Snow Leopard Conservation Grant
Snow Leopard Network

Final Report for 2010 Project

A Preliminary Investigation of Alpine Conservation Status and Its Implication on Snow Leopard Conservation in Wolong Nature Reserve, Sichuan, China
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Is the Conservation of Giant Pandas Further Endangering Snow Leopards

14 February 2011

I. Executive Summary:

Wolong Nature Reserve, China is located in the transition zone between Sichuan Basin and Tibetan Plateau. As part of the Southwestern China Mountains global biodiversity hotspot, the reserve is home for thousands of plant species and hundreds of mammal and avian species. While the reserve is globally known for hosting the largest wild and in-captive populations of giant pandas in its forests, its alpine region, covering about half of its 2000 km^2 territory and providing habitats for endangered species, such as snow leopard, received little attention and protection in the past. The main goal of this study is to understand the general conservation status of snow leopard, their prey and their alpine habitat at this eastern-most corner of their distribution range.

To achieve the goal an interdisciplinary research was conducted. First, remote sensing imagery of the study area was obtained and used to generate a reserve-wide land cover map with six classes – forest, shrub, grass, rock, snow and others. It is estimated that there exists over 500 km^2 of alpine and sub-alpine meadows, providing a large food source for blue sheep, snow leopards' main prey species in this area.

To understand the distribution and habitat needs of blue sheep and snow leopard, field surveys were conducted in 2010. Over 100 presence locations of blue sheep were confirmed in three selected areas of the reserve. These blue sheep occurrence data were then combined with biophysical characteristics and land cover data of the study area, both obtained from remote sensing imageries, and then fed into maximum entropy modeling framework (MaxEnt), a state-of-art environmental niche modeling tool. A final model with five variables was used to predict blue sheep habitat suitability across the reserve with good accuracy. The model shows that at landscape scale, blue sheep prefer areas with medium to high grass cover, medium terrain ruggedness and steepness and high shrub cover, which may be the result of a balance among food availability, locomotion difficulty across rugged terrain and escaping capacity from predators.

Combining modeling results with interview data on local stakeholders, the spatial distribution and population sizes of blue sheep were assessed. Some 2000-4000 blue sheep were estimated to live across the study area, distributing in and around multiple pasture land where local people raise their alpine livestock, mostly yaks. An apparent overlap was observed when yak population data were stacked with blue sheep habitat and distribution maps. Further interviews with herders unveiled a sharp increase of alpine livestock population from 3000 in mid-1990s to over 6400 in mid-2000s and then dropped to around 5400 in 2010. Over-grazing, herbal medicinal plant collection and poaching were believed to be the main anthropogenic threats to alpine wildlife habitat and population and the root causes behind include the lack of regulation and management on alpine ecosystem by the reserve and local households' lack of alternative income sources. The reserve's

long-term focus on panda and forest conservation seems to have resulted in a negligence of the problems in its alpine territory.

Snow leopard signs survey and camera trapping were also conducted in the reserve. About a dozen signs of large carnivores were found and 13 photos of snow leopard were obtained. Through this pilot study the feasibility of surveying and trapping snow leopard in this extremely high-relief topography was confirmed. Experience and lessons learned from this could be greatly helpful for future attempts.

This type of study is very useful at the early stage of endangered species research and conservation, and can provide critical information needed for timely conservation actions and more comprehensive and thorough research efforts. Specifically, findings from this preliminary study have well established a basic understanding of the conservation status and issues in the alpine regions of Wolong Nature Reserve, where snow leopard distribution is confirmed in multiple areas. This region has the potential to support the proliferation of several thousand blue sheep, which could be enough to sustain the living of a viable snow leopard population, given the current human-wildlife conflict issues being soon actively tackled and alleviated.

This study also comes at a critical time, when large amount of financial capitals are invested in conservation, restoration and reconstruction in this high-profile nature reserve of China two years after it was struck by a devastating 8.0 magnitude earthquake. The results of this study have been shared with the reserve's managers at various levels, and the hope is that we can start to address some of the identified threats to the reserve's snow leopard, their prey and habitat before they become more severe.

II. Objectives:

This preliminary study was to investigate the conservation status of snow leopard, their prey (primarily blue sheep in the study area) and habitat in Wolong Nature Reserve of China at the eastern border of the snow leopard's distribution range, with the following original objectives –

1. To map the major land cover types above the forest line;
2. To survey snow leopards and blue sheep signs in Wolong and construct habitat suitability map for blue sheep and snow leopard in Wolong;
3. To identify potential capture-mark-recapture camera trapping sites and test the camera trapping methodology for snow leopard abundance estimation in Wolong;
4. To map and reconstruct the recent history of pasturing activities in alpine meadows of Wolong;
5. To investigate the income structure dynamics of local herder and non-herder households and their attitudes toward snow leopard and alpine mammal conservation;
6. To build scenarios on the potential human-snow leopard conflicts in the near future to inform conservation policy design process.

As the first attempt to understand the conservation status of snow leopard, their prey base and habitat in Sichuan province of China, the main goal of this study is to grasp the big picture of the past, present and future condition of snow leopard prey, habitat and their potential threats in this reserve, rather than to collect the detailed snow leopard biological and ecological information. This is a necessary and important step toward mapping snow leopard habitat and distribution and assessing their population status and threats, based on which sound conservation policies may be made.

III. Methods:

Study area

The 2,000-km2 Wolong Nature Reserve in Sichuan, China (Fig. 1) is located along the eastern border of Tibetan plateau and inside one of the world's biodiversity hotspot areas. Extending from 1150 m to 6250 m in elevation, the reserve supports a variety of vegetation types and habitats where over 100 mammal species, around 300 bird species and more than 4,000 higher plant species can be found [1]. Permanent human settlements in Wolong were established by Tibetan pastoralists in late 17th century [2]. It was not until the 20th century human population in Wolong started to climb and reached over 5000 in early 2000s with more than 75% being Tibetan or Qiang minorities [3]. Pasturing was part of the tradition of the local community, but was mostly abandoned during the Cultural Revolution period (1966-1976) of China. All current herder households started herding after 1980.

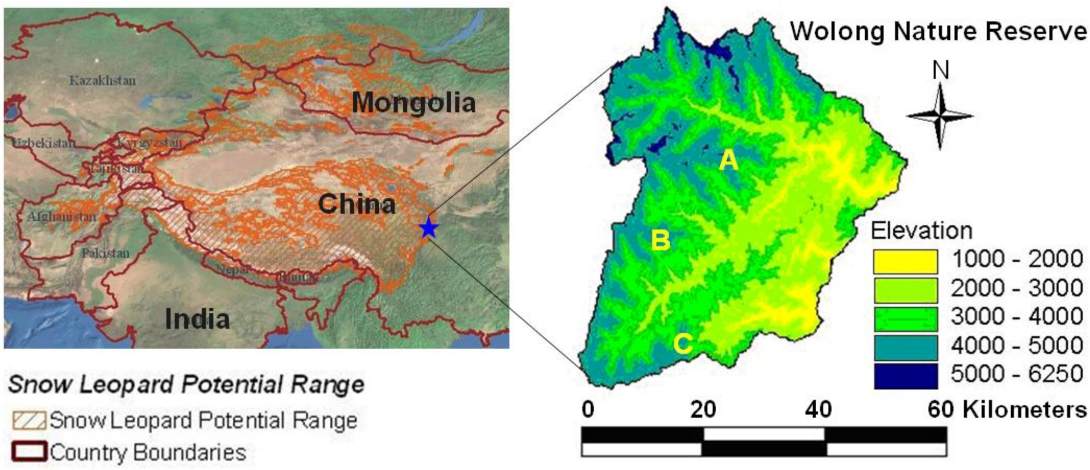


Fig. 1 Remaining snow leopard habitat (left, adapted from Snow Leopard Survival Strategy [4]) and Wolong Nature Reserve (right, showing elevation gradient and recently confirmed snow leopard evidence sites).

