year. The jaguar density trend 2002-2013 correlated positively with each intervention, but correlations were not strong (range 0.014 – 0.449). The strongest correlations were between jaguar trend and Community Assistance ($r = 0.386$, $P>0.2$), Law Enforcement ($r = 0.442$, $p=0.151$), Monitoring ($r = 0.40$, $p = 0.198$), and total annual spending ($r = 0.449$, $p = 0.143$). Lagging the correlation by one year (spending in 2005 affects density in 2006) or by 2 years did not improve any of the correlations. Rather the impact of investment weakened.

The partial correlation analysis indicated that only law enforcement x jaguar trend controlling for other covariates was somewhat strong (0.402, $p = 0.324$). All other partial correlations were less than 0.2 or weakly negative. Lagging the investment by one year gave a single somewhat strong partial correlation between jaguar trend and education ($r = 0.358$, $p = 0.385$). Lagging the investment by 2 years resulted in somewhat strong correlations between jaguar trend and natural resource management ($r = 0.407$, $p = 0.423$).

Yasuni National Park, Ecuador

WCS began working in the Yasuni Landscape in 2001, but we only have jaguar density estimates for 2008-2010, and financial information for 2007-2012. Intervention budgets were reported as average for the time period and total budgets ranged from $10,000 to $317,858 for a total investment of $688,373. No analysis was possible.

Bosawas Biosphere Reserve, Nicaragua

In 2009, WCS inherited initiatives started by the Saint Louis Zoo in the Bosawas landscape in 2001, with the first jaguar survey in 2006 and have had a presence there since 2007. We have financial data for 2007-2017. WCS has invested an average of

$14,902/yr ($1262 - $43,000) for a total investment of $163,923. Correlations between investment and jaguar density in the year of investment were positive for natural resource management (r=0.555, p=0.077) and cumulative investment (r=0.552, p=0.078). Natural resource management was the largest and most consistent investment (40% of total budget). Lagging the correlation by one year resulted in positive correlations between density and investment in education (r=0.559,p=0.093), jaguar-cattle conflict (r=0.621, p=0.055), and total investment (r=0.536, p=0.11). Lagging the correlation by 2 years resulted in positive correlations between density and law enforcement (r=0.649, p=0.059) and total investment (r=0.833, p=0.005).

A partial correlation analysis showed that natural resource management was the most consistently correlated effect with jaguar density (Density x NRM | ED, HWC, LAW = 0.762, p = 0.028, Density lag1 x NRM = 0.774, p=0.041 and Density lag2 x NRM = 0.665, p=0.15). Density lag2 x Law enforcement was positively correlated (r= 0.766, p=0.076). Other effects were positive but not highly correlated.

Madidi-Tambopata Landscape

Bolivia provided budget notes over a long time series (1999-2015), a period of sustained high-level investment in jaguars since 2000. Annual investment ranged between $28,000 and $1,095,000 for a total of $8,810,000 through 2015. Financial information was reported for the landscape and we assume that the Madidi-Hondo site and Upper Madidi site are representative of the landscape.

Jaguar density increased steadily during this time period along with total investment/year (r=0.839, p<0.001) and cumulative investment (r=0.901, p<0.001). Lagging density by 1 or 2 years made little difference in the strength of the correlation because of the annual increase in investments.

Partial correlations of density x local livelihood support controlling for natural resource management, education and law enforcement was consistently positive, though the strength of the correlation weakened at each lag in the comparison (0.744, p=.009; lag 1 0.676, p=0.032; lag 2 0.457, p=.216). Partial correlation of density x natural resource management was negative though the strength of the correlation weakened with each lag (-0.588, p=.057; 0.396, p=.258; -0.004, p=0.992). The partial correlation between density and education was strong only in the current year (r=0.935, p<0.001), but disappeared when the correlation was lagged. The partial correlation between density and law enforcement was consistently strong and positive across comparisons (0.812, p=0.002; lag 1 0.647, p=0.043; 0.746, p=0.021).

Table 1. Impact of Interventions for jaguar conservation.

