Landscape Scale Monitoring for Species and Threats: Jaguars in the Greater Madidi-Tambopata Landscape

Rob Wallace

Greater Madidi-Tambopata Landscape

Wildlife Conservation Society

Photo: Mileniusz Spanowicz/WCS

With contributions from: Miguel Antunez, Guido Ayala, Carolina Bertsch, Adriana Burbano, Laura Cancino, Ruben Cueva, Padu Franco, Isaac Goldstein, Catalina Gutierrez, Alicia Kuroiwa, Lucy Perera, Renzo Piana, John Polisar, Pablo Puertas, Ariel Reinaga, Nestor Roncancio, Teddy Siles, Mariana Varese & Galo Zapata at the Amazon Program meeting in Lima in May 2011 and/or the Wildlife Congress in Salta in May 2012.

And from: Arjun Gopalaswamy, Aaron MacNeil, Jim Nichols, Andres Novaro, Tim O´Brien, Samantha Strindberg, David Wilkie & Steve Zack at the WCS Workshop: Occupancy as a Metric of Conservation Effectiveness for Within and Cross Site Comparisons in August 2012.

Over the last decade the Wildlife Conservation Society (WCS) has developed a series of conceptual and spatially explicit standardized methods and associated tools with which to address conservation planning and interventions at a scale that responds to the needs of wide ranging landscape species (Sanderson *et al.*, 2002; Coppolillo *et al.*, 2004; Didier *et al.*, 2009). As such a number of spatially explicit methods for mapping human activities across the landscape as well as displaying the landscape from the perspective of a suite of transparently selected species are available.

One of the remaining challenges to complete the adaptive management cycle is to develop methodologies that permit efficient and effective monitoring at a landscape scale of target wide-ranging species and direct threats that are not visible from space. Given the size of most identified landscapes that render many established methodologies for monitoring at a specific study site scale inappropriate, WCS has identified presence-absence models including occupancy as a potentially effective monitoring analysis. In this light, WCS has been moving forward with landscape scale monitoring challenges through the WCS Tigers Forever program (Karanth & Nichols, 2010), as well as for great apes and forest elephants at the Nouabale Ndoki site in central Africa (Stokes *et al.*, 2010).

In the Greater Madidi-Tambopata Landscape following a series of discussions and analyses of existing information from differing sources and/or methodologies we also decided that at a landscape scale the most appropriate measure for direct threats and wide-ranging species would be a presence-absence style analysis. These discussions also broadened to the WCS Amazon Program and the various landscapes that WCS supports across that region at the Amazon Program meeting in Lima in May 2011 and then intensified at the Wildlife Congress in Salta in May 2012. We then produced a series of maps to illustrate the problem and work on a potential solution using the jaguar (*Panthera onca*) as an example, and presented them at the recent WCS Workshop: Occupancy as a Metric of Conservation Effectiveness for Within and Cross Site Comparisons, held at Bronx Zoo in August 2012.

WHAT KINDS OF DATA CAN WE USE FOR OCCUPANCY?

Figure 1 displays the concentrated nature of research based jaguar locations in the Greater Madidi-Tambopata Landscape up to 2009. As a comparison Figure 2 displays all jaguar locations systematized for the program including those that derive from a variety of structured interviews with local communities and park guards. The coverage of the second set of locations is considerably greater. More dramatically, Figure 3 displays research based locations for all mammals across the Greater Madidi-Tambopata Landscape up to 2009, and then Figure 4 displays all mammal locations including those derived from the structured interviews from local sources.

Clearly, information from local people potentially improves coverage for species locations vastly across the landscape and adds significantly to the amount of information that a reasonably active research team have been able to amass over a decade in the same landscape. As such, we are proposing to develop a monitoring system for landscape species based on four year sampling periods that are based firstly on an interview-based techniques with local communities, park guards, ecotourism guides and community natural resource management businesses that cover a broad portion of the landscape. Data from these sources would be complimented by researcher information from line transect and camera trap surveys as well as *ad libitum* observations over relatively small areas within the landscape, as well as targeted presence-absence sampling in areas of the landscape where data is scarce and where changes in presence may be expected.

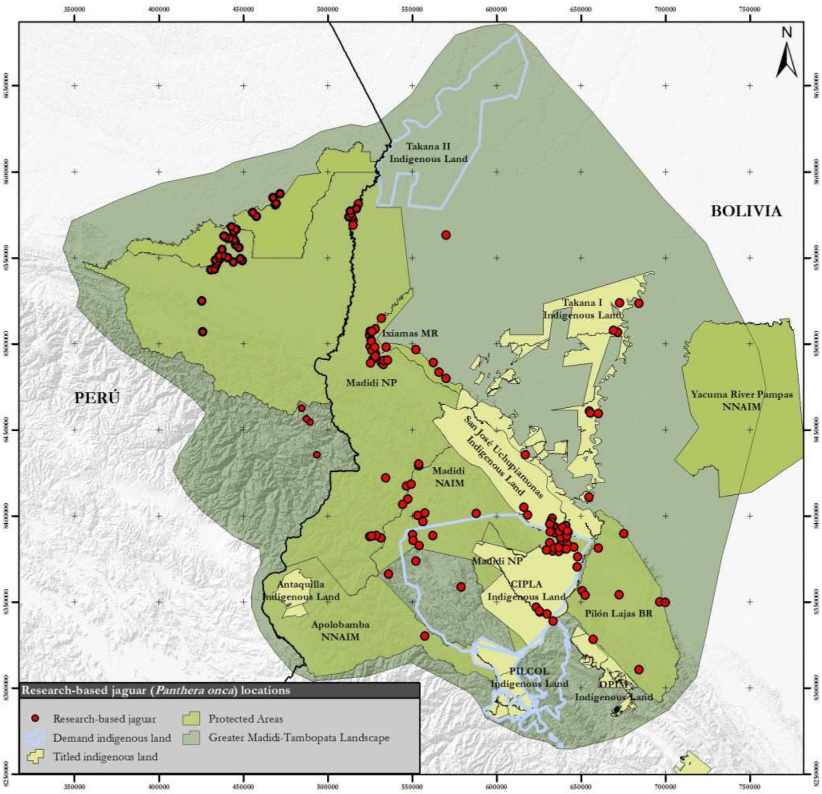

Figure 1. Research-based jaguar (*Panthera onca*) locations in Greater Madidi-Tambopata Landscape

