PONTIFICIA UNIVERSIDAD CATÓLICA DEL ECUADOR

FACULTAD DE CIENCIAS EXACTAS Y NATURALES

ESCUELA DE CIENCIAS BIOLÓGICAS

Vulnerability of a jewel scarab (Coleoptera, Scarabaeidae, Rutelinae) in a highly fragmented light-polluted landscape in Ecuador

Tesis previa a la obtención del título de

Máster en Biología de la Conservación

LUIS FELIPE CAMACHO CÁRDENAS

Quito, 2015

Certifico que la tesis de Maestría en Biología de la Conservación del candidato Luis Felipe Camacho Cárdenas ha sido concluida de conformidad con las normas establecidas; por lo tanto, puede ser presentada para la calificación correspondiente.

Santiago Espinosa, Ph.D.

Director de Tesis

Quito, 8 de Abril de 2015

AKNOWLEDGEMENTS

I wish to thank my thesis director Santiago Espinosa, and reviewers Santiago Burneo and Clifford Keil for their valuable contributions towards this study. I also thank Brett Ratcliffe, Max Barclay, Helena Maratheftis, Miguel Ángel Morón, Santiago Villamarín, Aura Paucar, Mathew Moore, and Donald Thomas for their support and good will towards this study. Special thanks to Gabriela Barragán for her support in the field.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 ABSTRACT

1. We examined the vulnerability of the Jewel Scarab, *Chrysina argenteola* (Bates, 1888), in Ecuador. We used niche modelling to infer the species' original distribution and Ecuador's deforestation map to calculate its present distribution. Using this distribution, we measured habitat loss, habitat fragmentation, and light pollution. Townsfolk were interviewed about the local availability of the scarab, and their answers were correlated with landscape metrics to address response of the scarab populations to local landscape configurations. Townsfolk were also interviewed to explore the extent and details of the exploitation enterprise of the scarab.

2. The data suggests that *C. argenteola* is relatively tolerant to habitat loss. The species is prone to inter-patch dispersion and has significant dispersal capabilities. Light pollution is continuously intercepting dispersing individuals throughout the landscape. Our results show, for the first time, evidence of both the interception and vacuum effect hypotheses of insect light attraction acting at a landscape level.

3. The trade of *C. argenteola* is a lucrative low-effort enterprise. The collection method uses urban light sources to catch attracted individuals. Internal trading of the species does not occur, instead depends on an external, foreign buyer. Exploitation of this species has not affected populations further from what they were already affected by habitat loss and light pollution.

4. A local and international conservation category is given for *C. argenteola* according to IUCN endangered species criteria. The species is under the "Vulnerable" conservation category in Ecuador, but should be considered as "Least concern" internationally.

Key words: *Chrysina argenteola*, exploitation, habitat fragmentation, habitat loss, insect conservation, landscape, light attraction, light pollution, wildlife market.

2 RESUMEN

1. Evaluamos la vulnerabilidad del escarabajo joya *Chrysina argenteola* (Bates, 1888) en Ecuador. Usamos modelamiento de nicho para inferior la distribución natural de la especie. Acorde al mapa de deforestación del Ecuador calculamos su distribución actual remanente. Sobre ella medimos la pérdida de hábitat, fragmentación de hábitat, y contaminación lumínica. Pobladores locales fueron entrevistados sobre la existencia local del escarabajo. Sus respuestas fueron correlacionadas con métricas de paisaje para investigar la respuesta de poblaciones del escarabajo a la configuración del paisaje local. Los pobladores también fueron entrevistados para explorar la extensión y detalles de la actividad de explotación del escarabajo.

2. Los datos sugieren que *C. argenteola* es relativamente tolerante a la pérdida de hábitat. La especie es susceptible a dispersarse entre parches de bosque y tiene importantes capacidades de dispersión. La contaminación lumínica está constantemente interceptando individuos que se dispersan a lo largo del paisaje. Nuestros resultados muestran por primera vez evidencia de las hipótesis de intercepción y efecto aspiradora de la atracción de los insectos a la luz a una escala de paisaje.

3. El comercio de *C. argenteola* es una actividad lucrativa y de poco esfuerzo. El método de colección usa las fuentes de luz urbanas para atrapar individuos atraídos. No existe un comercio interno de la especie, y más bien depende de un comprador externo. La explotación de la especie no ha afectado a las poblaciones más allá de lo que ya estaban afectadas por la pérdida de hábitat y la contaminación lumínica.

4. Una categoría de conservación local e internacional se determinó para *C. argenteola* según los criterios para especies amenazadas de la UICN. El escarabajo se encuentra en la categoría de conservación vulnerable en el Ecuador, aunque debería considerarse de menor preocupación a nivel internacional.

Palabras clave: *Chrysina argenteola*, explotación, fragmentación de hábitat, Pérdida de hábitat, conservación de insectos, paisaje, atracción a la luz, contaminación lumínica, mercado de vida salvaje.

3 INTRODUCTION

Insects tend to be vulnerable to extinction because species frequently have restricted geographical ranges, are habitat specialists and depend on hosts (Dunn, 2005; Chapman, 2009). It is estimated that a fourth of all insect species in the world are in imminent risk of extinction (McKinney, 1999). A projected number of 57,000 insect species per million species on Earth will become extinct in the next 50 years (Pimm & Raven, 2000). Insect conservation is important because these organisms support basal ecological process and are key for maintaining ecological services for human societies (Wallace & Webster, 1996; Price, 1997; Folgarait, 1998; Bignell & Eggleton, 2000; Losey & Vaughan, 2006; Thomas *et al*., 2008; Samways *et al*., 2010).

Studies on the vulnerability of insect species are scarce (McKinney, 1999; Dunn, 2005). The endangered species Red List of the International Union for Conservation of Nature (IUCN) has 4,610 insect species registered from a total of 53,267 animal species in their list (IUCN, 2013). Considering that the total number of described insect is around one million species (Chapman, 2009), less than 1% of the total insect diversity has been registered by the IUCN. Insect species represent around 70-80% of the total animal species described by science; however, they correspond to only 8% of the animal species evaluated by IUCN. This is evidence of how the attention given to insect conservation is insufficient (Dunn, 2005; Samways *et al.*, 2010).

The scarab genus *Chrysina* (Coleoptera, Melolonthidae, Rutelinae) is an eye-catching group of species displaying bright green and metallic silver and gold colors on their bodies. The group endures threats towards their conservation. North-American and

Central-American species have host plant relationships for feeding and depend on decaying wood for reproduction. This makes them vulnerable to loss of forest and habitat degradation (Hawks, 2002; Morón, 1991). These scarabs are mainly active at night and are attracted to artificial lights, mainly in the ultraviolet spectrum (Hawks, 2002). This probably makes *Chrysina* species vulnerable to light pollution. Lights pose a great danger towards insects attracted to them. Around one third of insects attracted to a light die (Eisenbeis, 2006). The dangers of light towards attracted insects include risks of mortality by an increase in predation risk, burn injury, and exhaustion (Eisenbeis & Hänel, 2009). Light pollution has been identified as a possible factor contributing to declines of moth populations (Fox *et al*., 2013). Finally, *Chrysina* species are valued in the insect collectors' market and unregulated harvest could affect local populations (Hawks, 2002; Jocque *et al.*, 2013). There are currently 96 described species of *Chrysina* none of which has been subject of a vulnerability study (IUCN, 2013).

The goal of the present study is to evaluate the threats and vulnerability of *Chrysina argenteola* (Bates) in Ecuador. This species is one of the few representatives of the genus in South America (Hawks, 2002). The species is reported to occur in Colombia, Ecuador, and Peru (Ohaus, 1918, Hawks, 2006). In Ecuador most of its geographical range seems to occur on the Chocó region and humid ecosystems on the western side of the Andes according to the invertebrate museum collection of the Pontificia Universidad Católica del Ecuador (QCAZ). The Chocó forest in Ecuador has undergone severe loss and fragmentation; it is estimated that only 22.4% of its original forest remains intact (Rodríguez-Mahecha *et al.*, 2004; Sierra, 2013). Additionally, extensive urban development in the region has increased light pollution across its distributional range of *C. argenteola*. The combination of habitat loss and fragmentation and light pollution could have a critical effect on metapopulation dynamics of this scarab. Finally, a market commercial for *C. argenteola* exists. Ecuadorian specimens are offered on the web for as high as US$100. Some townsfolk in Ecuador sell individuals for up to US$20 (L. C. personal observation). The extent and effect of this market on wild populations is still unknown. In this study, the level of threat towards *C. argenteola* by habitat loss, habitat fragmentation, and light pollution were analyzed. An investigation of the exploitation of the insect by local settlements was also conducted. Finally, a threat category for *C. argenteola* based on the IUCN red list was stablished (International Union for Conservation of Nature, 2012).

4 MATERIALS AND METHODS

Our specific objectives were: 1) to determine the current distribution of *Chrysina argenteola* in Ecuador based on estimations of its original distribution; 2) to evaluate threats such as habitat loss, habitat fragmentation, and light pollution to *C. argenteola* conservation; 3) to determine the relation between *C. argenteola* populations and local landscape configuration; 4) to explore the commercial trade in *C. argenteola*, and infer its effect on populations; and 5) to determine the conservation status for *C. argenteola* based on the B criterion of the IUCN Red List.

4.1 DISTRIBUTION OF *CHRYSINA ARGENTEOLA*

4.1.1 ORIGINAL DISTRIBUTION

The original distribution of *C. argenteola* was predicted based on 46 collection locality records from bibliographical (Bustamante & Cárdenas, 2007; Ohaus, 1918; Paucar, 1998) and collection sources (BCRC, EPN, MECN, MXAL, NHMUK, QCAZ, RBINS, UNSM, USNM) (Annex 1). When collection records lacked geographical coordinates, these were obtained using the protocol of the Mexican georeferencing manual for biological collections, CONABIO (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, 2008). The data was used to generate a predictive niche model for *C. argenteola* in Ecuador. The model was generated using the maximum entropy algorithm implemented in Maxent (Phillips *et al*., 2006) because it performs well with presence only data and low numbers of records (Elith, Graham *et al*., 2006; Hernandez *et al*., 2006).