	Site			
Intervention	Bolivia	Ecuador	Guatemala	Nicaragua
Research/Monitoring	No Data	No Data	Pos	No Data
Local Livelihoods	Pos	No Data	Pos	No Data
Human-Wildlife Conflict	No Data	No Data	Pos	Neutral
Community scout patrol/SMART	Pos	No Data	Pos	Pos
Education	Pos	No Data	Pos	Pos
Natural Resource Management	Neg/Neutral	No Data	Pos	Pos

Financial investment gives us some insights into the effectiveness of WCS intervention strategies. Investing in local livelihoods was clearly a sound strategy in Bolivia (Table 2). Investing in Jaguar Cattle conflict mitigation appears to have had little effect on jaguar density trends, although:1) trends might have been more negative in its absence; 2) surveys have generally until 2017 been in interior forests not along jaguar-cattle conflict mitigation fringes (this is being addressed in three areas in 2017).Support for community-based patrols and SMART to assist communities in protecting their territory and natural resources correlated with improved jaguar densities at all sites where the strategy was used. Assistance for natural resource management, whether as wildlife, non-timber forest products, or certified timber was also generally a positive intervention. Although the relationship between investment and density was negative for the Madidi landscape, between 2010 and 2015, the investment in NRM declined while the jaguar density increased; this negative relationship disappears as the lag increases from 1 year to 2 years.

Cost analysis

Table2 . Annual budgets for Fiscal Year 17 (July 2016 to June 2017).

Site	Country	PA area (km^2)	WCS investment	WCS investment/km^2
Cockscomb	Belize	495		
Madidi Hondo	Bolivia, Peru	6,038	$179,162	$29,6
Upper Madidi	Bolivia, Peru	12,762	$135,384	$10.61
Maya BR	Guatemala	20,382	$1,063,709	$52.19
Saslaya/ Mayangna Sauni Bas	Nicaragua	3,474	$165,783	$47,71
Yasuni	Ecuador	10,232	$116,459	$11.38

The estimated investment totals for FY17 across five sites where we obtained data range from $10.61 to $52,19 per km². Lacking a detailed breakdown on proportions of monitoring to interventions for FY17 we below use the long term data for that analysis.

Costs of monitoring

The two sites with the longest history of monitoring, Madidi-Tambopata (17 years) and the Maya Biosphere Reserve (12 years) averaged $78,235 and $84,575 annually. Averaged that is $81,405 per site per year as the cost of a long-term repeated monitoring program.

The WCS Jaguar Conservation Strategy completed in October 2015 provided 2020 goals for eight large sites, and clarified a need for consistent implementation of basic interventions ($440,00), coordination ($200,000), environmental education-public awareness ($80,000), regionally coordinated ranching and farming improvements ($100,000), Centralized monitoring coordination and travel ($90,000), personnel monitoring in sites ($114,000), field expenses monitoring in eight sites ($112,00), national policy outreach ($24,000) jaguar health, veterinary links, captures, addressing chronic jaguar cattle conflicts ($25,000) for a total of $1,361,000/year, of which $316,000 would be dedicated to monitoring across eight sites, which is 23% of the annual expressed need, while 77% is in direct or indirect interventions. These figures allocate $39,500 for monitoring to each of eight sites, which may be adequate in the lighter operations but is a low end for larger more comprehensive approaches. The estimate was made conscious of subsidies that additional grants and programs provide the country programs/sites through indirect interventions, administrative costs,, transportation, and office space..

Bookmarking estimates for jaguar monitoring that range between $39,000 and $81,000 annually, we examined the ratio of interventions to monitoring costs. In seventeen years of effecting jaguar conservation, Madidi-Tambopata spent a total of $10,498,000 of which $9,168,000 (87% total) was spent on interventions and $1,330,000 (13%) was spent on monitoring   In twelve years work to effect jaguar conservation over twelve years the Maya Biosphere Reserve spent a total of $5,675,467 of which $3,960,719 (70% total) was spent on interventions and $1,714,748 (30%) on monitoring. In the case of the Maya Biosphere Reserve monitoring included a broad array of monitoring including other flagship species, biodiversity expressed generally, and some landscape level monitoring so the estimated proportion of intervention funds to evaluation funds might be closer to the 23% in the strategy. Following the above 87-77%, at least three quarters of an annual budget should be allocated to the mix of interventions that contribute to jaguar conservation and roughly one quarter of the annual budget to evaluating the impact of those interventions using the theory of change.