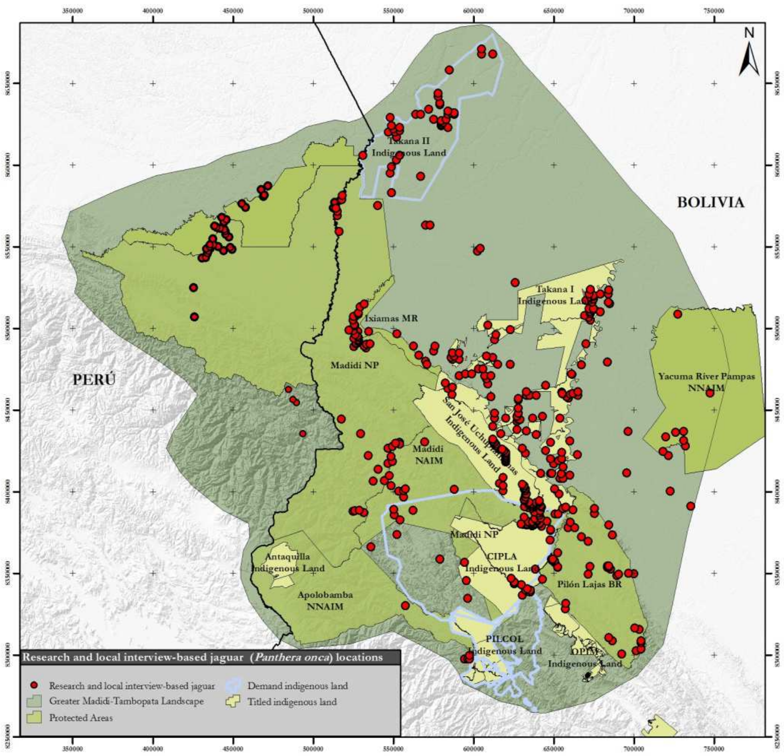

Figure 2. Research and local interview-based jaguar (*Panthera onca*) locations in Greater Madidi-Tambopata Landscape

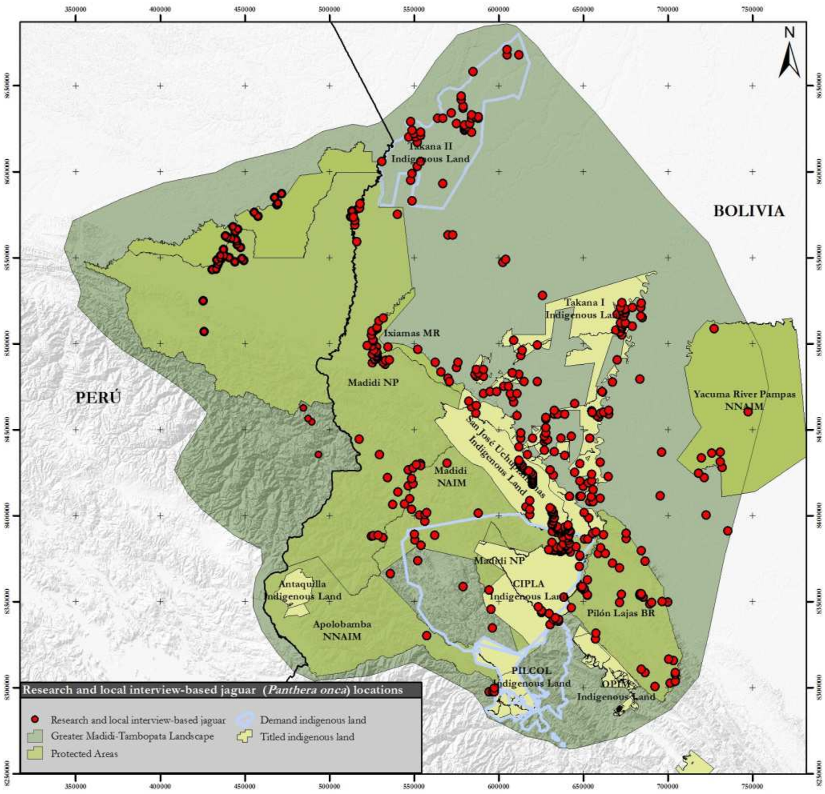

Figure 3. Research-based mammal locations in Greater Madidi-Tambopata Landscape

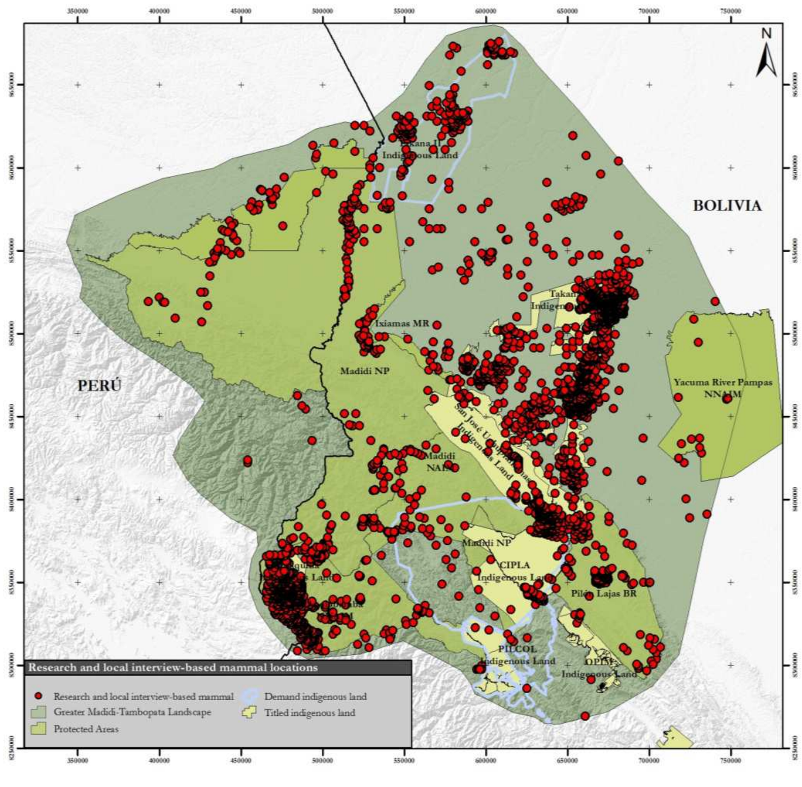

Figure 4. Research and local interview-based mammal locations in Greater Madidi-Tambopata Landscape

Here it is important to emphasize that interview data will only be relevant in any analysis for those species that we are confident that local communities and/or park guards can accurately identify. So for example, we would not expect communities or park guards to consistently distinguish between ocelot, margay and oncilla (*Leopardus pardalis*, *L. wiedii*, *L. tigrinus*), three very similar small spotted jungle cats in the Amazon. In the case of the jaguar, direct observations are unequivocal for local people, but footprints and scat sign maybe confused with puma (*Puma concolor*). Recognizing these potential confusions is critical for any interview based data collection study design.

At the New York workshop we asked recognized experts whether we could incorporate data from completely differing sources, such as those just mentioned, into an overall landscape scale occupancy analysis?

Mixed occupancy models allow the incorporation of differing sources as long as a) detection probabilities can be calculated for each data type, and b) these different types can then be calibrated at sites where data of more than one type occurs. Detection probabilities for park guard generated data should be easily calculated since the vast majority of this data stems from park guard patrols which are usually repeated over set routes allowing for replicates and as such detection probabilities across the routes.