Hosting the largest wild giant pandas population (ca. 150) in its 900 km2 of forests, almost all past scientific research and conservation efforts in Wolong have been focused on this world-known flagship species and national treasure of China, and also some other forest dwellers, such as snob-nosed monkey, takin and red panda. With almost half of its territory above tree line (~3,600 m), Wolong also hosts a large area of alpine land with comparable size to its forests. This alpine region provides important habitats for a distinct group of species, including snow leopards, wolves, Asian wild dogs, red foxes, Tibetan foxes, blue sheep and marmots [5], but has attracted little attention in the reserve's almost half a century of history.

Snow leopard distribution and status information in Sichuan province of China used to be "virtually unknown" [6]. Recent findings of snow leopard fecal signs (area A in Fig. 1, in July 2007), smuggled fur originated from Wolong (area B in Fig. 1, Personal communication with Hemin Zhang, Director of Wolong Nature Reserve, in July 2008) and camera trapping photographs (area C in Fig. 1, Fig. 2, in March and July 2009) and consistent findings of large herds of blue sheep (up to ~400) across its rocky alpine areas (Personal communication with herders) indicated that this region could be supporting a small but possibly viable snow leopard population at the very eastern boundary of their broad Himalaya range. Pasturing and poaching by both locals and outsiders from adjacent counties are known existing disturbances and threats to the snow leopards and other wildlife's habitat and population in this alpine ecosystem, but their intensity, extent, and consequences are not clear.

Past policies in the reserve have been focused on forest ecosystem and panda habitat conservation. This includes two recent national forest conservation programs, implemented in the reserve since early 2000s, namely Natural Forest Conservation Program (NFCP, a logging ban) and Grain-to-Green Program (GTGP, reclaiming sloped cropland to tree plantations) [7] respectively. These had led to some immediate positive socioeconomic consequences and an overall forest cover increase of about 4% [8]. On May 12th of 2008, one of the most devastating earthquakes in Chinese history struck Wolong with its epicenter just outside of the reserve and seriously damaged its forests and panda habitat. Analyses based on remote sensing imageries showed ca. 4.5% of immediate (by June 2008) forest damage [8]. Ecological and economic restoration is critical in the ongoing post-earthquake reconstruction process, but again the focus is on forests and panda habitats. A new round of household relocation from the remote mountainous villages to river and road side is being carried out, accompanied by a large amount of cropland reclamation into bamboo plantation and permanent construction.

Alpine land cover mapping

Landsat Enhanced Thematic Mapper image acquired on June 13, 2001 (Path 130, Rows 38–39 WRS-2) was obtained. A land cover map was generated from the image via an unsupervised classification algorithm with combined functionalities of the ISO Cluster and Maximum Likelihood Classification tools in ArcGIS 10 [9]. Twenty spectral classes were created. I then applied a post-classification sorting method in which these spectral classes were merged into six information classes (snow, rock, grass, shrub, forest and others) through a combination of visual interpretation and secondary information from published books and maps.

Accuracy assessment of the map was performed using ground truth points obtained in prior studies and this project. The locations of these points were determined using GPS. Overall land cover mapping accuracy is above 80%. Part of the disagreement between the image classification and ground truth data obtained in the field could be attributable to changes in land cover between remotely sensed data collection dates (2001) and field data collection period (2007-2010). Due to the cloudy weather condition in this high-relief mountainous area, it's hard to find cloud-free remote sensing images. Since neither the forest conservation programs nor the 2008 earthquake directly caused significant changes on meadow, shrub, rocky and snowy areas above the tree line, this discrepancy in image date and ground truth data collection time may not lead to significant error in alpine land cover mapping.

Blue sheep habitat modeling

The maximum entropy modeling framework (MaxEnt) was employed to model blue sheep habitat suitability in alpine Wolong. Specifically designed to make predictions based on incomplete information [10], Maxent is one of the best methods for mapping species distribution [11]. The algorithm contrasts the environmental conditions (characterized in a multi-dimensional hyper-volume space defined by multiple environmental variables) in species presence localities vs. the conditions in the background (i.e., the entire study area). The species–environment relationship is then established through simultaneously matching the contrasts and approaching a maximum entropy distribution (i.e., maximum uniform distribution) [10], which is used to estimate the probability of species occurrence across the study area given the spatial patterns of the environmental variables [10, 12]. Besides its good performance on mapping species distribution [11], Maxent also offers several other advantages over tradition modeling tools, such as logistic regression. First, it uses presence-only, rather than presence/absence data, and can help avoid the potential biases caused by uncertain or false absence data. Secondly, like other machine learning methods (e.g., neural networks), Maxent can capture complex and non-linear species–environment relationships, even with noise in input data [10, 11] (from this perspective, Maxent is superior to BioMapper, which is an Ecological Niche Factorial Analysis tool and was originally proposed to be used for blue sheep habitat modeling). Finally its continuous output values, i.e., species presence probabilities, are informative in terms of understanding the detailed spatial heterogeneity of the species habitat than binary outputs (i.e., habitat/non-habitat).

The software Maxent (version 3.3.3, http://www.cs.princeton.edu/~schapire/maxent/, [10]) was used to generate blue sheep habitat suitability models. During field survey in Jan. and Feb. of 2010, 110 signs of blue sheep were identified in three different areas. To avoid over-representation of the field presence locations I further screened the points to select only points at least 300 meters (10 pixels, this distance is determined arbitrarily) away from each other and ended up with a sample of 60 points. Another 19 locations were identified from the reserve's monitoring records in the past two years to increase the spatial coverage of sample as much as possible. Thus the final sample size of presence locations is 79. A total of 10,000 pixels were randomly selected from the study area as background data, and 13 variables were included in an initial model (Table 1), including seven pixel-level variables and six landscape-scale variables. For the landscape-scale variables, two background scales were chosen: 1km x 1km and 2km x 2km because they approximate the core area size and home range size of blue sheep in other regions of China [13].