DISCUSSION

Our jaguar conservation strategy is to work in a set of globally significant strategically located JCUs that contribute to range wide conservation (https://www.wcs.org/our-work/species/jaguars). The areas examined in these analyses all fall within protected area complexes. Our Paraguay program started in private cattle ranches and has expanded into protected areas but jaguar survey data were too recent to be included in these analyses. Panthera has carried the continuous jaguar corridor concept forward (https://www.panthera.org/initiative/jaguar-corridor-initiative) which attempts to maintain connectivity between JCUs (Rabinowitz 2006, Rabinowitz and Zeller 2010, Petracca et al. 2017). Inherent in our decision was a twenty- year experience in the broad suite of tools that contribute, directly, and indirectly to jaguar conservation. We understood how immensely challenging an undertaking defending an ungazetted range length corridor would be, and opted to focus on holding essential ground in a strategically located subset of JCUs.   We occasionally stray from strict adherence from this framework. We contributed diverse scientific guidance to the U.S. Fish and Wildlife Service for Mexico-US jaguar recovery plan, essentially a Guadalajara to Tucson jaguar corridor (Fisher et al. 2014; Matthews et al. 2015; Online Interface 2016; Polisar et al. 2014; Matthews et al. 2015; Sanderson and Fisher 2013; Stoner et al. 2015). The WCS jaguar focus in Ecuador includes the endangered populations west of the Andes (Ministerio del Ambiente and Wildlife Conservation Society 2014) and we have provided leadership in national processes in Paraguay (Polisar 2016, Secretaria de Ambiente et al. 2016). However, in general, we view our best role as holding ground in select areas needed to stabilize the range wide jaguar population, facilitate recovery, and to allow a corridor program to be effective. A short list of JCUs in which we have interventions and their areas includes Selva Maya Guatemala-Mexico-Belize 40,170km², Corazon del Corredor Nicaragua-Honduras 24,700km², Gran Yasuni Ecuador 47,317km², Gran Madidi Bolivia-Peru 58,658km² and Gran Chaco Paraguay-Bolivia 88,851km² (Σ = 219,526km²). Instituto Mamiraua and WCS Brazil work in the center of the 2,278,036km² multi-national central Amazon JCU. We help support patrols and have jaguar and prey survey data from the 43,220km² Manu JCU Peru which is linked to the Madidi landscape. We monitor hunting and its effects in the 22,829km² Pacaya-Samiria JCU Peru. Cockscomb is in the 6,155km² Maya Mountains JCU in Belize.

The analyses demonstrate that our strategy is working. Jaguars are increasing at an average of 7.8% per year where we work, while simply staying stable in a set of carefully selected comparison non-WCS sites. The WCS sites possibly function as important source sites (Walston et al. 2010) complementing strategies aimed at consolidating corridors between JCUs (Rabinowitz 2006, Rabinowitz and Zeller 2010).

Interventions across landscapes that contribute to jaguar conservation

We implement direct and indirect conservation tools that have led to the positive trends in jaguar conservation where we work. No contradiction is seen between community conservation, working with wealthy ranchers, and strict nature protection. Not only does each JCU require its own admixture, but in most, a diverse suite of tools are employed. The following summaries were developed with the assistance of seven WCS country programs cover a ten-year period, 2008-2017In many ways, the figures provided represent an underestimate.

Protected area and wildlife law enforcement in large protected area complexes

On the law enforcement side, WCS supported approximately 503 people to make over 5,080 foot patrols that covered 108,124 km to defend parks and biosphere reserves. Two hundred and eighty-one people ranging from military personnel through indigenous guards were trained in the Spatial Monitoring and Reporting Tool (SMART) that enhances patrol efficacy.