To reduce sampling bias, collection points less than 4 km apart from each other were not considered for the model. This was carried out procuring to maintain as many collection points as possible. After this, eighteen collection points remained. Phytogeographic and climatic information were used as predictive variables for the niche model. We used a layer of natural ecosystem for continental Ecuador (Sierra, 1999) to reflect geographical environments where *C. argenteola*'s host plants may occur. The climatic variables used were the Bioclim bioclimatic variables from the Worldclim 1.4 database at a 30 second resolution (Hijmans *et al.*, 2005). Only some climatic variables were selected for the model. Selection of these variables was performed by correlating the values of the 19 climatic variables from the 18 *C. argenteola* collection points included in the model. Correlation groups were formed where correlation indexes between variables were higher than r_p=0.8. Within each correlation group, variables correlated with fewer variables and with a lower mean correlation index were selected. After the analysis six, variables were selected: mean diurnal range (bio2), temperature seasonality (bio4), temperature annual range (bio7), mean temperature of the driest quarter (bio9), precipitation of the warmest quarter (bio18), and precipitation of the coldest quarter (bio19).

The model was calculated for all of continental Ecuador. No sampling bias correction method was applied because of the unavailability of data for spatial sampling effort of insects in Ecuador. For model evaluation, spatial partitioning of background data was carried out using a jackknife k-fold cross-validation using the same number of bins as collection points, as suggested for small datasets (Pearson *et al.*, 2007; Shcheglovitova & Anderson 2013). Niche models were constructed using regularization multipliers from 0.5 to 4 with increments of 0.5, and, using feature combinations L, LQ, LP, LQH, LQP, LQHP, H, QH, HP, HQP, and LQHP (were L is linear feature, Q is quadratic, H hinge, and P product). Exploration of different regularization multipliers, and feature class selection in model construction has been recommended by Merow *et al*. (2013), and Radosavljevic and Anderson (2014). All combinations between regularization multipliers and feature class combinations produced a total of 88 models. All were constructed using ENMeval package (Muscarella *et al*., 2014) in R 3.1.1 software (R Core Team). Merow *et al*. (2013) do not recommend using AUC as a best-fit-model criterion for small data-number models. As an alternative, AIC (Akaike's information criterion) was used as recommended by Muscarella *et al*. (2014). The model with lowest AIC was selected from the generated models. The selected model used the linear and product features and a regularization multiplier of 1.5 (Test omission rate = 0.167)

The original distribution range of *C. argenteola* in Ecuador was calculated by applying the "maximum training plus specificity" threshold to the niche model. This threshold has been recommended for predicting distributions more accurately (Liu *et al*., 2013), and for having a tendency to restrict distributions which is congruent with the precautionary principle of species vulnerability analyses (Syfert *et al*., 2014). Areas of the niche model that reached the montane mist forest of the western Andes (Sierra, 1999) were eliminated to limit possible altitudinal overestimations of the potential distribution. This limit was set because the western slope of Andes has been widely sampled in Ecuador and *C. argenteola* has never been documented in this type of forest or higher in altitude. Finally, the resulting polygon was assumed as the original distribution range of *C. argenteola* in Ecuador. The distribution extension, altitudinal range, and the forest types where the insect potentially dwells were determined.

4.1.2 PRESENT DISTRIBUTION

Based on the 2008 coverage and land use map of Ecuador (Ministerio del Ambiente del Ecuador, 2012), all disturbed areas and water areas were subtracted from the natural distribution of *C. argenteola*. This map was used as it is the most recent available. The remaining area was assumed as the present distribution of *C. argenteola*.

4.2 PRESENT LANDSCAPE CONFIGURATION AND LIGHT POLLUTION

4.2.1 HABITAT LOSS AND FRAGMENTATION

The area of present remaining habitat was calculated. The percentage this area represents was calculated in relation to its original distribution extension. Landscape metrics were measured to assess the level of fragmentation. These included: 1) number of habitat patches, 2) area of patches, and 3) patch isolation. Isolation was assessed by measuring the distance to the closest adjacent habitat patch for each patch. The percentage of habitat protected under the national system of protected areas of Ecuador was also calculated. All measurements and calculations were carried out using ESRI ArcMap 10.2 (Redlands, CA, USA) and Microsoft Excel 14.0 (Redmond, WA, USA).

4.2.2 LIGHT POLLUTION

Experimental evidence suggests that light attraction of insects is limited to a small area around the light (Plaut, 1971; Onsager & Day, 1973; Bowden & Morris, 1975; Muirhead-Thompson, 1991; Beck & Linsenmair, 2006). A light source attracts insects in its immediate vicinity, intercepting insects whose flight paths intersect by coincidence the limited attraction area of the light (Bowden & Morris, 1975; Muirhead-Thompson, 1991; Eisenbeis & Hänel, 2009). There is no evidence supporting the idea that insects are attracted to lights from afar (Beck & Linsenmair, 2006). At a landscape level, lights seem to represent barriers that intercept migrating insects that chose their flight path without any influence related to the light itself (Beck & Linsenmair, 2006; Eisenbeis & Hänel, 2009). The potential effect of light pollution on populations of *C. argenteola* was analyzed based on the interception hypothesis.

Landscape light pollution metrics were measured. These included: 1) the percentage of light polluted areas over the original distribution; 2) the percentage of area within a 100 m from remaining habitat borders that is light polluted; and 3) the percentage of inter-patch routes in the remaining habitat that are intercepted by light polluted areas. These routes were drawn as straight lines between all patches within a 5 km radius of each other. Nocturnal light information was obtained from the DMSP-OLS Nighttime Lights Time Series Version 4 (NOAA's National Geophysical Data Center) for the year 2012. Analysis was carried out using ESRI ArcMap 10.2 and Microsoft Excel 14.0.

4.3 LOCAL RESPONSES OF *C. ARGENTEOLA* TO LANDSCAPE CONFIGURATION

Chrysina argenteola is a conspicuous insect with no species with similar appearance within its geographical range in Ecuador. We interviewed people within the distribution range of the scarab based on collection records (Annex 1). The aims of the interviews were: 1) to infer the local abundance of the scarab; and, 2) to determine if light pollution is intercepting *C. argenteola* individuals. Interviews were carried out by two persons. A multivariate correspondence analysis (MCA) was carried out to determine if interviewers had an effect on respondent's answers.

Local abundance of the scarab was inferred by inquiring the places where local people have seen the scarab within the last six years. From all respondents in each place, the proportion of people who claimed to have seen the scarab was calculated. It is expected that this proportion reflects the abundance of *C. argenteola* locally. The six-year time frame was established as the present *C. argenteola* distribution is based on Ecuador's 2008 deforestation record. Only locations where at least five people were interviewed were considered for the analysis. In addition, landscape metrics were measured on the present *C. argenteola* distribution within a 5 km radius from each reported location. Metrics included: 1) the percentage of remaining habitat; 2) the number of habitat patches; 3) the area-weighted average patch size; 4) the distance to the closest habitat patch; and, 5) Percentage of the area impacted by light pollution.

The first approach was to test the individual relationship of each landscape metric with the abundance of *C. argenteola*. For this, the proportion of scarab reports from interviews for each location was correlated against each of the landscape metrics. Additional analyses tested the interaction between landscape variables further explained the proportion of scarab reports. Generalized linear models (GLMz) were used to test remaining habitat proportion interactions with 1) the number of habitat patches, 2) the average patch size, and 3) the light polluted area. The same three variables were also tested for significant interactions with the distance to closest habitat patch. All interactions were plotted on contour plots using the distance method with a distance power of two. Statistical analyses were carried out using R 3.1.1 software (R Core Team, 2012); contour plots were constructed using Minitab 17.1 software (Minitab Inc., State College, PA, USA).

To determine if artificial light sources intercepts scarabs, people in the locality were asked where they have seen the scarab; categories included: interacting with a light source at night (e.g. in a lit window or moving around a light), on an urban environment, in farmland, and in forests. We believe there is a high probability that *C. argenteola* individuals found in urban environments occur as a consequence of light attraction. So, light interaction and urban environment sources were considered as a single category. An ANOVA analysis was applied to determine the existence of differences on the proportions of scarab reports per source in locations.

4.4 EXPLOITATION OF *C. ARGENTEOLA*

A second set of questions were included in interviews to explore the exploitation of *C. argenteola* specimens for commercial purposes (Annex 2). Sex, age, ethnic identity, and occupation of interviewees were recorded. The questions of the interviews aimed to ask if people have ever traded the scarab; and, if so, to ask details of the enterprise such as how the scarabs were collected, if traders looked actively for the scarab, approximate number of traded scarabs, selling price, among others. Additionally, people who during inquiring declared a spontaneous interest in trading the scarab during interview were also recorded.

The proportion of people and towns engaged in commercial trade of the scarab was used as a measurement of the extent of this enterprise. A second MCA was applied to determine the possible relation between personal characteristics of respondents and trade in the scarab. This analysis, the proportion of people who were interested in incurring into trading, and details of the trading enterprise were used to explore the factors that might drive this activity. The impact of trading on populations of *C. argenteola* was discussed based on the extent of the business and its driving factors.

4.4.1 GENERAL ASPECTS OF *C. ARGENTEOLA*

Interviews also inquired about general aspects of the ecology of *C. argenteola* that could aid in understanding how the scarab relates to its environment. We asked about the time of the year that the scarab has been seen and to which plants the scarab has been seen attracted to. Any other relevant behavioral or ecological information was recorded. This information was used to aid discussion of responses of the scarab to local landscape, and the commercial exploitation of the species.

4.5 CONSERVATION CATEGORY

The category of threat of *C. argenteola* in Ecuador was determined based on the B criterion established by the Red List of the IUCN (International Union for Conservation of Nature, 2012). The evaluation was performed based on the following parameters: area of distribution (B1), fragmentation (B1a), and decline in quantity and quality of habitat (B1biii). The B1biii criterion was analyzed based on Ecuador's deforestations studies of Sierra (2013).