Table 1. List of variables tested in MaxEnt to model blue sheep habitat suitability in Wolong

Variable ID	Variable details	Unit
demutm	Elevation of each pixel re-sampled from ASTER Global Digital Elevation Map (GDEM, http://asterweb.jpl.nasa.gov/gdem.asp)	m
slope	Slope of each pixel derived from GDEM	degree
cvele_33	Coefficient of variation of elevation in a 1x1 km background area around the centroid pixel	-
cvele_65	Coefficient of variation of elevation in a 2x2 km background area around the centroid pixel	-
grass33	Grass cover in 1x1 km background area around the centroid pixel	%
shrub33	Shrub cover in 1x1 km background area around the centroid pixel	%
rock33	Rock cover in 1x1 km background area around the centroid pixel	%
forest33	Forest cover in 1x1 km background area around the centroid pixel	%
lc_wnr	Pixel-level land cover type (other, snow, rock, grass, shrub, forest)	0 - 5
grass	Dummy variable - whether the land cover of the pixel is grass	1, 0
forest	Dummy variable - whether the land cover of the pixel is forest	1, 0
shrub	Dummy variable - whether the land cover of the pixel is shrub	1, 0
rock	Dummy variable - whether the land cover of the pixel is rock	1, 0

The model was run a 10-fold cross-validation process. Durring each of the 10 runs (replicates) 90% of presence data were randomly selected, with the remaining 10% used for validation. The predicted blue sheep presence probabilities over the 10 replicates were averaged for each pixel to generate the final blue sheep habitat probability map. Receiver operating characteristic (ROC) curve was generated and the area under the curve (AUC) value was calculated. Generally the higher the AUC value, the more different the model output is from random. Relative contribution and importance of each variable in the model was also generated (see details of Maxent output at http://www.cs.princeton.edu/~schapire/maxent/tutorial/tutorial.doc). Through excluding variables with extremely low importance, a final model with five variables were generated and further interpreted.

Snow leopard habitat suitability modeling was originally planned but could not be carried out due to the limited presence information founded in the field survey (a total of 11 signs of large carnivores were found in area C (Figure 1), with 8 believed to be snow leopard signs).

Snow leopard camera trapping

Six camera trapping systems were set up in area C (Figure 1) following standard methods suggested in Jackson et al. [14], except that only one camera was used in each trap. Due to heavy snowfall in winter 209-2010, two trapping occasions of 5-6 weeks each were carried out between Jan. and May of 2010 instead of four occasions of two weeks each as planned. One system failed to work in each trapping season. Three systems ran out of batteries in the unexpected coldness before the end of the trapping season.

Social surveys with local stakeholders

Information on general history of yak herding in the reserve was obtained from the reserve's socioeconomic development department and an in-depth informal interview was conducted with the related personnel. Two focus groups were conducted with local participants and reserve managers to further understand the recent pasturing practices of the locals and the current alpine monitoring efforts.

Twenty-two herder households in the Wolong township were then interviewed. The main herder in the household was presented with a 1:50,000 topographic and vegetation map and was asked to locate their past and current pasturing areas, to report the approximate quantity of their livestock (mainly yaks) in mid-late 1990s, mid-2000s and present time, and also their knowledge about other herders' (including those from outside the reserve) livestock population sharing the same or nearby pastureland with them. It was planned to ask the herders to draw exclusive boundaries of their pasture land on the map, but none could draw one accurately, because the nature of the vagueness of the pasture boundary and the fact that most large pasture patches were shared by more than one herder families. Therefore, only rough locations of the pasture patches were identified.

General livestock distribution and population size were then estimated for the three time periods across the Wolong township and in two of the largest pasture patches. The interviewees were also asked about their observations of blue sheep around their pastures to estimate the population sizes of blue sheep in different alpine areas of the reserve. Through overlaying the current livestock distribution and density information with the blue sheep habitat suitability map, areas with highlighted livestock-wildlife interactions were identified. Through overlaying the herders' estimate of blue sheep population with the suitability map, areas with potential disturbances (low blue sheep population size/density in good habitat areas) were also identified. The reported numbers of yaks were later confirmed by visiting several pastures during the wildlife surveys.

The herders were also asked about the relative contribution (%) of different income sources in their households' income in the three time periods and questions about their attitude toward the alpine mammals were also asked. Another 30 non-herder households were interviewed about their income structure changes and attitudes toward alpine wildlife.

Mediated group modeling workshops were originally proposed to stimulate the stakeholders to understand the ongoing changes of the human-environment relationship in alpine Wolong, to foresee the potential future scenarios, and to find possible solutions. However, due to unexpected landslide and flooding in Aug. 2010 across the 2008 earthquake regions, the newly constructed road to the reserve was blocked for over two months. I waited in the closest city to the reserve in Aug. 2010 but eventually was not able to get in to carry out the workshops. Instead, informal phone interviews with three herder households, three non-herder households and two reserve managers were conducted in Oct. 2010. Besides discussing with the interviewees about their major concerns about different economic and conservation practices in the alpine regions of the reserve, the following specific questions were asked to the different stakeholders to understand their responses to some hypothetical scenarios.

For herders –

A. What would be your responses if other non-herder members of the community want to herd in your current pasture land?
B. What would you do if the reserve bans pasturing on the alpine meadows, given the fact that it is within the core zone of the reserve?
C. What would you if some other herders start to fence their pastures?

For non-herders –

A. Given that you have extra money to use, would you invest in alpine pasturing even if you know over-grazing is occurring?

For reserve managers –

A. What would be the reserve's response on some herders' fencing activities on the alpine meadows?

IV. Results:

1. Alpine land cover map in Wolong Nature Reserve

Figure 2 shows the land cover map of the reserve classified from the Landsat ETM+ imagery in June 2001. It shall be noticed that the remote sensing image was from summer, when the snow coverage is lowest in a year. The "Other" class (grey in Figure 2) includes a mixture of farmland, tree plantation, temperate shrub and grass land. Based on the map the estimated total area of the alpine and sub-alpine meadow across the reserve is 510 km2 and total sub-alpine shrub land is around 110 km2. These two land cover types were mostly distributed in the reserve from 3400 m and 4500 m and are the exclusive food base of both the yaks and blue sheep. Generally there exists a large vegetated alpine and sub-alpine area that is potential habitat for blue sheep.