Community conservation and natural resource management with local people

Working with communities, we promote 14 distinct non-timber forest products (NTFP) including cacao, Brazil nuts, fiber, palm fronds for floral displays, allspice, and rubber that provide economic incentives for forest conservation. Certified selective timber extraction provides another incentive for forest conservation. We have documented jaguars in forest concessions when they are well managed (Polisar et al. 2016, Tobler et al. in prep). This is significant when one considers that over 8,000km² of the MBR is multiple use zones and much of that includes certified timber extraction concessions, and much of jaguar range has potential for economically productive timber extraction linked to effective jaguar conservation.

We have secured 30 community conservation agreements that effect jaguar and prey conservation across 15,316km². Sixty-eight basic necessity surveys helped guide many of these community conservation efforts. Specific community wildlife management programs focused on caiman and peccaries have also advanced conservation objectives by improving livelihoods and management capacity in Bolivia and Peru respectively. In a number of these areas, e.g. Guatemala and Nicaragua, local community members patrol and protect their territory with zeal. On a larger scale, in the Amazon basin, and in Mesoamerica, WCS has working alliances with titled indigenous territories in which forest conservation and sustainable natural resource use are priorities. In Bolivia, indigenous territories (Tacana 3,890km², Lecos 2,500km², and Tsimane-Moseten 4,000km²) all maintain forest cover and are zoned at least 85% friendly to jaguars (10,390km² in total, one half the size of the country of Belize). We also collaborate with Miskitu, Mayangna, and Tawahka territories in Nicaragua and Honduras to effect jaguar conservation.

We employ 17 different strategies (including commercial and sport fishing, coffee, incense, chicken husbandry, native bee honey, ecotourism including bird watching, methods of space efficient improved production cattle husbandry, handicrafts) to improve livelihoods across 66 communities, leading to reduced pressure on wildlife and forests.

Working with ranchers to reduce human-jaguar conflicts on the edges of reserves

We have established 80 agreements to mitigate/reduce livestock owners' killing of jaguars. Calves, particularly young calves, are the most vulnerable to attack (Scognamillo et al. 2003; Polisar et al. 2003; Hoogesteijn and Hoogesteijn 2014). To help alleviate this issue, we have tested methods to directly reduce jaguar attacks, many focused on protecting calves, including improved distribution of cattle placing them further from forest, night enclosures, electric fences, flashing LED lights powered by solar panels, cowbells and donkeys in several countries. In the pastures where these techniques have been tested success at reducing predation rates has been 80-100% (Villalba et al. 2016). In the pastures where we have deployed these methods we have effected an 80-100% decrease in livestock losses to jaguars, something not reflected in either the trend or intervention analyses.

We also work with ranches to improve space efficient productive methods of managing livestock (forage improvements through silvopastoral systems and live fences, nutritional blocks, improved pastures, and rotational grazing, protection of water sources, veterinarian training and silage storage) in 281 ranches across Paraguay, Bolivia, Guatemala, Honduras, and Nicaragua that total 2,893km² that lead to reductions in both attacks and deforestation (Garcia-Anleu et al 2016). In Bolivia we have impact on 622km² on indigenous farms, in Guatemala on 744km² of ladino ranchlands, and in Paraguay in ten ranches that total over 2,000km² and raise over 72,000 head of cattle.

Our Paraguay program is too young (2012-2017) to have jaguar trend data that could feed these analyses, but has had impact on target ranches, partly informed by experiences obtained in Venezuela, where twenty years after Polisar et al. (2003) and Scognamillo et al. (2003) studied jaguars, pumas, their prey and cattle ranching on a ranch in Venezuela, Jędrzejewski et al. (2016) reported one of the highest jaguar densities ever recorded in the 7,095km² Llanos JCU. Strict forest conservation, a complete ban on hunting, abundant prey-producing ecotones, well-managed cattle herds, and the incentive of ecotourism are likely explanations.

The result of neutral trends in response to jaguar-cattle mitigation interventions needs to be qualified by: 1) no data included from the effective but young program in Paraguay: 2) few jaguar surveys completed by our current suite of programs in the specific areas where farm improvements and conflict mitigations are taking place and having impacts – most surveys have been further into the forests, something currently being addressed in Nicaragua, Honduras, and Guatemala, all with surveys in livestock management zones on the edge of biosphere.