For community interview data in order to be able to calculate detection probabilities it would be important to map knowledge areas at least at the community level or better still to interviewee level. The number of interviewees and number of records per occupancy analysis cell could then be calculated and used to create detection probabilities, as could the number of data collection cells (1 km^2) with detected presence within a larger occupancy analysis cell. In order to assist in the calculation of detection probabilities and calibration with other methods, workshop participants in New York stressed the need to adequately quantify and map the areas that each interviewee could speak about prior to asking where each interviewee had detected target species, as well as specifically ask about presence-absence of target species in each occupancy analysis cell within the interviewees expressed area of knowledge. Thus interviewees would first be asked to specify their area of knowledge on a map, would then be asked about where they had detected each target species in a specified time period, and would finally be specifically asked for each occupancy analysis cell within their specified area of knowledge whether they had detected each target species.

In occupancy analyses non-detection is not necessarily a problem, but misclassification and/or misidentification of species can represent major problems and must be controlled for in study design. So even for researchers when surveying for jaguar presence the bar will need to be set high for tracks that can be confused with puma (especially if the substrate is loose and/or dry), only including those that are unambiguously jaguar. Hence, fieldwork might be prioritized when substrates are wet and might also concentrate in areas where substrates are suitable, for example, along stream and riverbeds. In India tiger and leopard scat can be misclassified, so DNA analysis of a sample of scats is used to verify error rate. Strong verification data from the field allows control for interview misclassification.

WHERE DO WE NEED TO MONITOR AT A LANDSCAPE SCALE?

WCS landscapes and seascapes across the world are usually large and often immense. As such thinking about monitoring activities at the landscape scale for wide-ranging landscape species can be a daunting prospect from a cost and effort perspective. In the Greater

Madidi-Tambopata Landscape we have chosen to use other WCS established methodologies to help us think about monitoring priorities from a spatial perspective. Figure 4 shows clearly that large areas of the landscape are without data on biodiversity including landscape species and Figure 2 shows the same phenomena for jaguars. These maps tally well with maps (Figure 5) regarding the presence and density of human activities or threats in the landscape (human landscape), ie., where we are lacking data on jaguars and general biodiversity the density of threats is low or threats are simply absent.

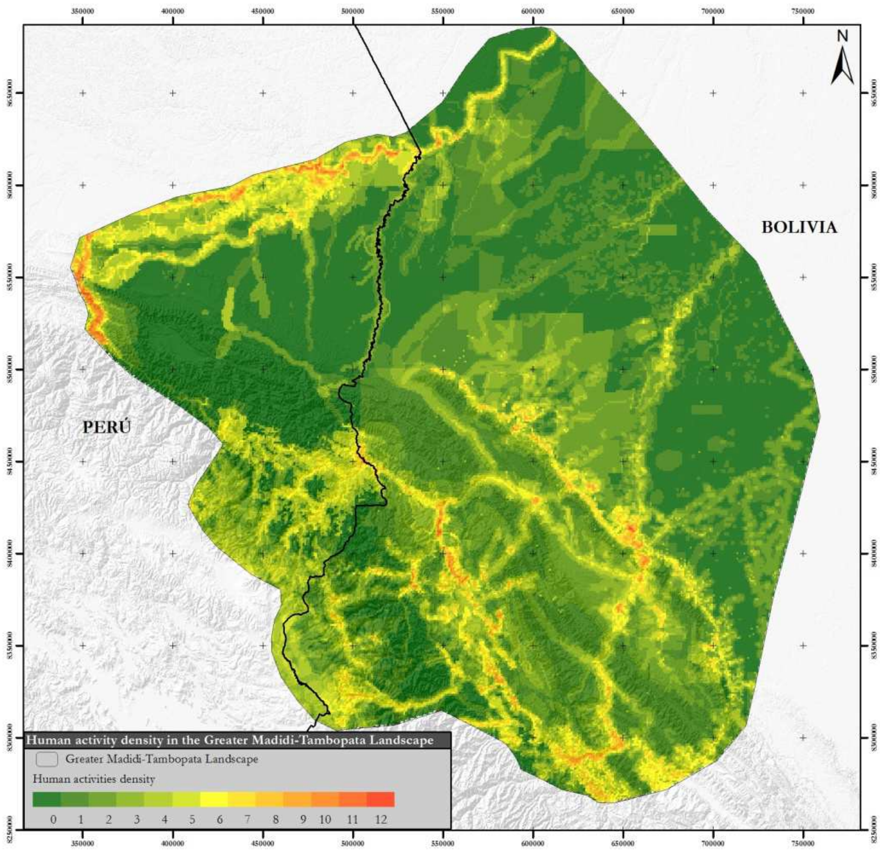

Figure 5. Human activity (threat) density in the Greater Madidi-Tambopata Landscape

We used our Jaguar Conservation Landscape (Figure 6), the GIS combination of a simple habitat suitability model (Jaguar Biological Landscape) and spatial representation of threats in the region (Human Landscape), to assess monitoring priorities for the jaguar. The Conservation Landscape divides the landscape into a series of management categories from the perspective of the jaguar. These management categories in the Conservation Landscape (Figure 6) are the product of habitat suitability model (not habitat, marginal habitat, good habitat and optimal habitat) and the threats model (no threat, light threat, moderate threat, high threat). Figure 7 takes the Conservation Landscape and drops the marginal habitat for jaguar, as we are not concerned with monitoring jaguars in marginal habitat. In any case marginal habitat for jaguar will be optimal habitat for other Greater Madidi-Tambopata Landscape specie: military macaw (*Ara militaris*) and Andean bear (*Tremarctos ornatus*).

In Figure 8 from a monitoring point of view we went one step further by cutting habitat that whilst considered good or optimal from the perspective of the jaguar is also not considered threatened with no detected human activities present or known: in other words true wilderness. In the larger continuous polygons of true wilderness in the landscape we