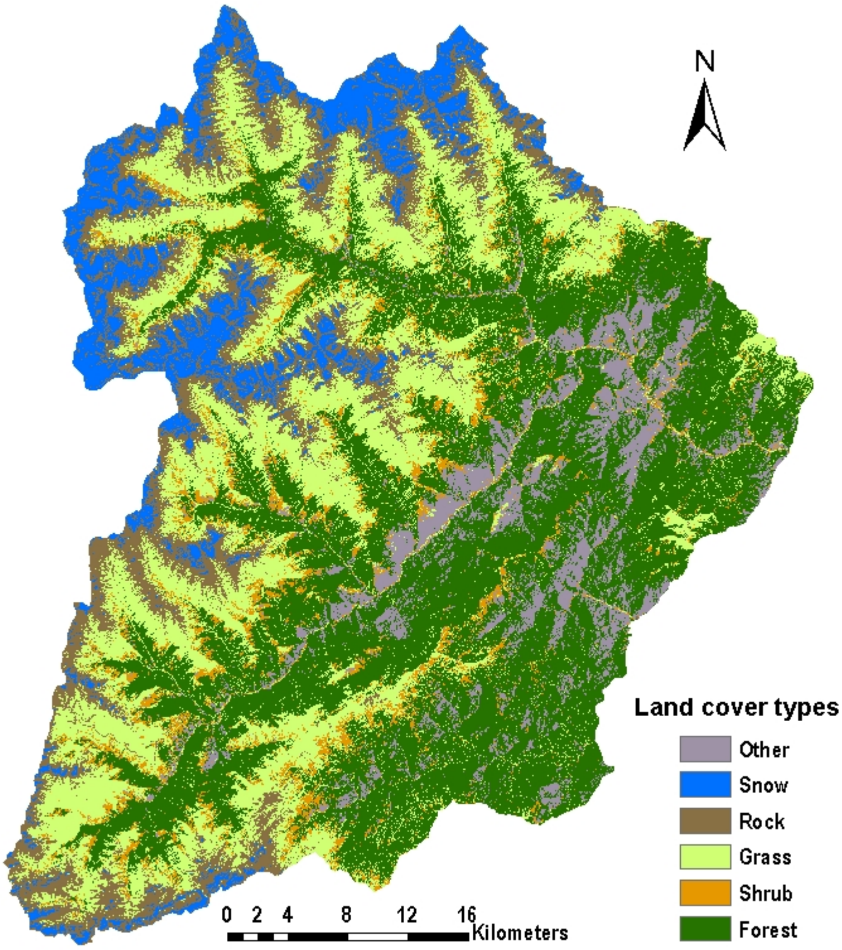


Figure 2. Land cover map of Wolong Nature Reserve classified from Landsat ETM+ image obtained in June 2001.

2. Blue sheep habitat modeling

All tested MaxEnt models perform well as reflected by their areas under the receiver operating characteristic (ROC) curves (AUC). Values for AUC between 0.8 and 0.9 are generally considered good, while AUC values greater than 0.9 are considered excellent. The initial model, with all 13 initial variable used, has the highest AUC value of 0.910. However, as MaxEnt tend to overfit and apparently some of the variables are highly correlated, other combinations of variables were tested and variables with low contribution are eliminated. The final model includes one pixel-level variable (slope) and four landscape-scale variables (grass33, cvele_33, rock33 and shrub33) and has an AUC value of 0.864 (average across ten replicates, with a standard deviation of 0.047) (Figure 3). The blue sheep habitat suitability map generated from the final model was shown in Figure 4.

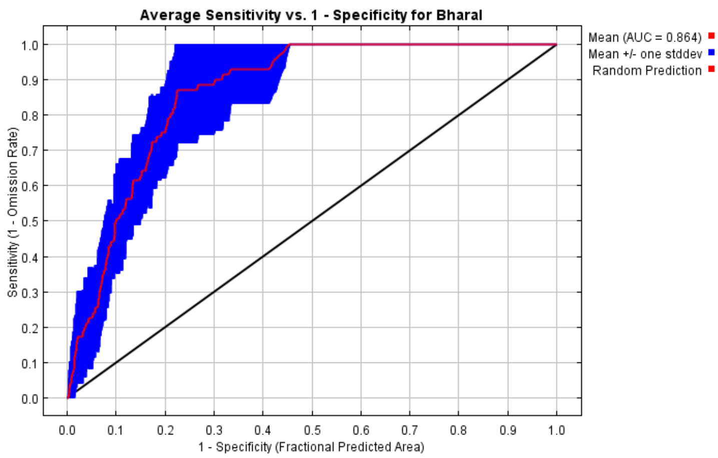
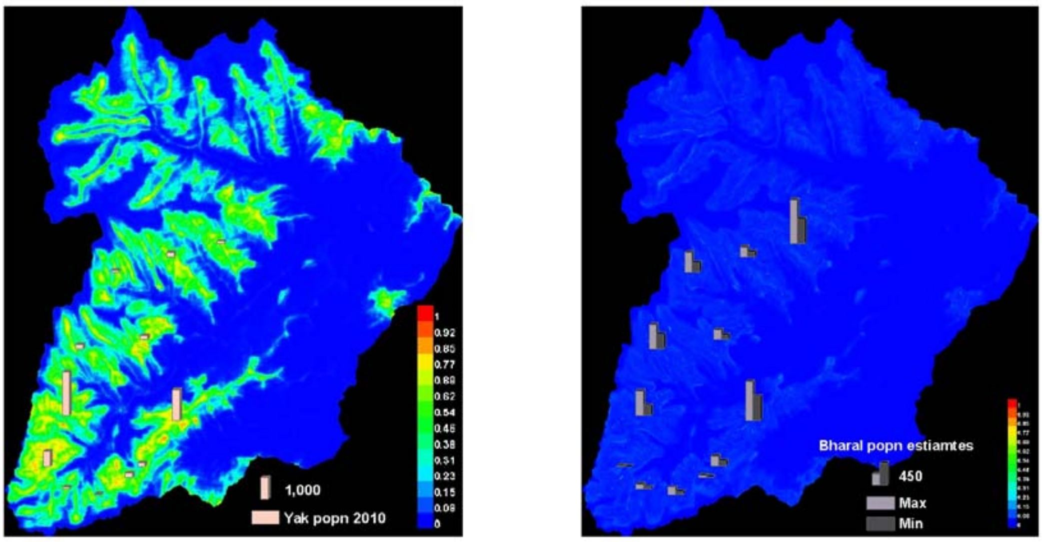


Figure 3. The receiver operating characteristic (ROC) curves of the final model with an AUC value of 0.864.

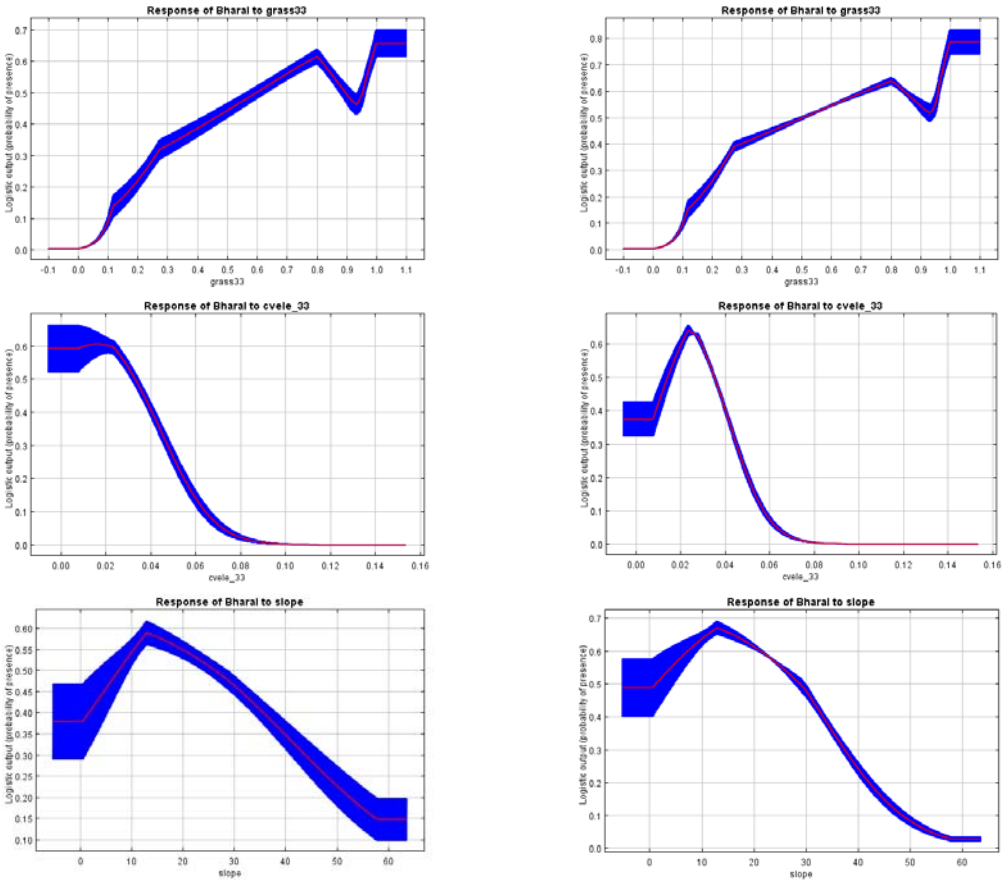


A B

Figure 3. Blue sheep habitat suitability maps – A. average of output habitat suitability maps from the ten model replicates, with reported distribution of yaks in the Wolong township, and B. standard deviation of the ten habitat suitability outputs, with herders' estimates of blue sheep population distribution in the Wolong township.