Education and training of public, ranchers and government for human-jaguar coexistence

We have trained 303 teachers in how to deliver our intensive Jaguars Forever curriculum, bringing jaguar conservation to approximately 900 students. Our Ecuador program has emerged as our most avid practitioner 2012-2017, but does not have a corresponding set of jaguar trend data. Recently concluded large scale occupancy sampling in Ecuador may serve as a baseline. The Bolivia country program's Identidad Madidi (Wallace 2016) has communicated the importance of biodiversity and jaguar conservation to over 125 schools in La Paz and El Alto, thus far reaching approximately 20,000 students in those urban areas in the Altiplano, plus approximately 2,500 students in the Gran Madidi conservation landscape, with the latter possibly having a measurable impact on jaguars in the landscape in future years.
https://bolivia.wcs.org/es-es/Especies/Jaguar.aspx

Across our sites, we have transmitted ways to reduce human-jaguar conflicts in 106 workshops with 482 ranchers, and in eighteen workshops we have trained 200 government personnel in methods for human-jaguar co-existence. Some of these areas were outside the areas analyzed in this project (e.g., Northern Honduras Jaguar Corridor, western and northern Rio Platano Biosphere Reserve in Honduras, Chiquitano Forest in Bolivia). Two of our leading practitioners of these exercises – Paraguay ranchlands and Guatemala MBR buffer zone did not fully enter into the investment-population response analyses in this paper.

Dissemination of the jaguar conservation message has been supported by 11 national web postings. In Paraguay, we produced a nationally read magazine article, and a nationally watched television program, reaching 5 million people. In addition, 20 international web postings generated from our sites reached additional millions, and 5 local radio spots reached local audiences. Identidad Madidi has reached 2 million people with the jaguar conservation message and has 80,000 followers.

These messages have been supported by the dissemination of six distinct technical manuals on human jaguar co-existence of which the most compelling are the products from Guatemala (Soto et al. 2007).and Paraguay (Wildlife Conservation Society-Paraguay 2016). Rapid growth in both jaguar-livestock conflict mitigation and camera trapping in our Paraguay program has been too recent to feed into these analyses, and the data extraction and analyses from Guatemala are incomplete.

National and Regional Policy and Planning

We have developed and contributed to six national jaguar conservation plans, most recently spearheading: 1) the national plan in Ecuador which is guiding jaguar conservation in that country (Ministerio del Ambiente and WCS 2014); and 2) a national plan in Paraguay (Secretaria del Ambiente et al. 2016). The latter plan contains realistic protocols for managing human-jaguar conflict ever offered, aiming at the roots of the conflicts, and suggesting tested and proven measures to prevent them. A jaguar Action Plan for Bolivia is being initiated end September 2017. We do not include clear metrics for these processes in this analysis, but they may be playing a factor in our success. In Paraguay, we have advised on modifications to an existing jaguar conservation law which likely will become one of the best conceived pieces on jaguar legislation in the species' range, with recommendations for reducing conflicts placed well before any efforts to remove individual jaguars. Paraguay is conducting their first rigorous CRC in that country's largest national park this year. Recently concluded massive large scale occupancy sampling and modeling in Ecuador can establish a baseline for measuring the impact of the national plan in the future.

We have also conceived, organized, and executed regional priority setting workshops for entire biomes. We led a regional workshop the Gran Chaco in 2012 that provided much of the basis and foundation for our rapid 2012-2017 expansion in Paraguay. More recently, we worked with World Wildlife Fund and Panthera to ensure the success of a multi-national workshop to plan the conservation of the jaguar in the entire Amazon Basin and Guianas, thus leading an the effort to publicize the results globally (Wildlife Conservation Society et al. 2016) which is now yielding additional potential synergies between conservation organizations to maintain jaguars in the Amazon..