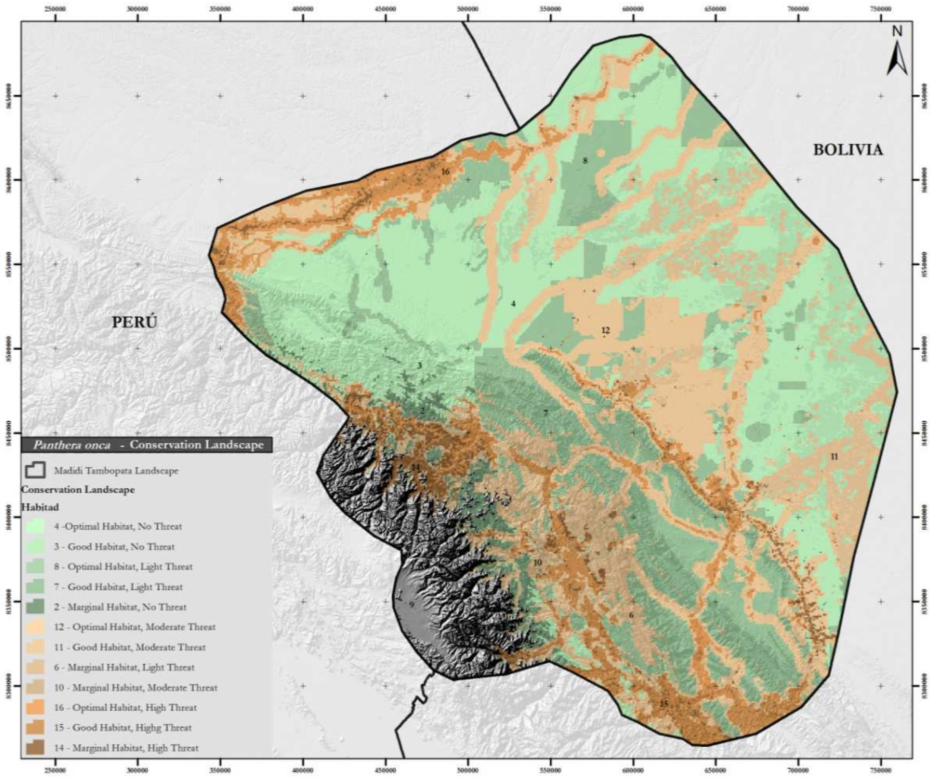

Figure 6. Overall Biological Landscape for Jaguar (*Panthera onca*) in the Greater Madidi-Tambopata Landscape

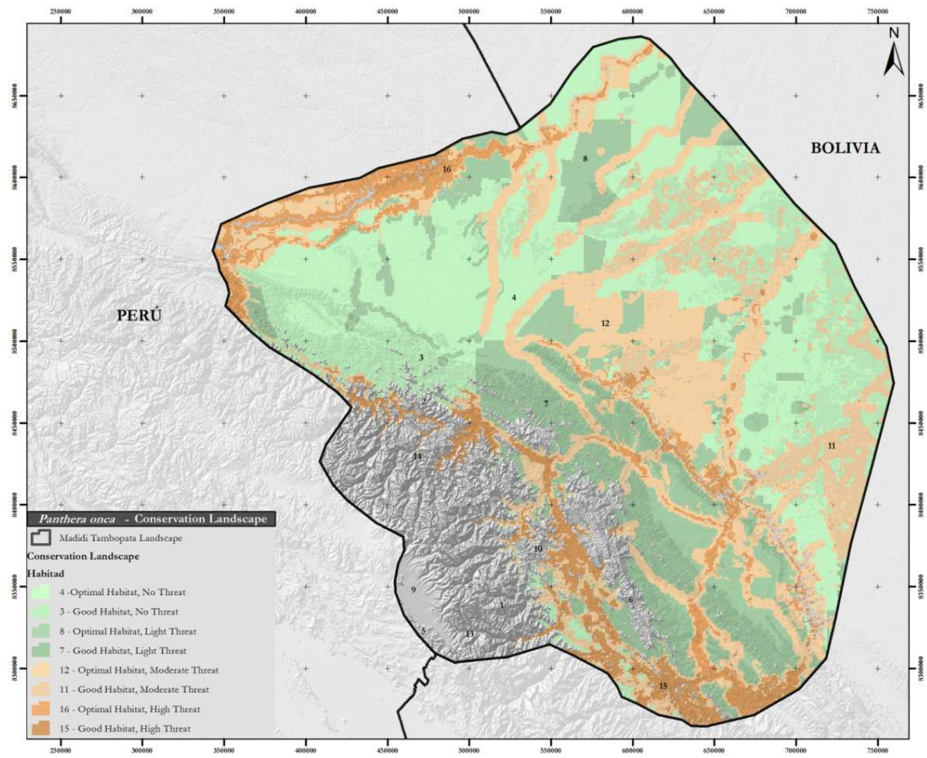

Figure 7. Biological Landscape excluding Marginal Habitat for Jaguar (*Panthera onca*) in the Greater Madidi-Tambopata Landscape

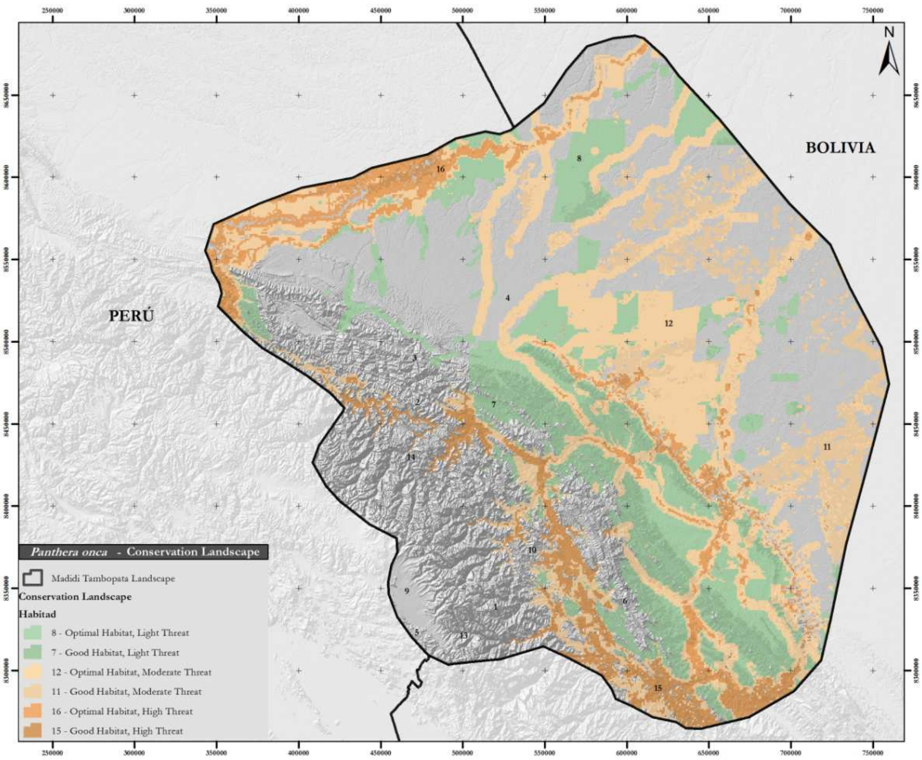

Figure 8. Biological Landscape excluding Marginal Habitat and Good and Optimal Habitat without Threats for Jaguar (*Panthera onca*) in the Greater Madidi-Tambopata Landscape