MaxEnt generates two types of curves to depict how each environmental variable affects the model prediction. The marginal responses curves (Figure 4A) show how the logistic prediction changes as each environmental variable is varied, keeping all other environmental variables at their average sample value. In contrast, curves in Figure 4B represent a different model, namely, a Maxent model created using only the corresponding variable. These plots reflect the dependence of predicted suitability both on the selected variable and on dependencies induced by correlations between the selected variable and other variables. While they show that at landscape scale, blue sheep habitat suitability generally tend to be high in areas with high shrub cover (a food source) and low in areas with really high rock cover (no food), the relationship between suitability prediction and other three variables are not linear. Suitability first increases as grass cover increases and decreases when grass cover is above 0.8. This may be due to competition with yaks in the best continuous grassland. The other two curves (cvele_33 and slope) both show that blue sheep prefer medium terrain ruggedness and avoid extremely flat or steep topography. This might be the result of a trade-off between food availability and escaping capacity across the landscape.

A. Marginal response curves *B. Single variable prediction curves*



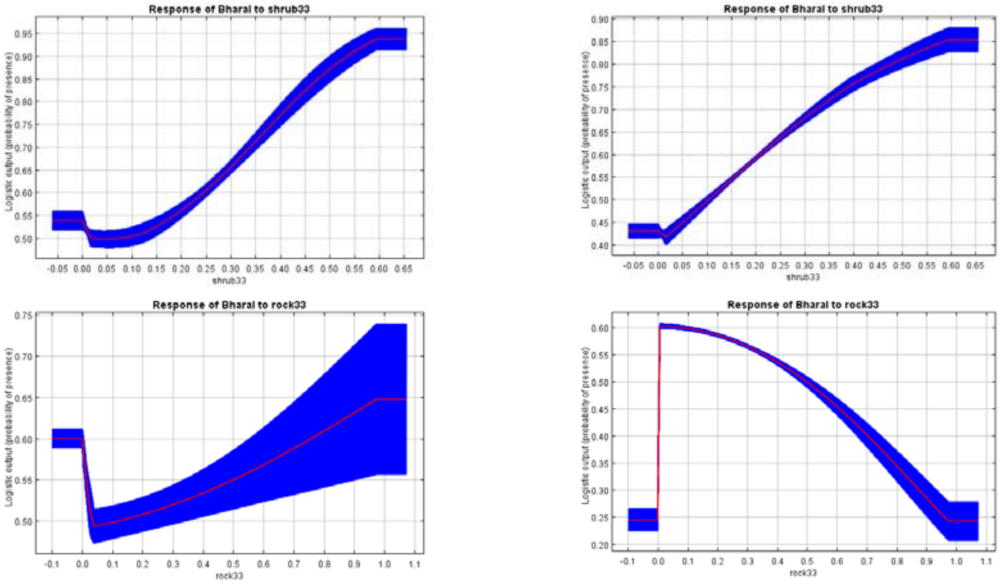


Figure 5. Marginal response curves (A) and single variable prediction curves (B) of each variable used in the final model. Curves in A show the marginal effect of changing exactly one variable, whereas the model may take advantage of sets of variables changing together. The curves show the mean response of the 10 replicate Maxent runs. Curves in B show the relationship between habitat suitability predictions and variables in single variable MaxEnt models.

MaxEnt generates different measurements of the relative contribution of each environmental variable (Table 2). In both measurements, grass cover (main food availability) in a 1km x 1km background landscape (grass33) turned out to be the most important variable. This is meaningful as grass provides the most important food for the blue sheep. The ruggedness of the terrain, as measured by the coefficients of variation of the 1km x 1km background landscape (cvele_33) and slope were second most important. Shrub availability (secondary food availability) and rock cover have limited contribution.

Table 2. Relative contribution of each variable in MaxEnt models.

Variable	Percent contribution	Permutation importance
grass33	58.2	68.4
cvele_33	22.4	22.7
slope	12.8	4.6
shrub33	5.9	2.3
rock33	0.7	1.9

Figure 6 shows the results of the jackknife test of variable importance, using AUC on test data. Again, grass cover and terrain ruggedness turn out to be the top two important variables. Overall, it seems that at landscape scale, blue sheep seems to prefer areas with medium to high grass cover, medium terrain ruggedness and steepness and high shrub cover. This may be the result of a balance among food availability, locomotion difficulty across rugged terrain and escaping capacity.

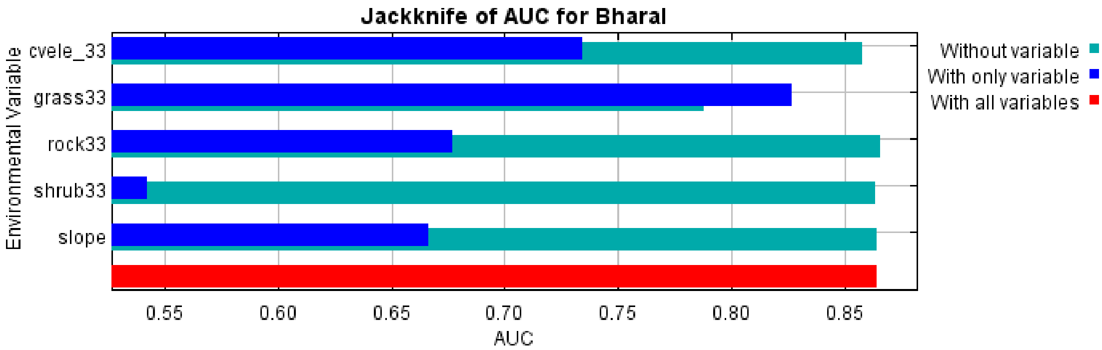


Figure 6. Jackknife test of variable importance, using AUC on test data. The environmental variable with highest gain when used in isolation is grass33, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is grass33, which therefore appears to have the most information that isn't present in the other variables. Values shown are averages over replicate runs.

In summary, using MaxEnt tool I was able to model blue sheep habitat suitability across the reserve with a relative small sample size (79) of blue sheep presence locations and a set of pixel-level and landscape-scale environmental variables that were all generated from remote sensing imageries. The final model with five variables provides a good prediction of habitat suitability across the reserve, while also well explains how blue sheep select habitat at landscape scale.