The re-emerging threat of trade in jaguar parts

We are currently developing strategies to better understand and counteract this threat. Our Bolivia staff has been at the forefront of the reports on teeth being smuggled to China. Systematic information has been lacking, yet actions to confront the threat require exactly that. We have initiated an investigation of the illegal trade of jaguar parts in Central America through desk research and direct communication with authorities and experts in order to develop a baseline of information on trade and trafficking. In early 2017, we submitted a proposal to the U.S. Fish and Wildlife Service to counter wildlife trafficking in the Amazon basin (Brazil, Peru, Colombia, Ecuador and Bolivia) by addressing critical information gaps around the emerging threat of increased trade in jaguar parts in that region. The intent is to collate, produce, and disseminate the information necessary to understand the jaguar trade across Central and South America to inform subsequent actions. In addition, the Bolivian program, tightly linked with national institutions is working with regional and global WCS experts in International Wildlife Trade (IWT) on proposals and action plans to counter the apparently aggressive nature of this threat in that country. This effort focuses on swift capacity building of Bolivian national authorities and tight links with globally competent WCS IWT specialists who work in the countries where the trade has been directed.

Proportions of investments in conservation investments and monitoring

A crude analysis of proportions of investments to monitoring in two sites, Madidi and MBR results in ~ 77-87% spent on interventions and 13-23% on monitoring, rounded to at least three quarters of the annual budget spent on interventions that effect jaguar conservation. In highly threatened sites where deforestation by colonists for small farms is rampant or where vast stretches of forest are leveled for monoculture crops or large cattle ranches, high impact interventions, in the admixture that addresses individual areas' threats are critical. Even in the central Amazon, where threat levels may be lower, visionary large scale interventions are the key to maintaining the current large areas of intact habitat, and high abundance of jaguars. Intervention to monitoring investment levels may vary according to threat levels. If a program/initiatives investments in monitoring exceed interventions one might question if the site could reassign proportions to better effect jaguar conservation. The breath of interventions presented and analyzed in this paper, and the depth in investments may demonstrate why WCS has effectively accomplished jaguar conservation.

CONCLUSIONS

Our 2020 deliverables are jaguar populations in eight large Jaguar Conservation Units that make a significant contribution to range-wide jaguar conservation are stable or increasing, with no net reduction in numbers or space occupied by jaguars; human-jaguar conflicts will be reduced to mortality levels that do not cause population decreases; hunting of prey will be at levels that sustain jaguar production and provide abundant natural alternatives to domestic livestock; and in-country funding and law enforcement institutional capacity will be sufficient to prevent habitat degradation and loss in those eight JCUs.

Accumulative and averaged jaguar population increases of 7.8% per year in our sites versus 2.8% in a suite on non-WCS sites provide evidence that we are making progress on our goals, and that our interventions are working for jaguars. The stable and increasing trends provide testimony to the efficacy of combinations of: 1) livelihood programs focused on controlled natural resource extraction; 2) restricted human access: 3) controlled hunting; and 4) effective habitat conservation. Population stability and increases have come primarily from: 1) well protected park interiors; 2) well-defended remote indigenous territories, and 3) the conservation impact of careful natural resource management, including well controlled FSC certified timber extraction concessions and non-timber forest product extraction areas. Patrols and law enforcement were positively correlated with population increases across sites, whether by park guards, indigenous communities, or forest concession participants. Engagement with local communities to generate economic opportunities and alternatives to destructive deforestation and overhunting has played a positive role in jaguar conservation (Polisar et al. 2016, Radachowsky et al. 2013); investments in local livelihood, community patrols, education, and natural resource management were all linked to positive trends in jaguar populations.

Several of our sites had inadequate repeated measures to indicate jaguar trends. One site was too recent to be included. One had been left behind out of economic expediency. One site with repeated measures, Mamiraua, exhibited a decline, perhaps a result of heavy jaguar mortality in Ribereño communities as a response to attacks on livestock. Systematic interventions to reduce cattle vulnerability have not been initiated there despite years of research on the topic. This is a site in which WCS has not had direct interventions for more than ten years, but our influence is now swinging back.

