Weight of Evidence Predictive Modelling and Potential Locations of Ancient Gold Mining Settlements in Benguet in the 16th to 18th Centuries

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Using the Weight of Evidence method in the analysis of geographic patterns, this paper sought to identify areas with high probability for being ancient settlement locations of small-scale subsistence gold miners in Benguet Province of Northwestern Luzon between the 16th to the 18th centuries. The training points used in this project include 24 known ancient village locations that are based on Spanish missionary accounts in the 18th century. The evidential themes that were used include: 1) distance from gold placer mines, 2) Slope class, and 3) Land-use class. Incidentally, the distance to placer mines is the same as distance to fresh water source for habitation purposes. The resulting response theme or unique conditions map shows areas that may potentially contain archaeological sites. The final map shows areas where there is a high probability of encountering an archaeological site.

INTRODUCTION
This work is part of a longitudinal research that tests the theory that the migration into the Benguet mountains of Southwestern Cordillera was mainly due to gold extraction (see Canilao 2009, 2010, 2011a, 2013). Previous researches on the theory were mainly based on a conjunctive approach of ethnohistory and archaeology (i.e., Palka 2009; Wilson and Rogers 1993; Spores 1980). The contribution of the current work is the use of GIS modelling to predict ancient settlement locations that were induced by placer and lode gold mining. It should be stated that the author has shown in various works that the technology of mining in Benguet have largely remained small-scale and environmentally safe before the advent of industrialized mining by the middle of the 20th century (see Canilao 2015, 2011b).

Based on ethnohistorical sources (Newson 2009; Mateo 2004; Scott 1988; Bagamaspad and Hamada-Pawid 1985), there are three types of settlements in Northwestern Luzon that emerged because of the gold trade which dates to the Protohistoric period (10th to 16th centuries). These include the coastal centers which are jump off points for gold before it is shipped overseas, the bulking stations where initial processing of the metal is done, and the mining settlements where they were mined in crude tunnels or panned in adjacent streams. In this paper, the objective is to create a geographic model that can guide the study of ancient gold mining settlements.

Weight of evidence analysis is a GIS based techniques for relating point pattern for locations of discrete events.
using several map layers (Agterberg and Cheng 2002). This method has been used mainly in geological mapping that seek to identify areas with high probability of mineral deposits. The technique aids researchers in identifying areas with high probability of a condition being met based on various evidentiary themes and training points with known mineral deposits. The same technique is also available in archaeology for modelling sites (i.e. see Diggs and Brunswig 2009).

Although it can be argued that geology is the most obvious predictor of gold-mining site settlement location, the novelty of this work is its emphasis on the occurrence of alluvial gold in placer mines moving along drainage systems laying atop various geological proveniences.

**Data Collection and Preparation**

The researcher acquired ancient maps from the translated work of the Spanish missionary Father Francis Antolin, O.P. dating to the late 18th century (Scott 1988). These maps show locations of ancient mines as well as ancient villages in Benguet. The researcher also acquired ancient maps of Ibaloi settlements based on oral traditions (Bagamaspad and Hamada-Pawid 1985, Prill-Brett and Salinas-Ramos 1998). The researcher also acquired images of topographic maps of Benguet based on aerial photographs from the 1970s. These maps show locations of gold mines in Benguet.

For purposes of a base map, the researcher also retrieved LandSat 8 scenes of Benguet province from libra.developmentsseed.org. The raw LandSat8 bands were layer stacked and mosaicked using ERDAS Imagine 2016 software (Hexagon Geospatial- Madison AL, USA). Finally, the researcher also acquired thematic maps showing both land classes and slope classes of Benguet province from PhilGIS.org.

**METHODS**

The first step was to georeference the topographic map/ and LandSat 8 base map using Universal Transverse Mercator WGS 1984 51N. The next step was to initiate a rubber sheet transformation function on the two historical maps. The transformed maps were then used as guides to digitizing settlement site locations as well as gold mine locations. At this juncture it is important to note that all the ancient site place names still appear in the topographic map based on 1970s aerial photography. The researcher then digitized tributaries that drain from the gold mines. The reason is that these streams and rivers are the sites for placer mining. The common method of the miners is to modify the cobbles and pebbles to form sluice boxes wherein controlled water pressure is able to parse out the heavy gold nuggets from other particles (Caballero 1996). It should be noted that, the placer mines also serve as fresh water sources for habitation purposes.

After all features have been digitized, the layers were plotted on the base map. The color jets of the LandSat 8 base map were configured for the Land and Water combination (Near Infrared- Shortwave Infrared 1- Red) (see Figure 1).