5 RESULTS

5.1 DISTRIBUTION OF *CHRYSINA ARGENTEOLA*

5.1.1 ORIGINAL DISTRIBUTION

All *C. argenteola* collection data were from the western side of the Ecuadorian Andes (Figure 1). The altitudinal range was between 160 m, in the Canandé Reserve in Esmeraldas, and 1600 m in the town of Las Pampas in Cotopaxi. Collection points were distributed in the evergreen mountain base forest of the coast, the evergreen low land forest of the coast, the evergreen low montane forest of the coast mountain range, and the semi deciduous montane base forest of the coast (Sierra, 1999).

The original distribution model of *C. argenteola* delimited the species range to a 32,381 km^2 area ranging from 8 to 1,607 meters above sea level (Figure 1). Suitable habitat was predicted only in the western side of the Andes. Sections of the evergreen low montane forest of the western Andes, the misty montane forest of the western Andes, and the evergreen foothill forest of the coastal mountain range (Sierra, 1999) were also predicted as being suitable for *C. argenteola* populations. The highest quality habitat for the species occurred where precipitation during the warmest quarter of the year was highest and daily and annual temperature variation was minimal.

5.1.2 PRESENT DISTRIBUTION

The present distribution of *C. argenteola* extends over 9,238 km^2, which represents 28.5% of the original distribution in Ecuador (Figure 1). Of the remnant habitat, 15.1% is protected under the National System of Protected Areas of Ecuador. From this percentage, 76.4% is protected by the Cotacachi Cayapas Ecological Reserve, 9.3% by the Los Ilinizas Ecological Reserve, 6.7% by the Mache Chindul Ecological Reserve, and 1.3% by the El Pambilar Wildlife Refuge.

5.2 PRESENT LANDSCAPE CONFIGURATION AND LIGHT POLLUTION

5.2.1 HABITAT LOSS AND FRAGMENTATION

Present remaining habitat consists of 11,865 patches, where a single 3,849-km^2 patch represents 41.6% of remaining habitat. The rest of current habitat is distributed in fragments ranging from 844 km^2 to less than 0.1 km^2 (Figure 2). Ninety five percent of the present habitat has another habitat patch less than a 100 m away (Figure 3).

5.2.2 LIGHT POLLUTION

Present light pollution extends over 37.4% of the original habitat range of the scarab. Moreover, 13.2% of the area less than 100 m away from the present distribution's border is polluted by light. Present distribution presents 799174 inter-patch routes, 23.9% of which are intercepted by light polluted areas (Figure 4).

5.3 LOCAL RESPONSES OF *C. ARGENTEOLA* TO LANDSCAPE CONFIGURATION

A total of 383 interviews from 49 towns were included in the analysis (Table 1). Interviewers did not have a significant effect on respondent's responses. Forty five percent (172) of respondents acknowledged to have seen *C. argenteola* within the last six years. Of these people, 75% (129) claimed to have seen the scarab attracted to lights or in other urban environments, 21% (37) in farmland, and 4% (7) inside the forest. Observations of scarabs were significantly higher in areas near lights (71.2% ± 5.3%), than in farmland (23.7% ± 4.8%) or forest (5.1% ± 2.9%) (F=58.707, P<0.001).

Reported observation proportions of *C. argenteola* correlated positively with the percentage of remaining habitat (r_p=0.63, P<0.001), the number of habitat patches (r_p=0.431, P=0.002), average patch size (r_p=0.464, P=0.001), and negatively with the distance to the closest habitat patch (r_p=-0.593, P<0.001) (Figure 5). Landscape light pollution was not significantly correlated with the reported observations of *C. argenteola*.

Analysis of landscape metric interactions revealed that increasing numbers of habitat patches were associated with increased proportions of *C. argenteola* reports even when remaining habitat (*Wald* χ^2=17.059, P<0.001) and habitat isolation (*Wald* χ^2=5.917, P=0.015) remained constant (Figure 6A, C). The average habitat patch size had a similar relation with the proportion of scarab reports when interacting with the amount of remaining habitat (*Wald* χ^2=22.737, P<0.001) and the habitat patch isolation (*Wald* χ^2=3.72, P<0.054) (Figure 6B, D). No interaction between landscape light pollution and other metrics significantly explained *C. argenteola* sightings. However, graphic evaluation demonstrated a general trend where intermediately lit environments had increased proportions of scarab reports. Highly lit environments had decreased scarab reports overall (Figure 7). Low lit environments had low proportions of *C. argenteola* reports unless the habitat was very close to the source location of the reports (Figure 7A).

5.4 EXPLOITATION OF *C. ARGENTEOLA*

Interviewers did not have a significant effect on the respondents' answers. Among all repondents 8.3% (33) had traded *C. argenteola*, and 4.1% (16) showed interest in beginning to selling it. No personal characteristic of respondents was correlated with trading activity. Among locations, 19% (12) had at least one person trading *C. argenteola*, and 13% (8) had at least one person interested beginning this activity. In some trading locations multiple families dedicated to trade the scarab.

As collection method, all traders waited near town or house lights at night to catch attracted scarabs. In the most active locations, respondents declared that they had sold one to five specimens every two to four weeks for up to US$20 each. A single collector family collected 14 *C. argenteola* specimens in 2014. Buyers were typically from the cities, such as Quito and Ambato, or other countries. Trading no longer occurs in many locations because people claim *C. argenteola* has become too scarce for a business to be maintained. Trading in these locations occurred for about twenty years. Only one of the studied locations continues to sell scarabs presently.

5.4.1 GENERAL ASPECTS OF *C. ARGENTEOLA*

Collection dates of *C. argenteola* specimens included in the study show peaks of occurrence in February, May, and October, which coincide with patterns derived from interviews (Figure 8). Also, elder members of the Tsáchila community revealed some new ecological aspects about the insect. For example: a) this species typically lays eggs in dead wood and recently cut trees, and occasionally on living trees; b) *C. argenteola* use more than one tree species to reproduce, including the guaba tree (*Inga* sp.); c) many males chase a single female to mate; and, d) *C. argenteola* adults feed on fermented sap from tree trunks and are attracted to sugar cane during harvest.

5.5 CONSERVATION CATEGORY

The present habitat remnant for *C. argenteola* is 9,238 km^2. The remaining habitat is severely fragmented with over 11000 habitat patches. The species' habitat has decreased in both quantity and quality, with sustained increments in fragmentation and urban lighting pollution over the years. All these satisfy criteria for the "Vulnerable" (VU B1ab(i,iii)) conservation category for *C. argenteola* in Ecuador (IUCN, 2012).

6 DISCUSION

6.1 DISTRIBUTION OF *CHRYSINA ARGENTEOLA*

6.1.1 ORIGINAL DISTRIBUTION

Our estimates may reflect only a portion of the current distribution of *C. argenteola* in Ecuador. Our original distribution model was based on museum data which mostly correspond to collections between 1981-2013, and the oldest record was from 1918. Most of coastal forests in Ecuador were cleared from 1900 to 1920 during the cocoa boom and early after World-War II during the banana boom (Mosandl *et al.*, 2008). Therefore, collection records reflect insect distribution after major habitat loss events. This may explain the lack of records of scarabs in the coastal region. Considering this and the existence of records of the scarab in humid and semi-deciduous forests in Western Ecuador, the original distribution of the scarab may have extended further to the west. The distribution may have occupied the slope of the western Andes to include of Esmeraldas and Manabí provinces, as well as mountain ranges in Guayas province. If this were true, the calculated present distribution of *C. argenteola* would not vary much as these areas are currently nearly completely deforested (Ministerio del Ambiente del Ecuador, 2012).

6.1.2 PRESENT DISTRIBUTION

Most of the original habitat of *C. argenteola* has been lost in Ecuador. Fortunately, relatively large habitat remnants contain most of the habitat diversity for this species. Remaining habitat occurs on the western slopes of the Andes, the northern lowlands, and the coastal mountain range. However, the geographical range of *C. argenteola* has had the highest deforestation rates in Ecuador (Sierra, 2013). This tendency has been predicted to continue in the future, especially in the northern Chocó region where most of *C. argenteola* remaining habitat is located (Sierra, 2013). In this scenario, the national system of protected areas of Ecuador will play an important role in the conservation of the species. Protected areas exist in each of the different habitats of the species. The Mache Chindul Reserve protects habitat in the coastal mountain range; El Pambilar Reserve protects lowland habitat; Los Ilinizas Reserve protects Andes slope habitat; and, The Cotacachi Cayapas Reserve protects a broad altitudinal range from lowland to the slopes of the Andes. The slopes of the southern Andes and semi-deciduous distribution territories remain unprotected by the National Protected Areas System.

6.2 PRESENT LANDSCAPE CONFIGURATION AND LIGHT POLLUTION

6.2.1 HABITAT LOSS AND FRAGMENTATION

The remaining distribution of *C. argenteola* populations is severely compromised by habitat loss and fragmentation. Luckily, more than half of the present *C. argenteola* habitat is distributed in patches over 1,000 km^2 which allows a metapopulation to thrive with large habitat refuges. Habitat loss has not been homogeneous throughout *C. argenteola* distribution range. Most present habitat is concentrated in the western slopes of the Andes, the northern lowlands, and the coastal mountain range. The Central lowland habitat is now virtually inexistent, which compromises connectivity between the different habitat regions. Although most of the remaining fragments are separated by less than a kilometre, their spatial configuration forms fragmented conglomerates isolated from each other. As a result, the coastal montane range region is now probably isolated from all other habitat regions. Connection between the low-land habitats is mostly through the Cotacachi Cayapas reserve. Connection between southern and northern slopes of the Andes habitats should still be probable by dispersion through the matrix.