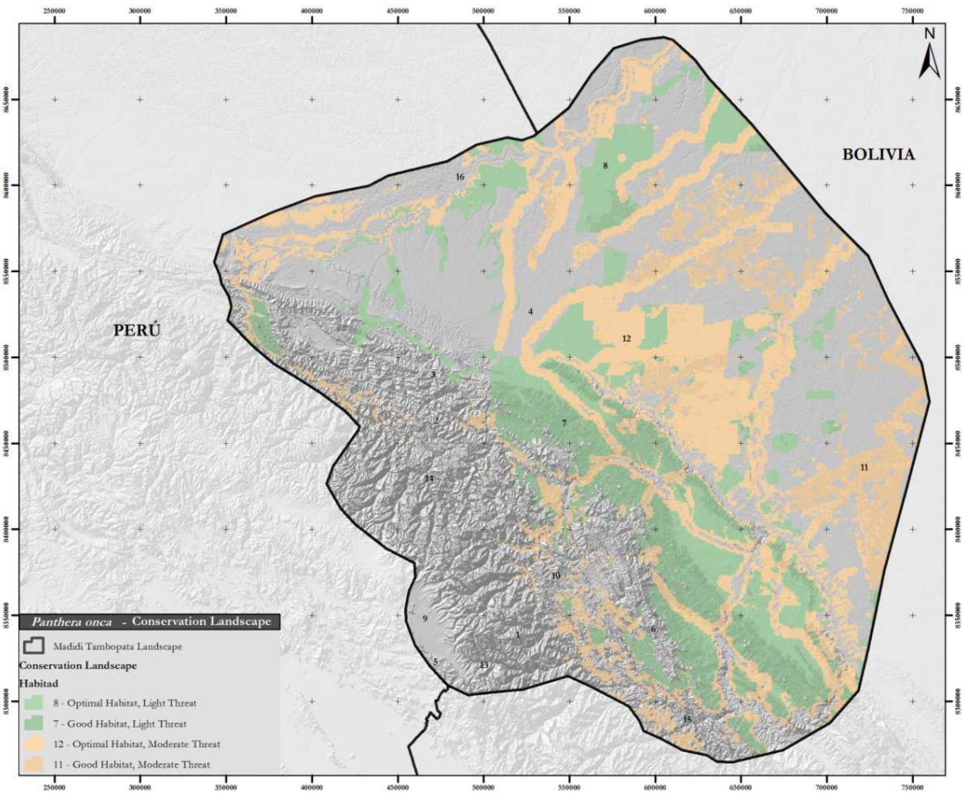

Figure 9. Biological Landscape excluding Marginal Habitat, Good and Optimal Habitat without Threats and Highly Threatened Habitat for Jaguar (*Panthera onca*) in the Greater Madidi-Tambopata Landscape

posit that monitoring may not be necessary under the assumption that no human activity equals no threat. Indeed trying to access these wilderness areas for monitoring purposes may actually represent a threat due to provision of access opportunities. We accept that this position is an assumption, although we are planning to sample some unthreatened areas as a means of verifying our assumption. These two steps, cutting marginal habitat (10,116 km^2) and non-threatened habitat (33,086 km^2) drastically reduced the size of the Jaguar Monitoring Landscape from 101,166 km^2 to 57,964 km^2.

Figure 9 takes this process one step further by cutting away habitat that we already consider as being so heavily threatened that it is no longer appropriate for jaguars. In a landscape conservation context there will always be areas of the landscape that are not suitable for certain species, our conservation landscapes should help us identify those areas which we consider too critical to lose a given landscape species. By taking this step we can reduce the monitoring landscape to 48,147 km^2 (Figure 9) and overall these steps reduced our focal area for jaguars by 52.4%. Figure 10 shows how existing records for jaguars in the Greater Madidi-Tambopata Landscape are distributed across the Priority Monitoring Landscape for jaguar showing that there is a reasonable coverage of records.

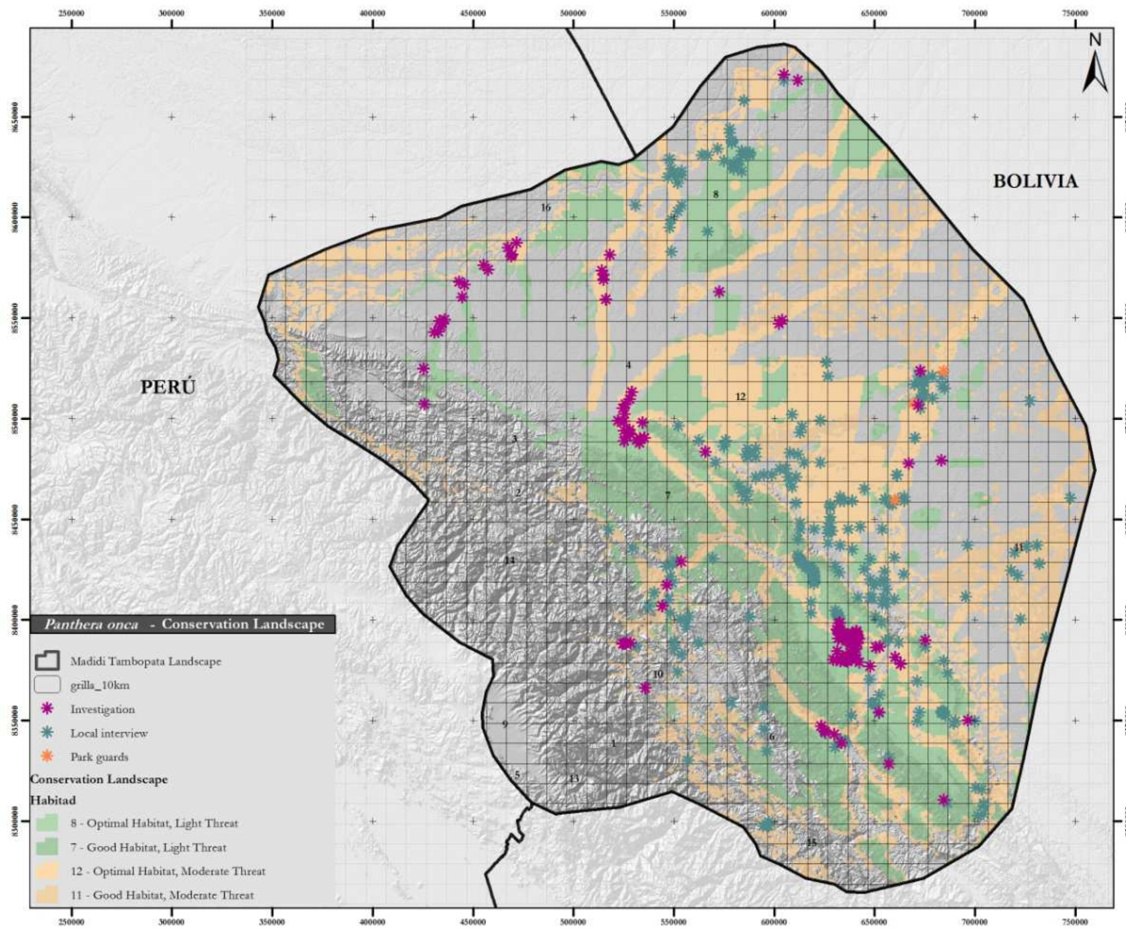

Figure 10. Priority Monitoring Landscape and Distribution of Records for Jaguar (*Panthera onca*) in the Greater Madidi-Tambopata Landscape

WHAT SHOULD OUR GRAIN OF ANALYSIS BE IN A LANDSCAPE SCALE OCCUPANCY MONITORING PROGRAM?

During the workshop in New York we discussed this issue at length. Of course on the one hand the short answer is that it all depends on the question(s) we are asking or the monitoring purpose(s) of the occupancy study. That response could also be given to many of the other questions raised at the workshop or indeed within this document, however, we chose to use the Greater Madidi-Tambopata Landscape jaguar example as a way of demonstrating the different scales and various questions we might have where occupancy might be a relevant tool.