The next step was to run a multiple ring buffer under the analysis- proximity toolbox of ArcMap 10.3 (ESRI- Redlands CA, USA). A maximum of 23 rings were set with 1 km distance each from the placer mine/ fresh water feature. The attributes of the resulting raster map was then modified to include a new field wherein six distance categories were created (see Figure 2). The breakdown is as follows; Category one was set for 1 to 3 km, Category two was set for 4 to 6 km, Category three was set for 7 to 10 km, Category four was set for 11 to 13 km, Category five was set for 14 to 16 km, and Category six was set for 17 to 19 km. The next step was to run a multiple ring buffer under the analysis- proximity toolbox of ArcMap 10.3 (ESRI- Redlands CA, USA). A maximum of 23 rings were set with 1 km distance each from the placer mine/ fresh water feature. The attributes of the resulting raster map was then modified to include a new field wherein six distance categories were created (see Figure 2). The breakdown is as follows; Category one was set for 1 to 3 km, Category two was set for 4 to 6 km, Category three was set for 7 to 10 km, Category four was set for 11 to 13 km, Category five was set for 14 to 16 km, and Category six was set for 17 to 19 km.

**Figure 1.** Layer stacked LandSat 8 scene of Benguet (2015) with superimposed gold mines, settlements, and placer mines in the 18th century. Landsat color jets set at Land and Water (Near Infrared- Shortwave Infrared 1- Red) (LandSat8 Credit: U.S. Geological Survey. Department of the Interior/ USGS).
9 km, Category four was set for 10 to 12 km, Category five was set for 13 to 15 km, and finally Category six for 16 to 23 km.

The Slope class thematic map was then prepared. First, this was re-projected to UTM WGS 1984 51N and clipped to the relevant study region. The attributes of the raster maps was modified by adding a new field with seven simplified categories. The breakdown is as follows; Category one was set for level to nearly level, Category two was set for gently sloping to undulating, Category three was set for undulating to rolling, Category four was set for rolling to moderately steep, Category five was set steep, Category six was set for very steep, and finally Category seven for Reservoir/ Unclassified (see Figure 3).

The Land-use thematic map was also prepared. As with the slope map, the land use map was also re-projected and clipped to the relevant study region. Then the attributes of the raster map was modified by adding a new, simplified field with 5 categories. The breakdown is as follows; Category one was set for alluvial paddy rice and irrigable, Category two was set for gently sloping paddy rice and irrigable, Category three was set for expansion area and built-up area, Category four was set for erodible lands and highlands, and finally Category five was set for Reservoir/ Unclassified (see Figure 4).

The researcher then imported all data sets to ArcView 3.3 software (ESRI- Redlands CA, USA) and run the Weight of Evidence extension. First, the Base Map was set using a rasterized version of Benguet Province. Second the training points were indicated to be the 24 digitized ancient settlement sites. Third the analysis area unit of cell was set at 0.25 km. The researcher then generated weight tables for the three evidential themes; namely, distance from placer mines/ fresh water (ordered-ascending), slope class (free-categorical), and land use class (free-categorical). Finally, the compute response theme layer function was implemented after all weight tables were created.
RESULTS

A response theme was generated (see Figure 5) together with a report (see Figure 6) showing that the overall test of conditional independence is 0.55. This number may be due to the small number of observed training points compared to the large number of predicted training points. This is due to use of ethnohistorical data, which is dependent on oral traditions and the perspectives of Spanish period travelers. The latter is quite illuminating however since these sites were plotted in early maps that have some level of accuracy whereas the former is open to generational manipulation (Canilao 2011a). The attribute table of the raster was show that some of the new fields include the unique condition grid cell values, which ranges from one to 138. A Posterior Probability field was also generated showing the sum of weights plus prior logit converted into probabilities. Also notable is a new field showing area per unique condition measured in square meters. The posterior probability raster shows five classes reflecting descending probability. The blue class represents 0.06- 0.3, the purple class represents 0.02- 0.06, the red class represents 0.0018- 0.02, the yellow class represents 0.0008- 0.0018, and finally the tan class represents probabilities from 0.000000002- 0.0008.

DISCUSSION

The unique conditions map provides some candidate locations that would have high probability of containing archaeological sites. The resulting Posterior Probability maps seem to indicate that there is great potential to see archaeological sites near or at reservoir areas. This makes sense because the areas are also merging points for the various tributaries with placer mining operations. This also makes sense because of its level terrain and proximity to fresh water thus being conducive for habitation/settlements. It should be noted that majority of the areas, however, are located in areas marked as reservoir. It should be stated that the reservoir area is a relatively modern construction. The reservoir was formed as a result of the Ambuklao hydroelectric-powerplant being built along the Agno River in the 1950s. The construction of the 129 m high dam resulted to flooding upriver— inundation of formerly occupied, built-up areas and agricultural areas including the ancient village sites of Ambuklao and Bolod. These two settlements are now submerged within the reservoir. Indeed, the sum of weights for both
the Ambuklao (#17) and the Bolod (#18) training points reflect the highest scores at 5.4 each. The third highest is the Buguias training point (#5) at 3.2.

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