6.2.2 LIGHT POLLUTION

The properties of the matrix between habitat fragments are determinant factors in their level of isolation (Ewers & Didham, 2006). Isolation is the property of a habitat fragment that determines its probability of being reached by migrant individuals (Bender *et al.*, 2003). Light pollution could be defined as a feature of the matrix and it could have a dramatic effect on *C. argenteola* habitat isolation. Light pollution represents a matrix feature which obstructs dispersion, and increases the probability of mortality of dispersing individuals (Eisenbeis, 2006). At a landscape level, light pollution is a trap more than a geographical barrier. At present, light-polluted areas represent more than a third of *C. argenteola*'s original range further isolating an already fragmented habitat.

A fragmented habitat landscape forces individuals to travel through the matrix between habitat patches to avoid local extinction (Ewers & Didham, 2006). At present, nearly a quarter of straight routes between habitat patches pass through light polluted areas. However, this result underestimates the extent of potential interceptions by light pollution between habitat patches. When searching for resources insects rarely fly in straight lines; even when following an odour plume flight paths usually have non-linear trajectories such as spiral loops or zigzags (Bell, 1990; Cardé & Willis, 2008). Consequently, when *C. argenteola* individuals travel through the matrix, an irregular flight path would cover a broader surface than a straight flight path. This would increase the chances of falling under the attracting halo of a light source.

Near 15 % of *C. argenteola*'s habitat border is adjacent to light polluted areas. The proximity to light sources could increase probability of interception of individuals dispersing from and to the patch, sealing it from immigration and emigration. It is possible that the light vacuum effect could be operating under this circumstance. The light vacuum effect has been proposed as a possible effect of extensive urban lighting (Eisenbeis, 2006). Urban lights have been reported to affect and even eliminate insects in their immediate surroundings (Kolligs, 2000; Scheibe, 2003; Hagen *et al*. 2015). *Chrysina argenteola* populations living in small habitat patches may be especially vulnerable to this environmental impact of artificial lighting.

6.3 LANDSCAPE CONFIGURATION EFFECTS ON *C. ARGENTEOLA* POPULATIONS

6.3.1 HABITAT LOSS AND FRAGMENTATION

Habitat reduction alone is believed to be sufficient for a population to become extinct (Tilman *et al*., 1994). Studies on rare butterfly species suggest an extinction threshold when remaining habitat falls below 20% (Summerville & Crist, 2001). Though, this threshold should considerably depend on the nature of each species (Ewers & Didham, 2006). The results suggest that *C. argenteola* is quite resistant to habitat loss. High proportions of reports of *C. argenteola* occurred in areas with 5% and 12% remaining habitat (Figure 4). Complete absences of reports were at 10% of remaining habitat and below (Figure 4). These results suggest an approximate remaining habitat threshold for the species. In addition to habitat loss, other factors such as habitat isolation and matrix composition may result in variability in reports of the scarab (Ewers & Didham, 2006). Surprisingly, occasional reports of the scarab continue to occur at remaining habitat as low as 0.1%. In this case, reports may represent castaway dispersing individuals from larger habitat patches afar.

The effect of habitat fragmentation on the *C. argenteola* metapopulation will depend on sensitivity to habitat loss, border effects, and its dispersal capabilities. Habitat fragmentation is expected to be at least as deleterious as the effects of habitat loss alone (Ewers & Didham, 2006). Regardless of a species' tolerance to habitat loss and border effect, reduction in habitat patch area imposes a limit on population size (Lande, 1993; Amarasekare, 1998; Burkey, 1999). This is especially dangerous for insect populations because of the highly stochastic nature of their population numbers over time (Schultz & Hammond, 2003). A 200 m border effect has been proposed as a solid, conservative distance over which effects on insect communities can be measured (Didham, 1997). This implies ideally rounded patches over 0.5 km in area begin to show areas free of border effects. Reports of *C. argenteola* were still frequent in landscapes where average habitat patch size was 7.4 km^2 (Figure 4), suggesting a minimum size requirement for the species. If this is the case, at least 20% of current remaining habitat could not maintain a population over time. Although, reports keep occurring where average habitat patch size was 0.2 km^2, which shows these are at least serving as stepping stones.

The data suggests that *C. argenteola* has strong dispersal capabilities. High proportions of reports of the scarab were in areas where the closest habitat patch was 1 km distant, and reports occurred for areas as far as 3.24 km from forest patches (Figure 4). Other similarly sized saproxylic coleopterans have shown strong dispersal capabilities. *Monochamus galloprovincialis* (Coleoptera: Cerambycidae) individuals were able to reach a pheromone plume 4 km away in 8 days (Hernández *et al*. 2011; Gallego *et al*., 2012). The positive relation between reports of the scarab and the number of habitat patches suggests *C. argenteola* travels frequently between patches. Added support to this lies in the positive relation of reports with the number of habitat patches even when remaining habitat area is low or isolated. The readiness of this species for inter-patch travel may explain why infrequent reports keep occurring in areas where habitat is scarce or distant. Given the potential dispersal capabilities of *C. argenteola*, the species may be able to reach more than 99% of its remaining habitat in Ecuador.

Reports of *C. argenteola* in areas with little remaining habitat and the propensity of the species to disperse between patches may be due to a hospitable matrix between patches. Interviews reported *C. argenteola* females ovopositing on recently cut and living guava trees. Saproxylic species that colonize fresh-cut timber or living timber tend to be host specific (Hamilton, 1978). In the tropics, this specificity is rarely at the species level but often at higher taxonomic relationships such as genus or family (Tavakilian *et al*., 1997). It is possible that *C. argenteola* relies on the genus *Inga* or some higher level such as Fabaceae or Mimisoideae as host plants. Several guava tree species commonly grow on farmland and even urban settings such as home gardens and parks within the scarab’s distribution. This matrix could allow *C. argenteola* populations to exploit resources outside of the habitat patch and exist, at least momentarily, even in very small habitat patches. Moreover, a single guava tree may serve as a stepping stone for a dispersing *C. argenteola* individual. The possibility of a *C. argenteola* population living completely without the need of a forest patch is highly improbable provided the direct relation between the quantity of habitat and the reports of the scarab.

6.3.2 LIGHT POLLUTION

The results show light polluted areas are continually intercepting *C. argenteola* individuals throughout its habitat. However, light pollution by itself failed to explain the local abundance of the scarab. I propose a model to explain the insect interception dynamics of light sources in the landscape (Figure 9). In the absence of a light source there is no attracting halo, therefore no insect is intercepted. With increasing artificial light the attracting halo increases, therefore the quantity of intercepted insects increases. The number of intercepted insects will continue to increase with increasing lighting until the light vacuum effect begins (see discussion above). In this case, mortality caused by light begins to affect the local population by reducing its number of individuals. As a result, after the lighting vacuum effect threshold, increasing lighting should decrease the number of intercepted insects until complete landscape depletion. Increasing habitat quality or habitat quantity will dramatically increase attraction rates of increasing lit areas and will delay insect depletion in the landscape. Low quality habitats should be particularly sensitive to the threshold to reach the vacuum effect levels of artificial light. Our present results support our model. Intensely lit and low lit environments had low proportions of *C. argenteola* reports, and increased habitat quality drastically increases scarab reports even in low light environments. High quality habitat seems to be less vulnerable to increasing lit areas and vice versa. These results support the light interception and vacuum effects hypothesis acting on a landscape level simultaneously.

6.4 EXPLOITATION OF *C. ARGENTEOLA*

Considering current selling prices of *C. argenteola* specimens and collection rates, should allow an approximate US$40 to US$200 gain per month by a family during the months when adults are available. Ecuador's basic monthly salary is US$354; therefore, selling *C. argenteola* specimens could represent an 11.3% to 56.5% increase in family income during the months adult scarabs are available, 2-5 months per year. Furthermore, as collection of the scarab is performed by waiting around lights at night, the enterprise requires investment of minimum effort without interfering with other productive activities during the day. Results also suggest that the existence of an external buyer triggers *C. argenteola* commerce. In this context, despite trading of the species involved approximately one of every then respondents in one every six visited towns; *C. argenteola* trading is a volatile phenomenon that can happen anywhere within the scarab's distribution.

In towns where many families declared they engaged in trade of *C. argenteola* for years, the number of extracted specimens may have been in the magnitude of thousands. Local depletion of the scarab was reported in many of these places; however, I believe local depletion of *C. argenteola* was not achieved as a result of over-collection but rather the effects of light pollution and habitat loss. All traded specimens were collected at urban lights, and these insects were already at high risk of mortality because of the effects of light attraction alone. Traded specimens probably were from larvae that developed and emerged from forests near these towns, which have high risk of deforestation because of farmland expansion. As a consequence, traded *C. argenteola* specimens were already at high risk whether traded or not. Landscape light pollution and habitat loss should be more important concerns in *C. argenteola* conservation rather than exploitation of the species. Hawks (2002) also believes that habitat loss is a much greater menace to Rutelinae scarabs than over-collection. This is a widely maintained position for conservation of insects in general (Samways *et al.*, 2010).

6.5 CONSERVATION CATEGORY

Chrysina argenteola's habitat has been severely compromised by habitat loss, fragmentation, and light pollution in Ecuador. Therefore this insect deserves the "Vulnerable" category of conservation. Reports of the species exist up to the Valle del Cauca (M. A. Morón personal collection) and Chocó Departments in Colombia (Neita *et al*., 2006). Surely, the Departments of Nariño and Cauca also have populations of the species. This territory comprises an area of more than 50.000 km^2 and much of the forest remains in a fairly good condition (Rodríguez-Mahecha *et al.*, 2004). As a result, the global *C. argenteola* vulnerability category should probably be "Least Concern" (IUCN, 2012). This requires additional investigation to confirm the status of *C. argenteola* in Colombia.

6.6 CONCLUSIONS

This study is the first application of interviews to survey wild insect populations in Ecuador. Despite the limited interview sample size and the high error associated with the perception of the respondents, the data was sensitive enough to support hypothesized phenomena at a landscape level. Surveys are an alternative to study conspicuous insect species when resources for research are limited.

Chrysina argenteola's habitat in Ecuador has been severely compromised by habitat loss and fragmentation. Although, the scarab is relatively tolerant to habitat loss and has strong dispersal capabilities, fragmentation and light pollution synergetic effects jeopardize populations throughout the distribution of the insect. Exploitation of the species has probably not affected populations further from what they were already affected by habitat loss and light pollution. These results must reflect the conservation reality of many light attracted species living in similar landscape configurations as *C. argenteola*. We strongly urge the scientific community to further study the synergetic effect of habitat fragmentation and light pollution on populations of forest insects.