When thinking about the grain of the analysis we need to firstly consider the biology of the target species. For example, from the perspective of jaguars in the Amazon and considering their ranging behavior, 200 km^2 cells might be an option. However, should the grain of a study only be determined using biological considerations? Unfortunately, 200 km^2 cells will probably not respond to the scale of finer scale threats in the landscape and as such not allow detection of change in a monitoring framework.

On the other hand it is also important to recognize that we may be interested in more than one species. For example, at the level of an entire landscape there will be more than one landscape species and probably more than one landscape species where occupancy would be relevant. Can one size fit all species? Or rather should occupancy studies be variable for species according to individual ranging patterns?

In the case of jaguars in the Greater Madidi-Tambopata Landscape we have three different questions at three different scales. The Greater Madidi-Tambopata Landscape is recognized as a large jaguar conservation unit from the WCS Range Wide Priority Setting processes, and WCS camera trapping data from the region has revealed healthy population densities at small discrete study sites representing less than 5% of the overall jaguar landscape. Thus, our first question is, what is happening to jaguars at the overall landscape scale?, recognizing that our camera trap surveys cannot hope to give us regular monitoring information on jaguars which occur across approximately 101,000 km^2 of the landscape, but that for both WCS and more importantly our local partners, such as the national protected areas and indigenous organizations, it is important to be able to show effectiveness in terms of wildlife and biodiversity conservation at a landscape scale.

Our second question is more specific about the effectiveness of indigenous territory management for jaguar and wildlife conservation. For 13 years WCS has worked with the Tacana indigenous people in developing and implementing their territorial vision for the Tacana TCO (indigenous territory) that discontinuously covers approximately 10,000 km^2 within the landscape. Recent deforestation studies have been able to demonstrate that indigenous territorial management is very effective at maintaining forest cover in the region (Forrest *et al.* 2008). However, the Tacana would also like to be able to show their contribution to wildlife and biodiversity conservation, including jaguar. Our working hypothesis has been that the indigenous territory still has populations of peccaries, tapir and jaguar, and that if indigenous people have ownership of their land deforestation will be less and wildlife friendly land uses will be more commonly practiced. As such our expectation is that jaguar relative abundance and/or occupancy will change with habitat quality, threats, and management regime.

Finally, along the San Buenaventura-Ixiamas road that runs 110 km parallel to the limit of Madidi National Park cutting across the Tacana TCO we wish to generate extensive information on wildlife before the road is improved in 2013 with funding from the World

Bank. We wish to focus on showing the wildlife conservation value, including connectivity between the TCO and Madidi park, of this 1,000 km^2 area and create an extensive baseline to share with the World Bank maintaining pressure to develop adequate environmental mitigation strategies and activities with which to guarantee the most important wildlife corridors. Our questions include: Whether the road results in increased human population density and decreased forest cover? How does forest fragmentation influence jaguar movement? Roads will likely increase colonization outside of the indigenous territory because private lands can be traded and converted to ranches. Colonization and clearance for fields may further reduce the porosity of existing corridors and may also increase hunting.

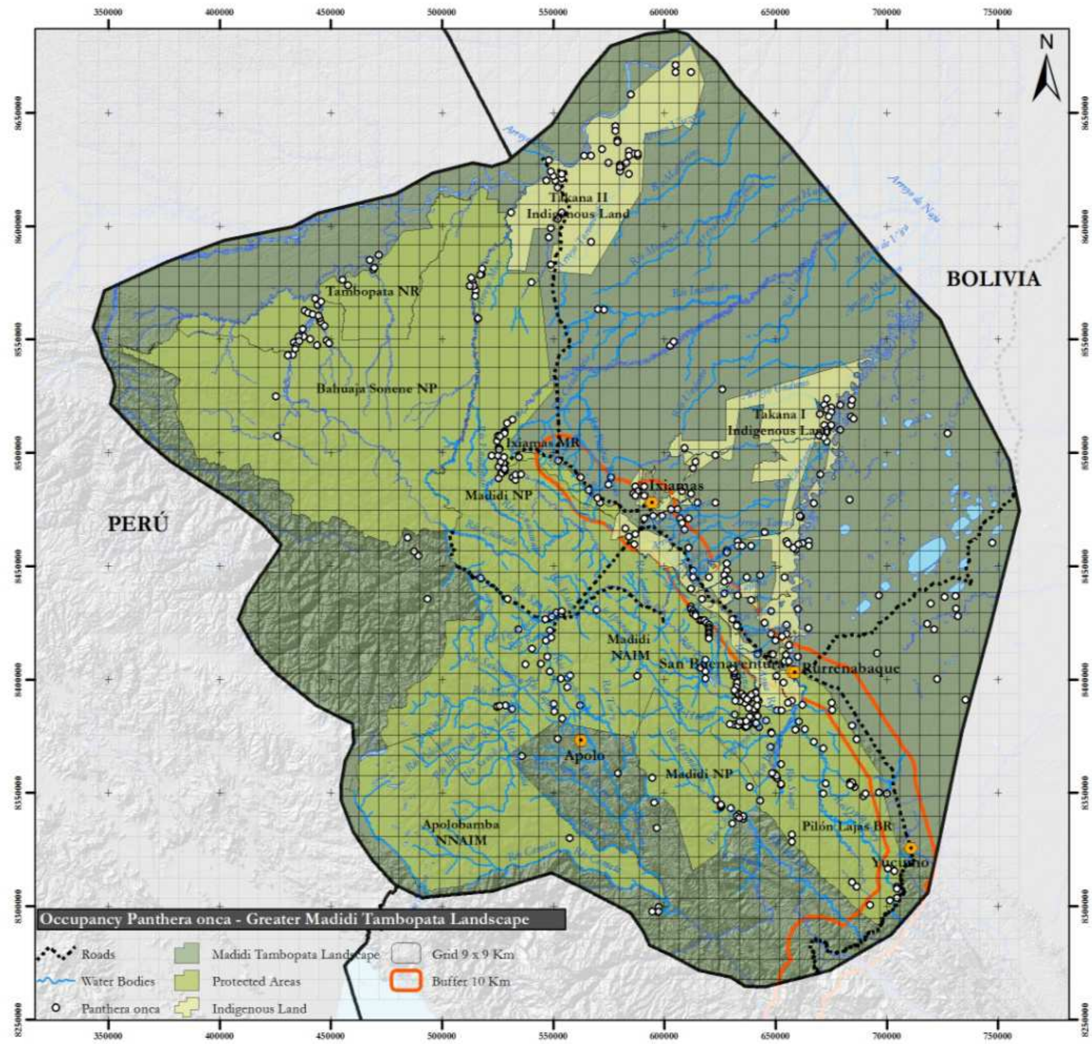

Figure 11. Bolivian portion of Greater Madidi-Tambopata Landscape with 81 km^2 Occupancy Analysis Cell Design for Jaguar