3. Snow leopard camera trapping

In a total of about 270 camera days, 13 pictures of snow leopard were obtained (see an example in Part VI, Photographs), besides pictures of other wildlife, such as blue sheep, marmot, and stone marten. At least two different individuals can be identified based on the 13 pictures, but these did not meet the minimal needs for snow leopard abundance estimates, neither were they enough for snow leopard habitat modeling.

As a preliminary study, the main purpose was to test the feasibility of carrying out camera trapping in this extremely high-relief topography, and to estimate costs for future research. The results show that it is possible to carry out camera trapping in this reserve, though the overall cost is relatively high. And there remains a couple of concerns –

The selected test area is relatively easy to access than many other potential good snow leopard distributed areas. It takes significant time to set up camera trap systems, downloading pictures from them and exchange batteries and storage media.
The winter coldness is a big challenge on the trapping system, especially the batteries.

If future surveys in other areas were to be carried out across a larger area in the reserve, two, no more than three, survey seasons between Dec. and early May might be feasible. Special batteries with large capacity that can last longer in cold winter shall be prepared too.

4. Recent changes in yak herding in alpine regions of Wolong township

All 22 herders interviewed had their yaks on meadows in the mid-western and southwestern part of the reserve (Figure 2). These are mostly within the territory of Wolong township, one of the three townships that the reserve encompasses. It was reported that a few other households did herd in the northern part of the reserve, but that region is generally easier to access from outside the reserve, as a result it is mostly used by herders from adjacent counties. Thus results reported here reflected information about pasturing in Wolong township of the reserve, where over 70% of the alpine and sub-alpine meadows are located.

Six of the 22 interviewed herder families started pasturing after 2000 and they reported several reasons on why they choose to pursue this income source during the specific time period – 1. the increasing demand and price of yak meat in the outside market; 2. the availability of start-up fund from agriculture after they started to plant cash crop since 1990s; and 3. the availability of extra labors released from farmland and fuelwood collection activities as a result of the implementations of the two forest conservation programs. The third reason was originally hypothesized as the main driving force of the pasturage expansion and herding intensification after 2000, however, most respondents did indicate that the previous two economic reasons were more important in their decision-making. Fourteen of the other 16 households report to increase their yak population for the same economic reasons.

Figure 3A shows the estimation of the current yak distribution across Wolong township. The numbers reflect the total yak population in all the major pasture areas. Most herder households share information with each other, especially for those living in he same village, so that I was able to obtain information about all areas. Currently, over 60% of the yaks were distributed in the two groups, namely Balangshan (~2,000 yaks as of 2010) at the west and Maanqiao (~1,400 yaks as of 2010) at the middle-south. Figure 7 shows the trend of yak population changes across the Wolong township and in the two main areas from 1990s to present time. It was noted that the total yak population doubled from about 3000 in 1990s to about 6400 in mid-2000s and dropped to about 5400 in 2010. This trend is consistent with herders' observations of the increase in adult yak death rates in many areas when they were crowded, possibly over the carrying capacity of the meadow, by mid-2000s. Since then, owners of some large herds started to sell more yaks. Some of the most experienced herders, who started herding before 1990s, indicated that currently crowding and the resulted over-grazing issue still exist in most pasture areas, especially the Maanqiao area, where many of the new herder put their yaks and one new herder even put into several dozens of horses. All respondents indicated that the quality of the meadow had declined significantly since 1990s and all believed that over-grazing was the leading cause.

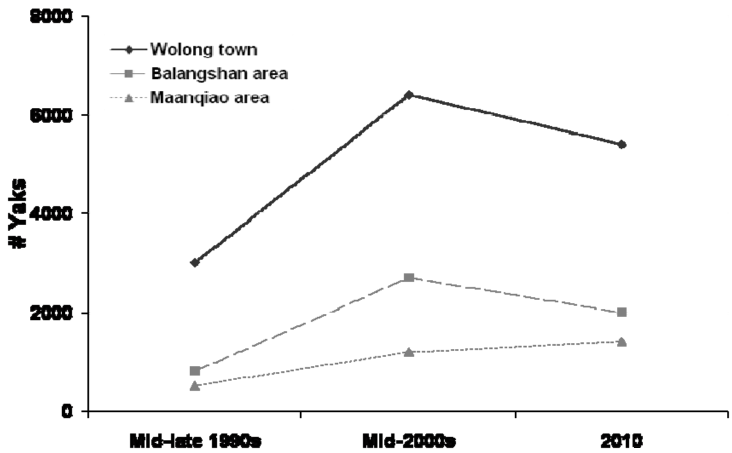


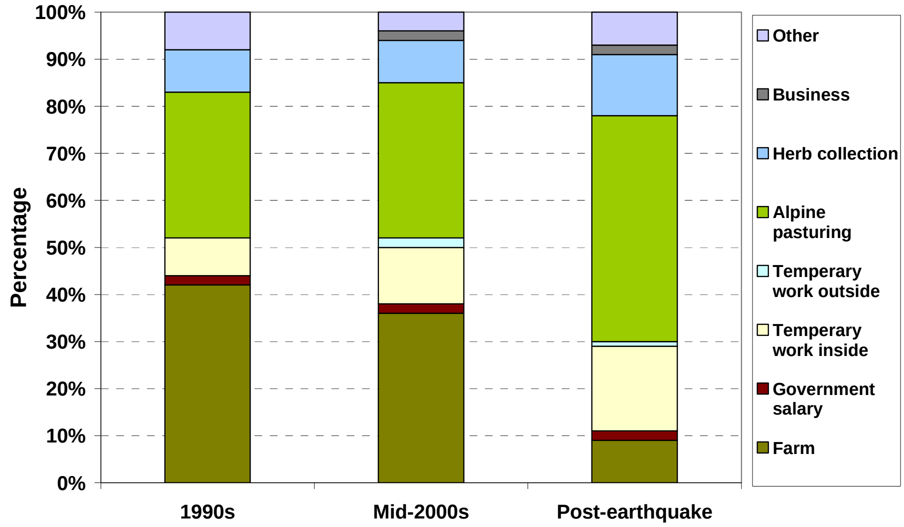
Figure 7. Trend of yak population changes across Wolong township and in Balandshan and Maanqiao areas.

Overall, the sharp increase of yak population in the last 15 years in alpine and sub-alpine Wolong have led to over-grazing in pasture areas across the Wolong township. Although reactions have been made by some herders, it is highly probable that over-grazing and grassland degradation will continue. One root cause of this issue lies in the open-access nature of the meadows, which is legally state-owned but practically not monitored and enforced.