7 LITERATURE CITED

Amarasekare, P. 1998. Allee effects in metapopulation dynamics. American Naturalist 152: 298–302.

Beck, J., Linsenmair, E. K. 2006. Feasibility of light-trapping in community research on moths: attraction radius of light, completeness of samples, nightly flight times and seasonality of Southeast-Asian hawkmoths (Lepidoptera: Sphingidae). Journal of Research on Lepidoptera 39: 18-37.

Bell, W. J. 1990 Searching behavior patterns in insects. Annual Review of Entomology 35: 447-467.

Bender, D. J., Tischendorf, L., Fahrig, L. 2003. Using patch isolation metrics to predict animal movement in binary landscapes. Landscape Ecology 18: 17-39.

Bignell, B. E., Eggleton, P. 2000. Termites in ecosystems. In: Termites: evolution, sociality, symbioses, ecology (Abe, T., Bignell, E., Higashi, M. eds), pp. 363-387. Springer Science & Business Media.

Bowden, J. & Morris, M. 1975. The influence of moonlight on catches of insects in light-traps in Africa III: the effective radius of a mercury-vapor light-trap and the analysis of catches using effective radius. Bulletin of Entomological Research 65: 303-348.

Burkey, T. V. 1999. Extinction in fragmented habitats predicted from stochastic birth-death processes with density dependence. Journal of Theoretical Biology 199: 395–406.

Bustamante, M. R., Cárdenas, R. E. 2007. Bichos una mirada a la macrodiversidad tropical. Trama. Quito, Ecuador.

Cardé, R. T., Willis, M. A. 2008. Navigational strategies used by insects to find distant, wind-borne sources of odor. Journal of Chemical Ecology 34: 854-866.

Chapman, A. 2009. Number of living species in Australia and the world. Australian Government, Department of the Environment, Watern Heritage and Arts, Canberra, Australia.

Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. 2008. Georreferenciación de localidades de colecciones biológicas, manual de procedimientos. Comisión nacional para el conocimiento y uso de la biodiversidad (Conabio), México D.F., México.

Didham, R. K. 1997. An overview of invertebrate responses to forest fragmentation. In: Forests and Insects (Watt, A., Stork, N. E., Hunter, M. eds), pp. 303–320. Chapman and Hall, London, United Kingdom.

Dunn, R. 2005. Modern insect extinctions, the neglected majority. Conservation Biology 19: 1030-1036

Eisenbeis, G. 2006. Artificial night lighting and insects: attraction of insects to streetlamps in a rural setting in Germany. Ecological Consequences of Artificial Night Lighting (ed. by Rich, C. & Longcore, T. eds), pp. 345–364. Island Press, Washington D.C., U.S.A.

Eisenbeis, G., Hänel, A. 2009. Chapter 15. Light pollution and the impact of artificial night lighting on insects. In: Ecology of Cities and Towns (McDonnell, M., Hahs, A., Breuste, J. eds), pp. 243-263. Cambridge University Press, Cambridge, England.

Elith, J., Graham, C., Anderson, R., Dudík, M., Ferrier, S., Guisan, A., Hijmans, R., Huettmann, F., Leathwick, J., Lehmann, A., Li, J., Lohmann, L., Loiselle, B., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., Overton, J., Peterson, T., Phillips, S., Richardson, K., Scachetti-Pereira, R., Schapire, R., Soberón, J., Williams, S., Wisz, M., Zimmermann, N. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography 29: 129-151.

Ewers, R. M., Didham, R. K. 2006. Confounding factors in the detection of species responses to habitat fragmentation. Biological Reviews 81: 117-142.

Folgarait, P. J. 1998. Ant biodiversity and its relationship to ecosystem functioning: a review. Biodiversity and Conservation 7: 1221-1244.

Fox, R., Parsons, M.S., Chapman, J.W., Woiwod, I.P.,Warren, M.S., Brooks, D.R. 2013. The State of Britain’s larger moths 2013. Butterfly Conservation and Rothamsted Research, Wareham, England.

Gallego, D., Sánchez-García, F. J., Mas, H., Campo, M. T., Lencina, J. L. 2012. Estudio de la capacidad de vuelo a larga distancia de *Monochamus galloprovincialis* (Olivier 1795). (Coleoptera: Cerambycidae) en un mosaico agroforestal. Boletín de Sanidad Vegetal Plagas 38: 109-123.

Hagen, O., Santo, R. M., Schlindwein, M. N., Viviani, V. R. 2015. Artificial night lighting reduces firefly (Coleoptera: Lampyridae) occurrence in Sorocaba, Brazil. Advances in Entomology 3: 24-32.

Hamilton, W. D. 1978. Evolution and diversity under bark. In: Diversity of insect faunas (Mound, L. A., Waloff, N. eds), pp. 154-175. Royal Entomological Society of London, London, United Kingdom

Hawks, D. 2002. Jewel scarabs. University of Nebraska State Museum & Planetarium Museum Notes, 112.

Hawks, D. 2005. UNL State Museum - Division of Entomology. *Checklist of Chrysina species (Scarabeidae, Rutelinae, Rutelini)* [en línea]. [ref. de 5 de abril de 2014]. Disponible en Web: <http://museum.unl.edu/research/entomology/Guide/ Scarabaeoidea/Scarabaeidae/Rutelinae/Rutelinae-Tribes/Rutelini/Chrysina/Chrysina-species/C-argenteola/C-argenteola.html >.

Hernandez, P., Graham, C., Master, L., Albert, D. 2006. The effect of sample size and species characteristics on performance of different species distribution modelling methods. Ecography 29: 773-785.

Hernández, R., Ortiz, A., Pérez, V., Gil, J. M., Sánchez, J. 2011. *Monochamus galloprovincialis* (Olivier, 1795) (Coleoptera: Cerambycidae), comportamiento y distancias de vuelo. Boletín de Sanidad Vegetal Plagas 37: 79-96.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., Jarvis, A. 2005. Very high resolution interpolated climate surfaces for global land areas Global Change Biology. International Journal of Climatology 25: 1965-1978.

International Union for Conservation of Nature. 2012. IUCN red list categories and criteria. International Union for Conservation of Nature, Gland, Switzerland.

International Union for Conservation of Nature. 2013. *IUCN Red List of Threatened Species Version 2013.2* [en línea]. [ref 27 de marzo de 2014]. Available in Web: <www.iucnredlist.org>.

Jocque, M., Vanhove, M., Creedy, T., Burdekin, O., Núñez-Miño, J., Casteels, J. 2013. Jewel scarabs (*Chrysina* sp.) in Honduras: key species for cloud forest convervation monitoring? Journal of Insect Science 13: 1-18.

Kolligs, D. 2000. Ökologische auswirkungen künstlicher lichtquellen auf nachtaktive insekten, insbesondere schmetterlinge (Lepidoptera). Faunistisch-Ökologische Mitteilungen 28: 1-136.

Lande, R. 1993. Risks of population extinction from demographic and environmental stochasticity and random catastrophes. American Naturalist 142: 911–927.

Liu, C., White, M., Newell, G. 2013. Selecting treshhoolds for the prediction of species occurrence with presence-only data. Journal of Biogeography 40: 778-789.

Losey, J. E., Vughan, M. 2006. The Economic value of ecological services provided by insects. Bioscience 56: 311-323.

McKinney, M. L. 1999. High rates of extinction and threat in poorly studied taxa. Conservation Biology 13: 1273-1281.

Merow, C., Smith, M. J., Silander, J. A. 2013. A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. Ecography 36: 1058-1069.

Ministerio del ambiente del Ecuador. 2012. Línea base de deforestación del Ecuador continental. Ministerio del ambiente del Ecuador. Quito, Ecuador.

Morón, M. 1991. Estudio biogeográfico-ecológico preliminar del género *Plusiotis* Burmeister (Coleoptera, Melolonthidae, Rutelinae). Giornale Italiano di Entomologia 5: 309-323.

Mosandl, R. Günter, S., Stimm, B., Weber, M. 2008. Ecuador suffers the highest deforestation rate in South America. In: Gradients in a tropical mountain ecosystem of Ecuador (Beck, E., Bendix, J., Kottke, I., Makeschin F., Moandl, R. eds), pp. 37-38. Springer-Verlag Berlin, Heidelberg, Germany.

Muirhead-Thompson, R. 1991. Trap responses of flying Insects. Academic Press, London, England.

Muscarella, R. Galante, P. J. Soley-Guardia, M. Boria, R. A. Kass, J. M. Uriarte, M., Anderson, R. P. 2014. ENMeval: An R package for conducting spatially independent evaluations and estimating optimal model complexity for MAXENT ecological niche models. Methods in Ecology and Evolution 5: 1198–1205

Neita, J. C., Orozco, J., Ratcliffe, B. 2006. Escarabajos (Scarabaeidae: Pleurosticti) de la selva baja del bosque pluvial tropical «BP-T», Chocó, Colombia. Acta Zoológica Mexicana 22: 1-32.

Ohaus, F. 1918. Scarabaeidae: Euchirinae, Phaenomirinae, Rutelinae. En: Coleopterorum catalogus (Junk, E., Schenkling, S. eds), pp. 1-241.W. Junk, Berlin, Germany.

Onsager, J. & Day, A. 1973. Efficiency and effective radius of blacklight traps against Southern Potato Wireworm. Journal of Economical Entomology 66: 403-409.

Pearson, R.G., Raxworthy, C.J., Nakamura, M., Peterson, A.T. 2007. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. Journal of Biogeography 34: 102–117

Phillips, S., Anderson, R. Schapire, R. 2006. Maximun entropy modeling of species geographic distributions. Ecological modeling 190: 231-259.

Pimm, S., Raven, P. 2000. Extinction by numbers. Nature 403: 843-845.