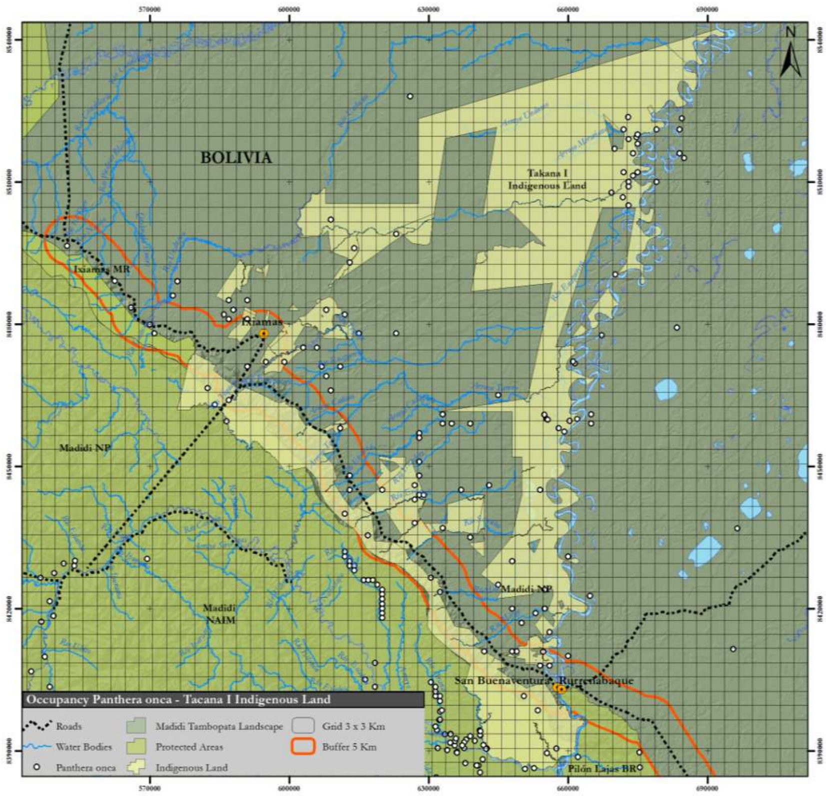

Figure 12. Tacana Indigenous Territory (TCO) with 9 km^2 Occupancy Analysis Cell design for Vulnerable Wildlife including Jaguar

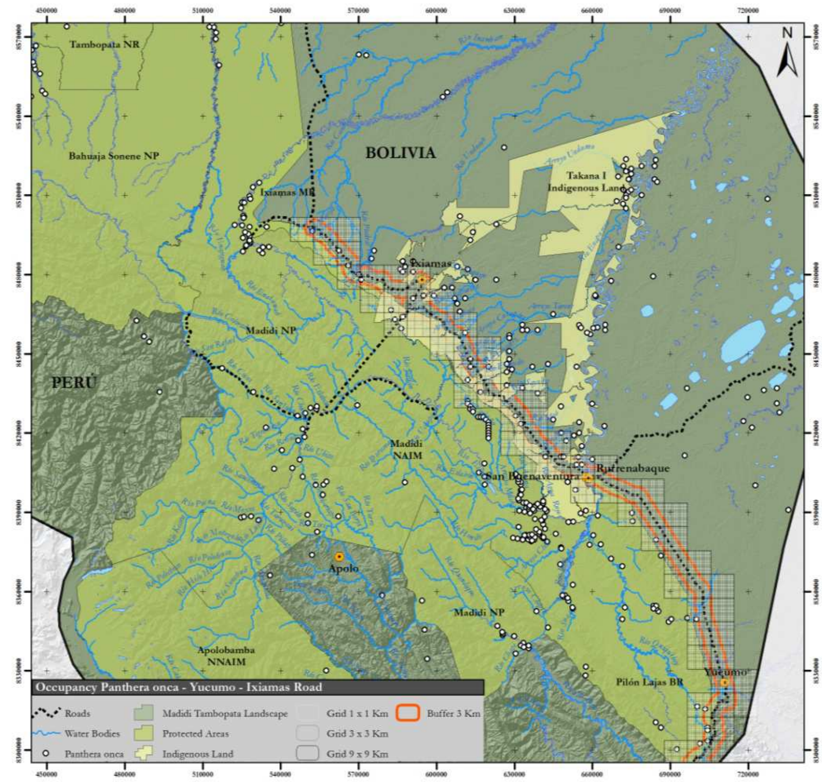

Figure 13. San Buenaventura-Ixiamas Road with 1 km^2 Occupancy Analysis Cell design for Vulnerable Wildlife

In light of these three monitoring priorities for jaguars we propose the following design for the grain of the occupancy studies:

1) At the landscape scale we will use occupancy analysis cells of 9 x 9 km or 81 km2 that responds well to jaguar biology and specifically ranging data in the region. Figure 11 demonstrates this design. This same design also responds to the biology of four of the remaining six landscape species: Andean bear (*Tremarctos ornatus*), Andean condor (*Vultur gryphus*), maned wolf (*Chrysocyon brachyurus*) and military macaw (*Ara militaris*), but is far too broad for vicuna (*Vicugna vicugna*) and for the aquatic giant otter (*Pteronura brasiliensis*) occupancy would be a more linear design along Amazonian streams, rivers and lagoons. The jaguar design would also be relevant for other wide-ranging species in the lowland landscape such as the white-lipped peccary (*Tayassu pecari*).

2) At the Tacana TCO we will use a finer scale occupancy analysis cells of 3 x 3 km or 9 km^2 (Figure 12) that will allow us to include other vulnerable wildlife species in the indigenous territory occupancy analysis such as lowland tapir (*Tapirus terrestris*), collared peccary (*Pecari tajacu*) and spider monkeys (*Ateles chamek*). The 9 km^2 cells of this analysis will be nested within the 81 km^2 cells of the landscape scale analysis.

3) Finally, at the scale of the San Buenaventura-Iximas road we will use 1 x 1 km or 1 km^2 cells (Figure 13) allowing us to include less wide ranging species of wildlife such as red brocket deer (*Mazama americana*), paca (*Cuniculus paca*) and howler monkeys (*Alouatta sara*). Again, these 1 km^2 cells will be nested within the 9 km^2 cells of the above analysis.

HOW MANY OCCUPANCY ANALYSIS CELLS REQUIRE DATA FOR A ROBUST RESULT?

A key issue at the New York workshop was: what % of occupancy analysis cells requires data in an occupancy analysis at a landscape scale? And linked to that, how must the sampled cells be distributed across the landscape? Clearly in most cases we cannot hope to sample all occupancy analysis cells in a given landscape or area of study, although if this is possible it is often the best solution. One alternative approach is simply a systematic random checkerboard pattern to identify sampling cells.

Experts recommended that by quantifying a series of covariates for each analysis cell, and stratifying sampling such that each type of analysis cell has a meaningful number of cells with data, the total number of cells for which data is required can be dramatically reduced. Here it is important to gather as much field data as possible to correctly identify potential covariates on occupancy so as to get the scale and design correct.