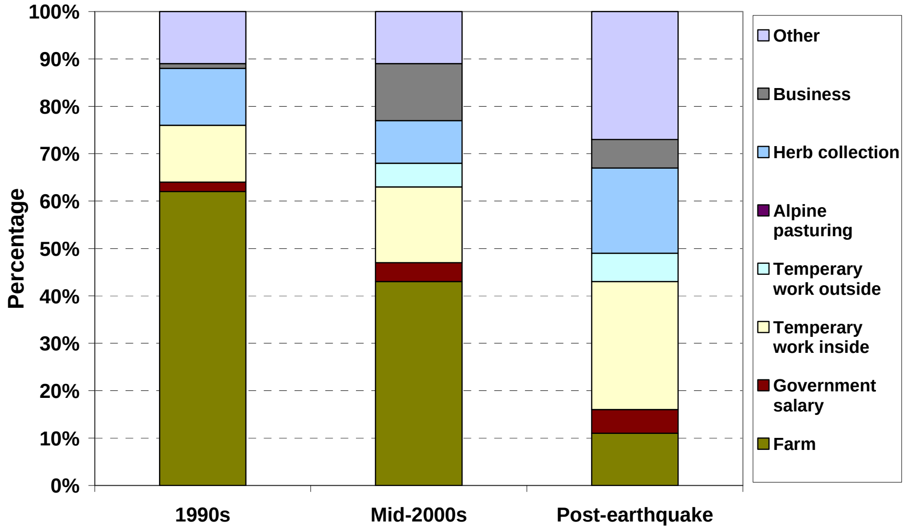
Based on local households' responses the direct contribution of forest and panda habitat conservation policies on recent over-grazing did not stand out as strong as I originally hypothesized. However, by overlaying the yak distribution on top of blue sheep habitat suitability map generated by MaxEnt (Figure 3A), an apparent overlap between yaks and blue sheep can be observed. Generally both species mainly feed on grass on the meadow. Since all alpine and sub-alpine meadow areas are included in the core zone of the reserve to ban human activities, this spatial overlap between yak and blue sheep populations well reflects the negligence of alpine conservation and management in the past.

5. Income structure changes of herder and non-herder households

In both herder and non-herder interviews, self-reported household income structure information at three different time periods were recorded and averaged within each group (Figure 8). While the two groups income structure were relatively similar to each other in 1990s, significant changes happened in mid-2000s, when business income emerged as one of the main income sources of non-herder households. After the earthquake, the only road from inside the reserve to outside was frequently blocked by landslides and mudslides. This severely affected local people ability to sell their agricultural products to the outside market and their agricultural income dropped significantly. Both groups are seeking to maintain their current income sources and increase their income from new sources. Pasturing income is becoming more important for herder household, currently contributing to almost 50% of their total income. Non-herder households' income from herbal medicinal plants collection, which often took place in alpine and sub-alpine meadows, is also increasing. Currently during the earthquake reconstruction period, a large demand of labor exists and provides income to many herder and non-herder households. However, this income source is temporary and will decline sharply after the reconstruction is completed.



A.



B.

Figure 8. Income structure changes of herder households (A) and non-herder-households (B).

Both groups were asked about their expectation and plans about future income sources. While all herder households stated that pasturing income would still remain as one of their main income sources in the near future, only four indicated that they have plan to expand their current yak population through purchasing additional animals from outside. Other herders reported that they tended not to increase their yak population as at the current condition the pasture land might not be able to support more yaks without increasing mortalities. Out of the 30 non-herder households interviewed, nine expressed intentions to obtain future income through alpine pasturing. While the lack of suitable meadow for new yak populations was one major concern of some of the households, the lack of start-up fund was also an obstacle for some others as many used their savings in reconstructing new houses after the earthquake. Therefore, it seems that the total yak population may not increase significantly in the near future, but if the meadow is still left as open-access resource, there are still a considerable number of local households with intention to start pasturing in the alpine areas, once their current financial burden is overcome.

6. Local people's experience and attitude toward alpine mammals

A series of questions were asked during household interviews about different stakeholders' experience and attitude on large alpine wildlife, generally two groups – the blue sheep and the carnivores (e.g. snow leopard, wolf, and Asian wild dog). Generally the herders had more experience observing signs of carnivores than non-herders, but only six herders claimed to have observed live individuals of any large carnivores in the last ten years. Both groups claimed to have observed blue sheep signs and live individuals year around. Some old herders attributed the low density of carnivores to past hunting practices in 1980s and early 1990s, when hunting these "pests" was encouraged by the reserve.

When being asked whether they like, dislike or are indifferent to the existence of blue sheep, snow leopard and wolf around their community, most non-herders chose "like" or "be indifferent" for each species. As of the herders, 12 out of 22 indicated that they dislike wolves, wild dogs or snow leopards, as they perceived that these carnivores preyed on their livestock, especially the yearlings. Almost half (10 out of 22) indicated that they dislike blue sheep, mainly because they thought blue sheep compete with their yaks for food, especially during the food limited winter season. Some even consider this competition directly led to the recent increasing death rate in their yaks. One herder, who is a seasonal mountain guard employed by the conservation stations every year, also showed concern of disease transmission between blue sheep and yaks.

Both groups were also asked how many alpine carnivores and blue sheep they would prefer living nearby their community and pasture land in the next 10 years. The responses are generally consistent to the respondents' attitudes toward the different species in the previous question with the exception of two herders who dislike all of the species but prefer their population to increase in the next ten years. When asked their rationale, both indicated that more wildlife could be good tourism resources, which may bring other income for the local community.

Some additional questions were also asked about the interviewees' knowledge on giant panda and snow leopard's conservation status in China's wildlife conservation act system (e.g. which protection class is snow leopard in) and on the reserve's zoning distribution (e.g. whether they know the concepts of experimental zone, buffer zone and core zone, whether they know the boundaries of each zone in Wolong Nature Reserve and whether they know which zone their pasture land was located in). Surprisingly (or not?), while almost everyone knows that giant panda is a class I protected species in China, only less than 10% of the interviewees in each group correctly stated that snow leopard is also a class I protected species and only one interviewee correctly answered the zoning-related questions. Clearly there are gaps between the reserve's conservation settings and policies and the local people's understanding about them.

The herders were also asked about their estimation of the blue sheep population size around their pasture land and resulted range data in each pasture area were plotted on MaxEnt output of blue sheep habitat suitability (Figure 3B). Summing up the herders estimation based on their year around observations, there exist between 2000 and 4000 blue sheep individuals across the Wolong township meadows. While the distribution of the reported blue sheep distribution mostly falls on suitable habitat (Figure 3B), very few (>20) blue sheep were reported in one large meadow at the southwestern corner of the reserve, namely Daping. About seven hundred yaks were reported to roam around the area, and the density is not as high as in the two largest pasture land, Balangshan and Maanqiao, as reported in previous sections. Several herders indicated that due to its closeness to the main road and the western entrance of the reserve the area suffered a high exposure to poachers from outside the reserve. This issue has been widely known for years, but so far not yet been addressed by the reserve.

Overall local stakeholders had a variety of experience with alpine wildlife species and a considerable percentage of the herders showed negative attitudes and acceptance capacity toward certain species, including snow leopard, mainly due to the perceived negative effects on livestock. It is still unclear to what extent these negative attitudes have been turned into actions and how serious the impact on the wildlife population is. One herder told me that he used to put snares around their pastures for blue sheep, and actually killed a snow leopard in early 2000s. Considering that the low density of snow leopards and other large carnivores in the reserve, any single loss could lead to serious negative impacts on their local population.