Plaut, H. 1971. Distance of attraction of moths of *Spodoptera littoralis* to BL radiation, and recapture of moths released at different distances of an ESA blacklight standard trap. Journal of Economical Entomology 64: 1402-1404.

Price, P. 1997. Insect ecology. John Wiley & Sons Inc., Nueva York, E.E.U.U.

Radosavljevic, A., Anderson, R. 2014. Making better MAXENT models of species distributions: complexity, overfitting and evaluation. Journal of Biogeography 41: 629-643.

Rodríguez-Mahecha, J., Salaman, P., Jorgensen, P., Consiglio, T., Suárez, L., Arjona, F., Bensted-Smith, R. 2004. Tumbes-Chocó-Magdalena. In: Hotspots revisited (Mittermeier, R., Gil, P., Hoffmann, M., Pilgrim J., Brooks, T., Mittermeier, C., Lamoreoux, J., Da Fonseca, G. eds), pp. 80-84. Cemex, Ciudad de México, México.

Samways, M., McGeoch, M., New, T. 2010. Insect conservation. Oxford University Press, New York, U.S.A.

Scheibe, M. 2003. Über den einfluss von straßenbeleuchtung auf aquatische insekten (Ephemeroptera, Plecoptera, Trichoptera, Diptera: Simuliidae, Chironomidae, Empididae). Natur und Landschaft, 6: 264-267.

Schultz, C. B., Hammond, P. C. 2003. Using population viability analysis to develop recovery criteria for endangered insects: case study of the Fender's blue butterfly. Conservation biology, 17: 1372-1385.

Shcheglovitova, M. and Anderson, R. P. 2013. Estimating optimal complexity for ecological niche models: a jackknife approach for species with small sample sizes. Ecological Modelling, 269: 9-17.

Sierra, R. 1999. Propuesta preliminar de un sistema de clasificación de vegetación para el Ecuador continental. Proyecto INEFAN/GEF-BIRF & EcoCiencia, Quito, Ecuador.

Sierra, R. 2013. Patrones y factores de deforestación en el Ecuador continental, 1990-2010. Y un acercamiento a los próximos 10 años. Conservación Internacional Ecuador, Forest Trends. Quito, Ecuador.

Summerville, S. K., Crist, T. O. 2001. Effects of experimental habitat fragmentation on patch use by butterflies and skippers (Lepidoptera). Ecology 82: 1360-1370.

Syfert, M., Joppa, L., Smith, M., Coomes, D., Bachman, S., Brummitt, N. 2014. Using species distribution models to inform IUCN redlist assessments. Biological Conservation 177: 174-184

Tavakilian, G., Berkov, A., Meurer-Grimes, B., Mori, S. 1997. Neotropical tree species and their faunas of xylophagous longicorns (Coleoptera: Cerambycidae) in French Guyana. The Botanical Review 63: 303-355.

Tilman, D., May, R. M., Lehman, C. L. Nowak, M. A. 1994. Habitat destruction and the extinction debt. Nature 371: 65–66.

Thomas, C., Bulman, C., Wilson, R. 2008. Where within a geographic region do species survive best? A matter of scale. Insect Conservation and Diversity 1: 2-8.

Wallace, B. J., Webster, J. R. 1996. The role of macroinvertebrates in stream ecosystem function. Annual Reviews of Entomology 41: 115-139.

8 FIGURES

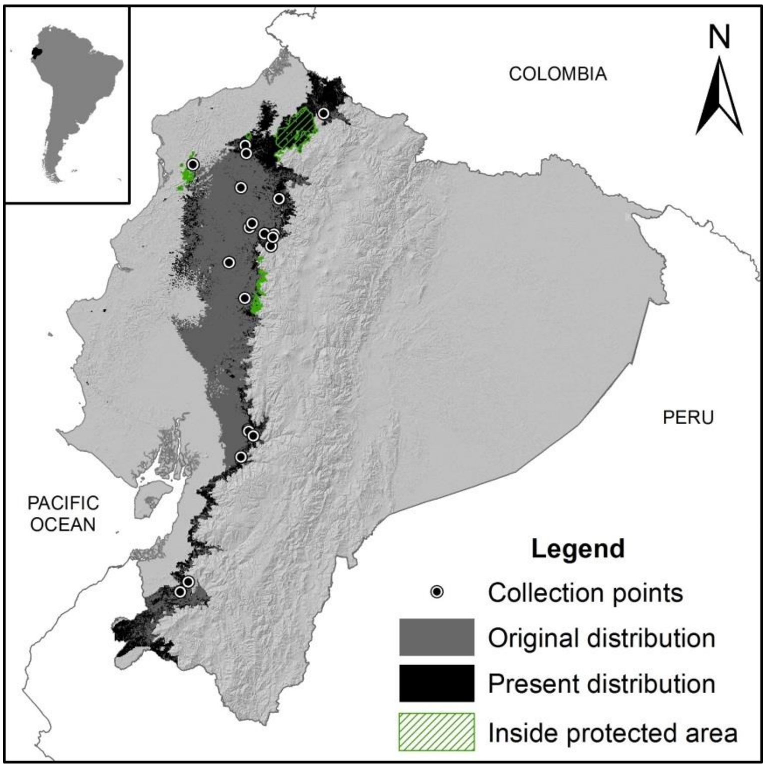

Figure 1. Original and present distribution of *Chrysina argenteola* in Ecuador.

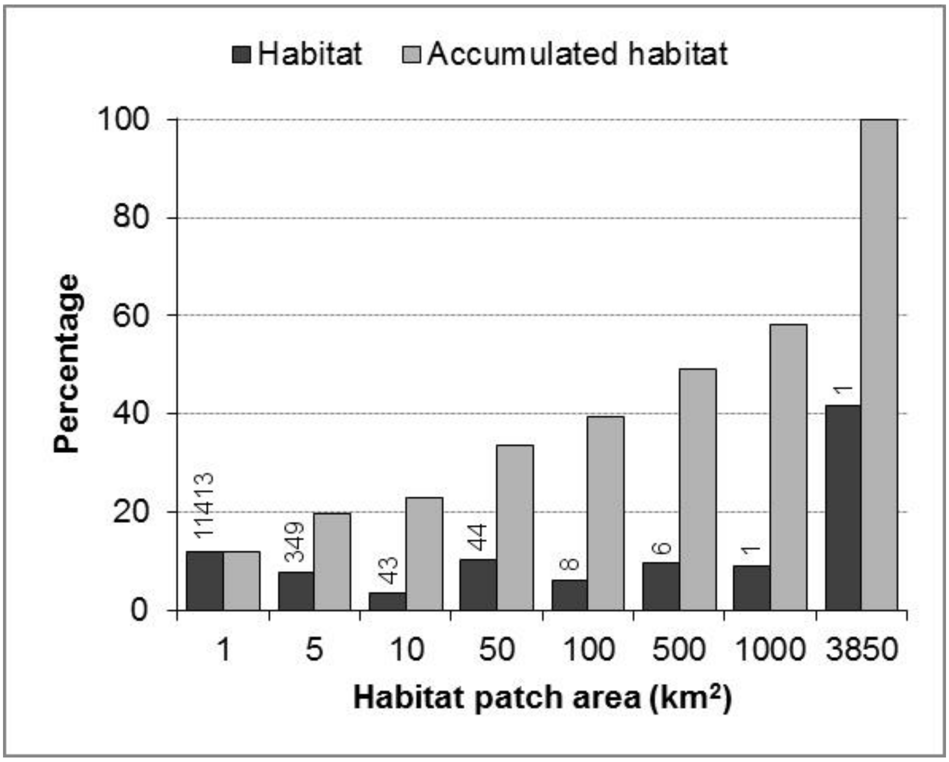

Figure 2. Habitat percentage and accumulated percentage of different habitat patch sizes ranges on *Chrysina argenteola* present distribution in Ecuador. Numbers over bars represent the number of habitat patches.

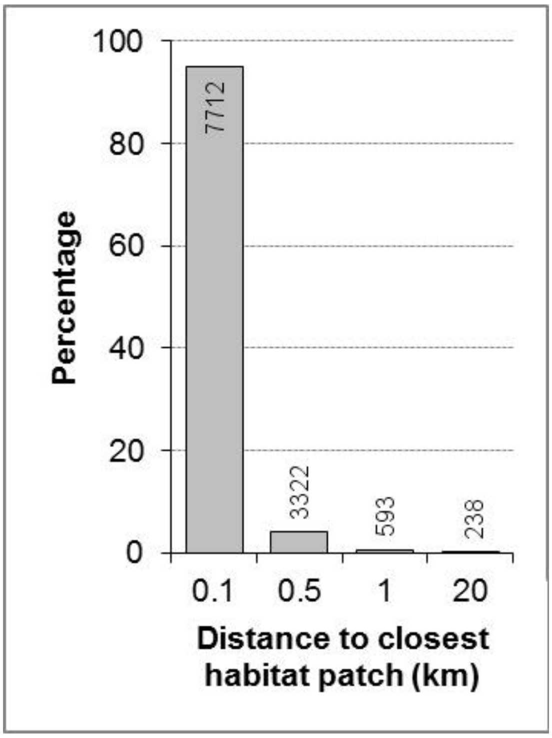

Figure 3. Habitat percentage at different distance ranges to the closest habitat patch in present distribution of *Chrysina argenteola* in Ecuador. Numbers over bars represent the number of habitat patches.