In the case of the Tacana TCO and the San Buenaventura-Ixiamas road studies for jaguar proposed above there are three management categories: Tacana indigenous territory, private land including campesino communities, and national park. If a grid cell is a mixed pixel then this can be controlled this by weighting the cell by the proportion of each target management regime. Equal effort in each management regime would be ideal but this is not essential to compare occupancy within each management regime. To say something about the influence of management regime on jaguars we only need to use where we have detection data and it will not be necessary to extrapolate across the landscape. We will also recognize and control for heterogeneity in each management regime by identifying a number of potential covariates, for example, habitat type (foothill forest, floodplain forest, lowland savanna), proximity to road, proximity to villages, proximity to towns, water-stream density, travel cost surface, land-use zoning, more or less patrolling in the park, and perhaps most critically prey abundance, particularly white-lipped peccary abundance. This may require us to develop a two species occupancy model: jaguar and white-lipped peccary.

AT WHAT GRAIN SHOULD THE DATA COLLECTION & EFFORT TAKE PLACE?

At the very least a data sampling regime has to be designed at the grain of the occupancy analysis. In the case of the nested design described above, all data on wildlife presence will be collected with either a GPS and/or assigned to a 1 km^2 grain. Effort for park guard and/or community interview data is important to calculate (as described above) and is easily calculable for line transect and camera trap data. Opportunistic observational data is more problematic to contextualize with effort.

For the three designs described above we will first systematize interview data. Then we will look for wildlife, including tracks and sign, in cells where folks have said they have seen jaguar and where they have not to provide better geographic coverage for sampled cells and to help with false positive. Specific monitoring efforts should be undertaken in areas where information is scarce.

Care needs to be taken for the selection of the best detection methods in cells where direct sampling will take place, especially if the monitoring concerns multiple species. For example, the selection of one method, for example camera traps, might be placed in one way for tigers and other locations for tiger prey because they are mutually exclusive.

HOW OFTEN SHOULD WE SAMPLE AND HOW LONG CAN THE SAMPLING PERIOD BE?

Is it an acceptable approach to define sampling periods as every 4 years given that in most situations we would not expect to be able to detect change on an annual or biannual basis. If so can we pool data from 4 years of effort as data set one and then compare with a similar pooled data set from the subsequent 4 years? The recommendation from the experts was that verification surveys should be done soon after interview data were collected. However, this would depend on the question and how quickly we would expect to see change. This issue is not fully resolved. We propose to pool data from interviews and park guards at a landscape scale from each 4-year period. For the two finer scale analyses we propose carrying out all field work including interviews in a one year period, which is realistic, and responds better to rates of change and population closure for wildlife species.

PROPOSED MONITORING APPROACH FOR JAGUARS GREATER MADIDI-TAMBOPATA LANDSCAPE & LOCAL PARTNER BUY IN

At a landscape scale, the five national protected areas in Bolivia and Peru (Apolobamba, Madidi, Pilon Lajas in Bolivia and Bahuaja Sonene and Tambopata in Peru) are already implementing data collection on ten priority species because the visual maps of occupancy using multiple data sources provide readily understandable decision-making tools independent of their statistical robustness. Nevertheless, we would like to feel more comfortable spending time and effort on monitoring such that we can say something quantitative about our wildlife targets.

In short, and considering the details already provided above, we propose occupancy-based monitoring at the landscape scale and for individual protected areas or other management units calculated every 4 years using multiple data sources and data pooled over the 4-year period. This would be complimented by population abundance monitoring at a small number of strategically located sites.

The occupancy monitoring systems that we propose for human activities and wide-ranging wildlife species is based on three types of data:

1) Presence-absence/occupancy data for wildlife species and threats analyzed every 4 years using a 81 km^2 grid system and derived from the following sources:
   i) Interviews with local communities,
   ii) Interviews and monitoring data from park guards,
   iii) Interviews and monitoring data from ecotourism guides and other community-based natural resource management initiatives,
   iv) Monitoring data from indigenous hunting and fishing management initiatives,
   v) Directed research to verify interview-based information and gather data in geographic holes in the interview data, including some areas where no human activities exist.

2) Information on the distribution of human activities across the landscape every 3 to 5 years derived from the following sources:
   i) Interviews and monitoring data from park guards,
   ii) Interviews and monitoring data from ecotourism guides and other community-based natural resource management initiatives,
   iii) Monitoring data from indigenous hunting and fishing management initiatives,
   iv) Directed research to verify interview-based information and gather data in geographic holes in the interview data,
   v) Updated GIS of all human activities derived from multiple sources including government data, non-governmental organization data, community mapping exercises and satellite image interpretation.

3) Complimentary targeted research on wildlife abundance using a variety of established methodologies dependent on the species:
   i) In areas where changes in abundance might be expected according to the human landscape model,
   ii) In areas where changes are not expected according to the human landscape model.

Obviously there is a significant difference between gathering data from interviews with local communities about species and gathering data from the same sources about threats to biodiversity. We still need to consider this difference in the design and statistical analyses for the proposed system.

By drawing together data from a variety of sources this process will also facilitate the interaction and collaboration of a variety of actors (protected areas, indigenous territories, community natural resource initiatives, and others) and thereby move towards the institutionalization of landscape-scale monitoring for species and human activities that require a landscape-scale analysis.

REFERENCES

Coppolillo, P., H. Gomez, F. Maisels, R. Wallace. 2004. Selection criteria for suites of landscape species as a basis for site-based conservation. Biological Conservation 115:419-430.

Didier, K.A., M.J. Glennon, A. Novaro, E.W. Sanderson, S. Strindberg, S. Walker, S. Di Martino. 2009. The Landscape Species Approach: spatially-explicit conservation planning applied in the Adirondacks, USA, and San Guillermo-Laguna Brava, Argentina, landscapes. Oryx 43:476-487.

Forrest, J.L., E.W. Sanderson, R. Wallace, T.M. Siles, L.H. Gómez, P. Coppolillo. 2008. Patterns of land cover change in and around Madidi National Park, Bolivia. Biotropica 40:285–294.

Karanth, K.U., J.D. Nichols. 2010. Non-invasive survey methods for assessing tiger populations. In: Tigers of the world: science, politics and conservation of *Panthera tigris* R.L. Tilson & P.J. Nyhus (Eds.). Elsevier, New York, USA.

Sanderson, E.W., K.H. Redford, A. Vedder, P.B. Coppolillo, S.E. Ward. 2002. A conceptual model for conservation planning based on landscape species requirements. Landscape and Urban Planning 58:41-56.

Stokes E.J., S. Strindberg, P.C. Bakabana, P.W. Elkan, F.C. Iyenguet, B. Madzoké, G. Aimé, F. Malanda, B.S. Mowawa, C. Moukoumbou, F.K. Ouakabadio, H.J. Rainey. 2010. Monitoring great ape and elephant abundance at large spatial scales: measuring effectiveness of a conservation landscape. PLoS ONE 5: e10294. doi: 10.1371/journal.pone.0010294