7. Concerns. issues and future scenarios

The major concern of the herders during the phone interviews are about outsiders' activities inside the reserve, including herding, herbal medicinal plant collection and poaching. When being asked about their responses toward non-herders' intention to participate in pasturing, two herders indicated that they would not oppose to such activities as no one owns the meadow, but if too many livestock use the same area, they would consider selling more of their yaks. The other herder indicated that he would oppose if the “intruder” comes from other villages. About pasture fencing, the herders pointed out that it could only be done in certain small patches of meadow and would not be possible in large areas such as Balangshan and Maanqiao. If the reserve bans pasturing, all herders would sell out their livestock and two indicated that they would ask for monetary compensation. One herder actually suggest to grant local community some use rights of the meadow, based on which they can legally drive outsiders away from the reserve.

When the non-herders were asked about their intention of investing in alpine pasturing, one of them indicated as long as yaks can be sold for good price in the outside market, over-grazing would not be his main concern. The other two said that they would rather use their money to do small tourism-related business as they have no pervious herding experience.

The reserve managers expressed their worries about poaching activities in the alpine region, and also showed concerns about grassland degradation issues caused by over-grazing and herbal medicine collection too. The managers also addressed the following obstacles they face toward mitigating human disturbances in alpine regions – A. pasturing had been a tradition of the local community before this region was designated as a reserve, making it difficult to negotiate with the locals about this issue; B. monitoring cost in the alpine region is extremely high considering its vast coverage and low accessibility from the reserve’s headquarter in temperate forested areas; C. the recent earthquake significantly affected the income of local people, banning pasturing in the near future may result in increasing natural resource extraction from forests, compromising panda habitat conservation achievements in the reserve; and D. the reserve’s focus in the near future is still post-earthquake reconstruction, which won’t complete till at least 2013, before which there would not be enough financial and human capital available to address alpine conservation issues. When being asked for their thoughts about the emerging meadow fencing issues, both managers indicated that in theory it should not be allowed, but in practice it is difficult to enforce.

These phone interviews cannot replace the mediated group modeling workshops, but still provide useful information to understand the concerns, interests, intentions and potential behaviors of the different stakeholders in the reserve.

8. Summary

Through employing the state-of-art environmental niche modeling tools (e.g. maximum entropy modeling framework (MaxEnt)), I was able to map the landscape-scale habitat suitability of blue sheep, snow leopard’s main prey species, in Wolong Nature Reserve. Combining modeling results with interview data from local communities, the spatial distribution and population sizes of blue sheep were estimated. Local stakeholder interview results showed that the main threats on alpine wildlife came from over-grazing of the meadow and poaching, and the root causes behind include the lack of regulation and management on alpine ecosystem by the reserve and local households’ lack of alternative income sources.

Findings from this preliminary study have well established a basic understanding of the conservation status and issues in the alpine regions of Wolong Nature Reserve, where snow leopard distribution is confirmed in multiple areas. This area has the potential to support the existence of several thousand blue sheep, which could be enough to sustain the living of a viable snow leopard population, given the current human-wildlife conflict issues being actively tackled and alleviated.

V. Discussion:

The following is what I learned from this preliminary study conducted with very limited resources at a very difficult period (after the 2008 earthquake in the area) that may be helpful for others wishing to do similar projects.

1. In areas like Wolong Nature Reserve where no previous study on snow leopard exists, pre-field work preparation, including information collection from all kinds of publications and discussion and/or focus groups with key stakeholders are critical. This would help the researchers develop useful survey instruments to catch the big picture of the conservation issue of interests.
2. Working in rural areas like Wolong Nature Reserve, where the literacy of local people is relatively low, the language of the survey questionnaires shall be carefully designed in a way that can be most easily understood by locals so that their answers are meaningful.
3. Nowadays a wide range of data and software are readily available for free, including myriad of remote sensing products (e.g. the Global Digital Elevation Model (GDEM) and Landsat ETM+ imageries) and various types of wildlife habitat tools (e.g. MaxEnt, BioMapper, etc.). This is a double-edged sword. First, these make landscape-scale estimation of wildlife habitat modeling much easier and quicker than it once was. This can potentially save decision-makers valuable time to take conservation actions. However, it is also a challenge to understand the strengths and weaknesses of the different modeling tools to be able to pick up the most appropriate one for the specific question and to correctly interpret the model outputs. For example, in this study, overfitting is a drawback of MaxEnt if variables were not carefully selected. As it is generally difficult to collect a large sample of rare and endangered species' presence data, environmental niche modeling tools like MaxEnt are powerful from the perspective of generating meaningful habitat suitability maps using a relatively small sample of presence locations and not requiring strict absence information.

The results from this study, which have been shared with managers at various levels in the reserve, showed again that management of complex socio-ecological system like Wolong is a daunting challenging. While some negative signs of alpine ecosystem degradation have been observed, it seems that the trend may be reversible if immediate actions are taken. First the reserve needs to establish an alpine ecosystem and wildlife monitoring program as soon as possible, based on which more indicators should be monitored and more information be collected. Second, education programs shall be initiated to inform the locals about the conservation status (e.g. the fact that snow leopard is also a class I protected species in China, like giant panda) and the ecological importance of snow leopard and other carnivores. In the long run, non-agricultural and non-pasture income sources should be actively explored and provided to local community to help them find alternatives. Payment for ecosystem services (PES) program would be another useful conservation tool to help alleviate or eliminate human disturbance to alpine wildlife and ecosystem in Wolong.

Based on the current findings, the following additional work is suggested –

1. A new tool just came out recently based on an manuscript in press in *Ecological Applications* and it will allow us to compare models selected using information criteria [15]. This provides a more objective way of selecting the best MaxEnt model and will be tried soon.
2. It seems that alpine and sub-alpine meadow degradation happened in the last 10-15 years and it may be able to confirmed using remotely sensed data. This work is currently in preparation. It would also be helpful to conduct a survey on several selected meadow areas to understand the condition of meadow degradation and estimate the current carrying capacity of pastures.

3. It is needed to expand the current spatial coverage of blue sheep and snow leopard surveys to collect their presence data across a larger area (including areas outside but adjacent to the reserve) so that snow leopard habitat in and around the reserve may be modeled and mapped.
4. The originally planned mediated modeling workshop is still necessary to get different stakeholders together to develop future scenarios and explore potential solutions. It is also needed to conduct more in-depth social studies on the specific aspects of the institutional structure of the local community that directly related to their pasturing practices, so that local people's potential actions can be better understood and studied.

VI. Photographs:

Several photos taken during the project and several others showing typical alpine landscapes of Wolong taken before are listed below.

1. Winter snow leopard habitat in Wolong Nature Reserve
2. Bird's eye view of alpine terrains in Wolong Nature Reserve in winter.
3. A snow leopard captured by an infra-red camera trap in April 2010.
4. A small group of blue sheep in early winter in Wolong Nature Reserve.
5. Bird's eye view of alpine terrains in Wolong Nature Reserve in summer.
6. Mountains in Wolong Nature Reserve, summer.
7. The Four Sisters Mountain (6250 m, second highest peak in Sichuan province) at the western border of the reserve. It was reported that large groups of blue sheep are observed in this area every year and snow leopard was also reported to exist in this area.
8. Similar to 7.

Photo credits:
1-2: Mr. Meng Ming of the Dengsheng Conservation Station at Wolong Nature Reserve;
3-8: Wei Liu.

Please check photos in the appendix at the end.

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Appendix