The jaguar population trend analysis re-emphasized the importance of repeated sampling in consistent site. Two sites from the Madidi-Tambopata site in Bolivia supplied material for repeat surveys in this analysis, driving some of the positive trends, and amply demonstrating the value of repeated measures, and there are several more in that landscape than can do so in the future. There needs to be some repeat surveys in Yasuni National Park in Ecuador. Recent large occupancy baselines can function as that. Mamiraua in Brazil is blessed with a number of repeat surveys. The need for permanent monitoring sites has been emphasized in Mesoamerica, yet also has been limited by available funds in the region (Laguna del Tigre and Holmul in Guatemala sampled 2012, and 2013 were designed to initiate permanent monitoring plots on the western and eastern edges of the MBR respectively, Kipla Sait Tasbaika site in the core of Bosawas (sampled 2007, and 2011, adjacent to 2006 Mayangna Sauni Bu) was designed as a permanent monitoring plot. The youngest program of all, in the Paraguayan Chaco has established a permanent monitoring site in the country's largest national park. The oldest program of all, the Cockscomb Basin maintained monitoring as it passed hands from WCS to Panthera and the results are seen in Harmsen et al. (2017).

Demographic and occupancy analyses of jaguar populations in protected areas through repeated methodologically similar surveys are a stated priority in our strategy to measure impact of conservation intervention. The primary constraint we face is equitable distribution of resources for strategically systematic monitoring. Additional resources of would allow us execute repeat surveys across more sites. An optimal sum to effect long term monitoring would be $648,000/year. However, even $312,000 would help more us accomplish more repeated measures across time and space. Financial resources are either unevenly distributed across regions, and/or opportunistically available and then absent again. Repeated measures, at minimum on a five year cycle (Polisar et al. 2014b) or even faster (annual is informative (Harmsen et al. 2017)) are not only optimal, they are necessary to evaluate impacts. Nowhere is the WCS tension between talking strategically and acting opportunistically more evident than in the challenges of accomplishing long-term population monitoring.

Baselines to measure trends have generally been lacking in specific jaguar-cattle conflict mitigation areas, although: 1) Paraguay has conducted relative abundance index sampling (RAI)on ranchlands that can be used in the future; 2) the MBR is conducting occupancy sampling in its buffer zone; 3) sampling has been completed in livestock intervention zones in Nicaragua's Bosawas Biosphere Reserve (though not ready for this paper); 4) sampling is current taking place on the edge of livestock intervention zones in two biosphere reserves in Honduras; and 5) Bolivia initiated surveys in a Municipal Reserve also characterized by cattle ranching in late 2016 (Santa Rosa de Yacumen). Boron et al. (2016) generated rigorous jaguar density estimates in areas that included cattle ranching, testimony that coexistence is possible. Year-round camera trapping in working cattle ranch in Venezuela (2013-2014) published by Jędrzejewski et al. (2016) generated jaguar density estimates double those in Boron et al. (2016) in a site where WCS had invested twenty years ago (Polisar et al. 2003) with the differences likely due to strict forest protection, controlled hunting of native prey, high quality livestock management that separated cattle from forest, and benefits from ecotourism.

Notable vision and discipline in establishing and practicing repeat measures for these exercises were led by the Bolivia Madidi-Tambopata program, Mamiraua, and the Nicaragua Bosawas Program. Guatemala established that economically productive forests managed for certified timber extraction can work as a tool for jaguar and prey conservation (Tobler et al. in prep). The MBR probably has more protected area legal protection victories than any other country in the entire WCS Latin America region facing Mesoamerica threat levels that dwarf those in the central Amazon. New baselines for jaguar-cattle mitigation areas are underway in four countries (Guatemala, Honduras, Nicaragua, Paraguay). Recently concluded massive occupancy sampling in Ecuador will provide a baseline for the future there.

Although there is a gradient in rigor from CRC through OM to RAI (Polisar et el. 2014b, 2016), with the optimal design being CRC in core areas repeated at a frequency that can generate demographic rates embedded in a larger scale matrix of repeated occupancy sampling that spans threat and management gradients, the most important element is simply repeated measures over time.

Jaguars and the Theory of Change

Our theory of change proposes that effective conservation of emblematic wildlife and the last of the wild places requires: (a) strengthened management by communities and indigenous groups, national agencies, and local municipalities; (b) support for effective governance of these areas and natural resources by stakeholders in terms of their authority, legitimacy, motivation, and capacity; (c) incentivized resilient livelihoods of the people who depend on direct use of natural resources for subsistence and income. For jaguars, WCS has delivered a,b,c, in admixtures adapted to each site to abate threats resulting in an eigenvalue of conservation success expressed as jaguar population average annual increases of 7.8%.

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