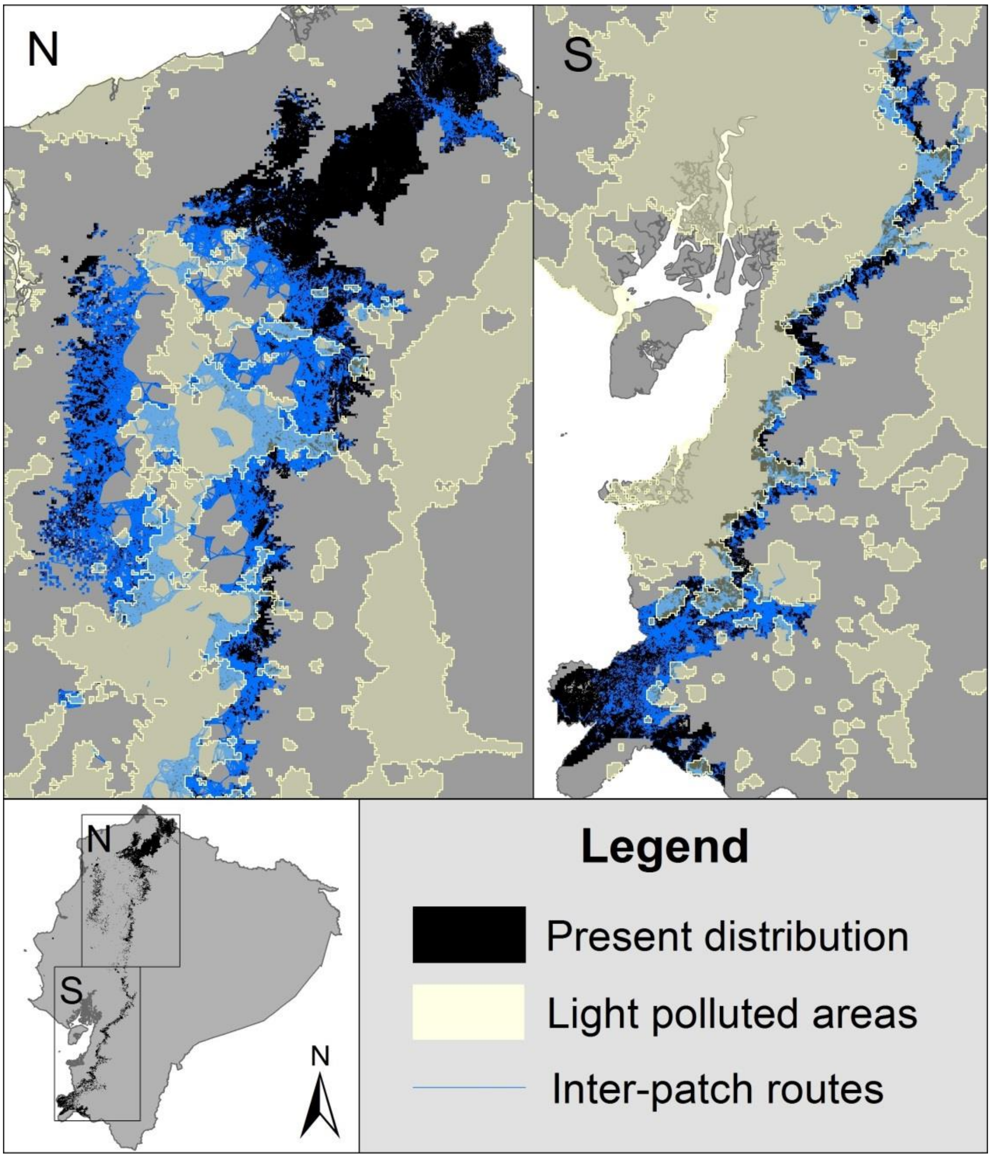

Figure 4. Light pollution and inter-patch routes in the present distribution of *Chrysina argenteola* in Ecuador. The severely fragmented habitat renders 799174 inter-patch routes making its spatially dense quantity appear like polygons. Intercepted routes appear under the transparent light polluted areas.

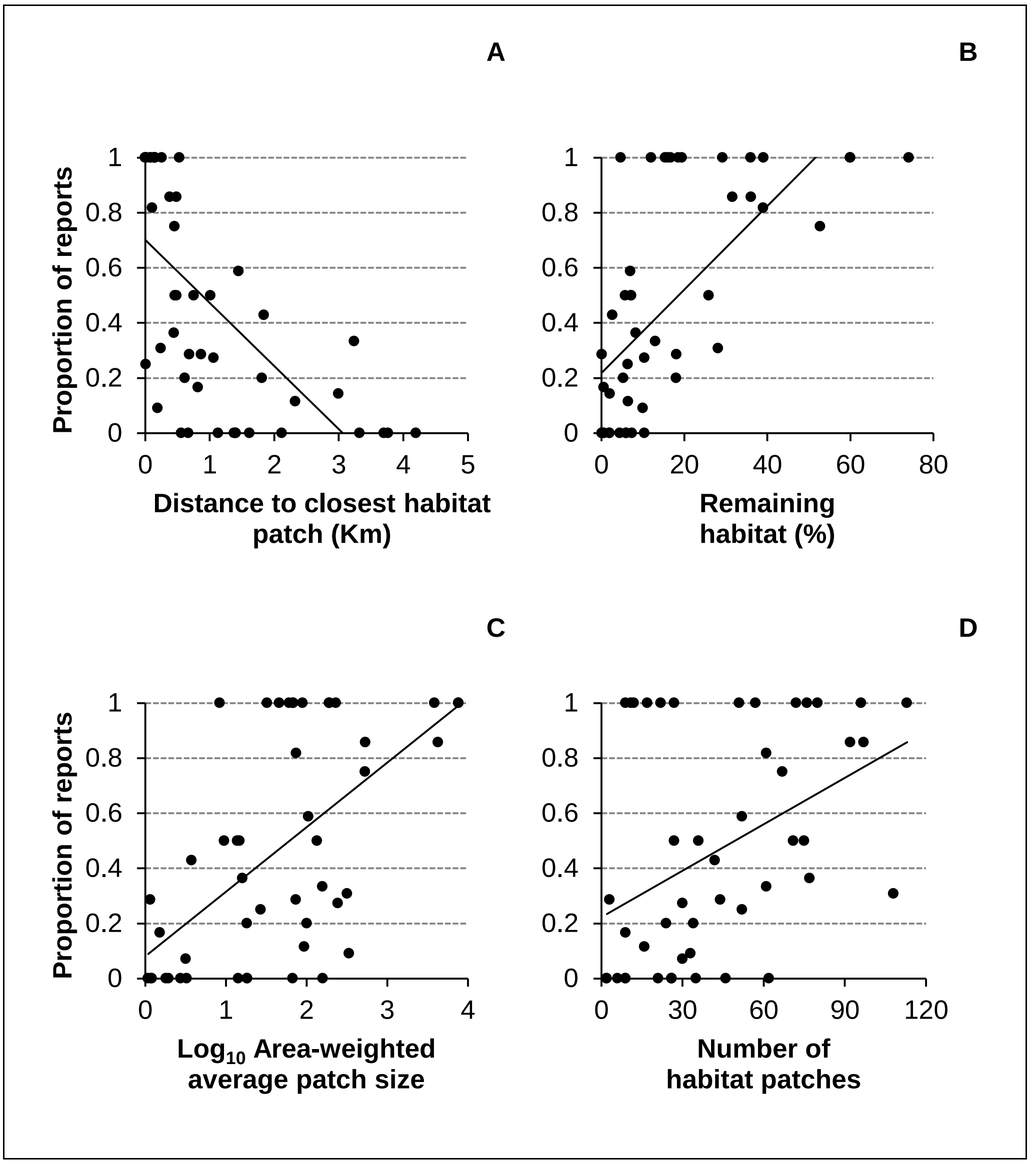

Figure 5. Proportion of people who saw *Chrysina argenteola* at each site (N=48) depending on: the distance to the closest habitat patch (r_p=-0.593, P<0.001) (A); and the percentage of remaining habitat (r_p=0.63, P<0.001) (B); the area-weighted average patch size (r_p=0.464, P=0.001) (C); and, the number of habitat patches (r_p=0.431, P=0.002) (D); all within a 5 km radius.

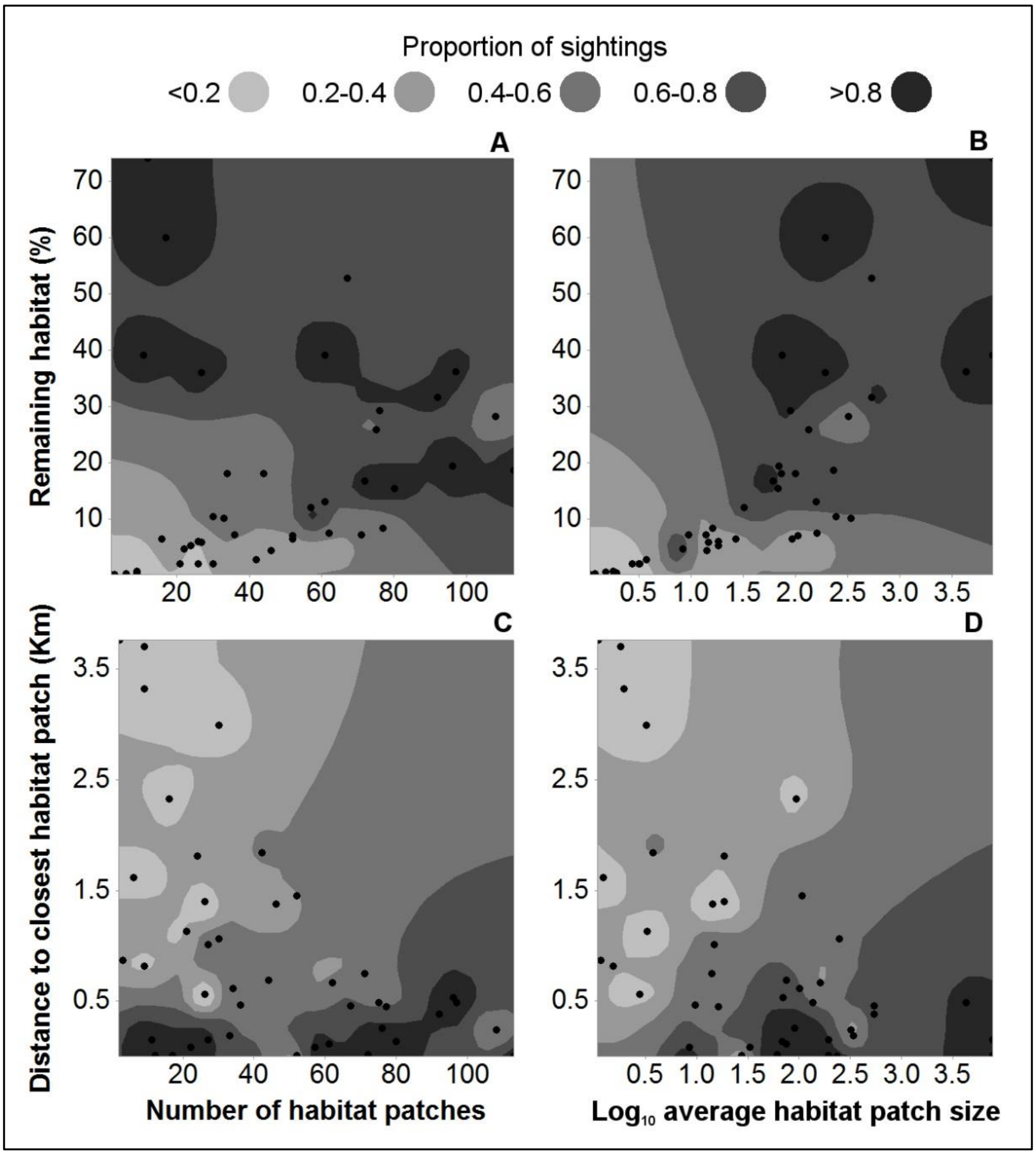

Figure 6. Proportion of people who have seen *Chrysina argenteola* within each site (N=48) depending on landscape variable interactions: remaining habitat percentage within a 5 km radius interacting with the number of habitat patches (A) and the $\log_{10}$ transformed area-weighted average habitat patch size (B), and distance to closest habitat patch interacting with the habitat patch number (C) and the habitat patch average size (D).

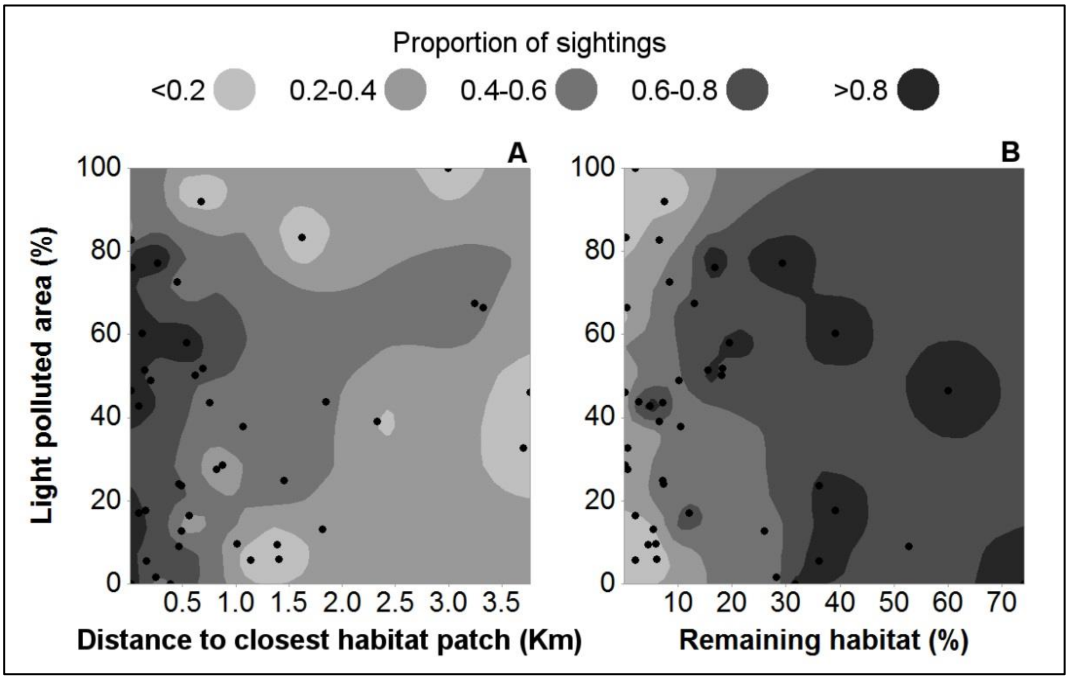

Figure 7. Proportion of people who have seen *Chrysina argenteola* within each site (N=48) depending on landscape interactions between the percentage of light polluted area and the distance to the closest habitat patch (A) and the amount of remaining habitat (B).

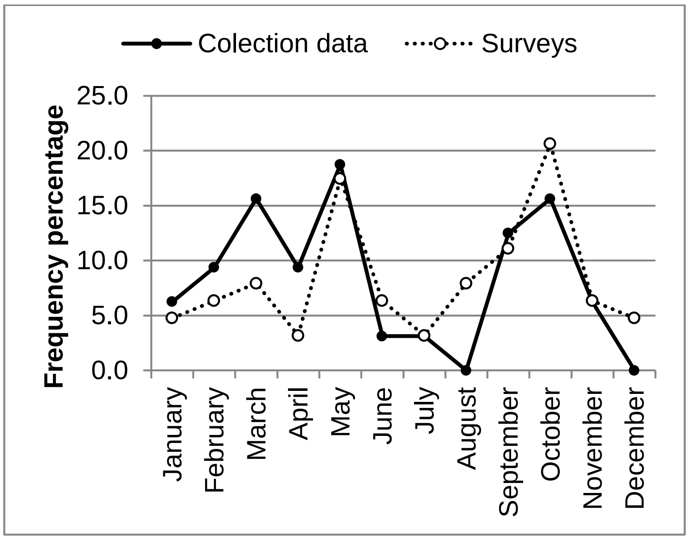

Figure 8. Percentage of frequency of collection dates (N=41) and sightings by local people (N=85) of *Chrysina argenteola* in each month.

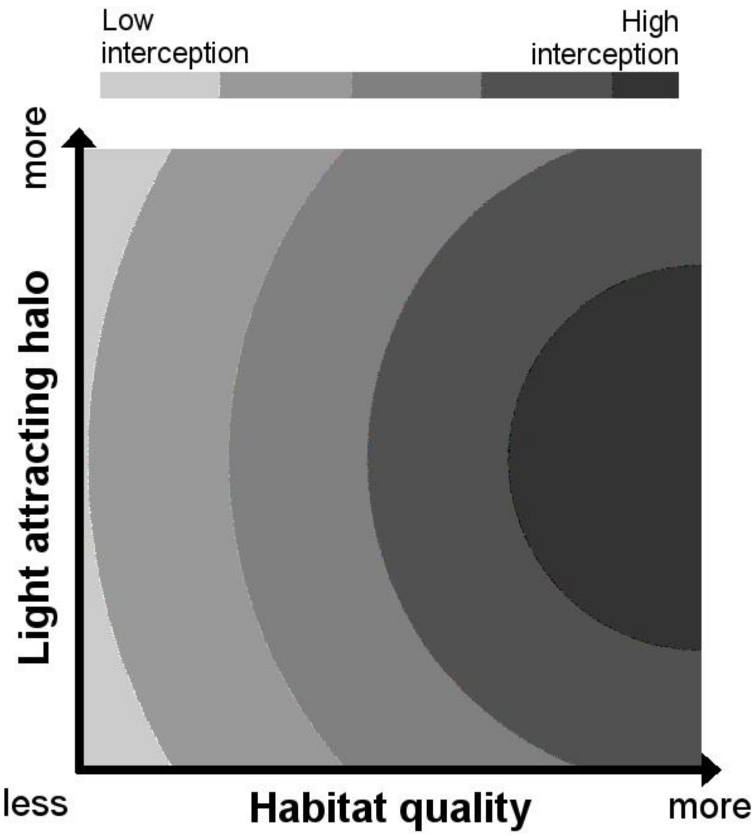

Figure 9. Proposed model of landscape insect interception depending on lighting area and habitat quality. Low light environments have low chances to intercept insects because of a reduced attracting halo. Highly lit environments have low chances of interception because of insect depletion caused by the light vacuum effect. Highest chances of insect interception occur at intermediately lit environments that have not passed the light vacuum effect threshold. Higher quality habitats increase the interception effect of light, and delays the light vacuum effect threshold.

9 TABLES

Table 1. Number of people interviewed concerning *Chrysina argenteola* at each location.

Location	Province	Latitude	Longitude	Number of interviews
Alluriquín	S. Domingo de los Tsáchilas	-0.353499	-78.939444	19
Buena Suerte	Pichincha	0.05	-79.219944	7
Chiguilpe	Pichincha	-0.320444	-79.212167	6
Cóngoma	S. Domingo de los Tsáchilas	-0.339138	-79.282964	5
Conrad Adenaguer	Pichincha	0.153604	-79.01476	6
Cristal del Lelia	S. Domingo de los Tsáchilas	-0.40175	-79.029028	5
Cristóbal Colón	Esmeraldas	0.456461	-79.159149	5
Cristóbal Colón	Pichincha	-0.048555	-79.181513	15
Dos Ríos	S. Domingo de los Tsáchilas	-0.304639	-78.894417	6
El Cisne	Pichincha	0.172735	-79.039888	5
El Paraíso	S. Domingo de los Tsáchilas	-0.313417	-79.0235	5
El Tránsito	S. Domingo de los Tsáchilas	-0.308694	-78.867389	9
Espejo	Pichincha	-0.220234	-78.977275	5
Fruta de Pan	Esmeraldas	0.386609	-79.203608	5
Guayabillas	Pichincha	0.204472	-78.917056	7
La Abundancia	Pichincha	0.053952	-79.253754	5
La Bonanza	Pichincha	0.132189	-79.10242	5
La Caoni	Pichincha	-0.006296	-79.208924	5
La Celica	Pichincha	0.156745	-79.066442	21
La Concordia	Manabí	0.009091	-79.391749	5
La Florida	S. Domingo de los Tsáchilas	-0.277056	-79.018528	9
La Playita	S. Domingo de los Tsáchilas	-0.276528	-79.075361	6
La Pradera	S. Domingo de los Tsáchilas	-0.38605	-78.914127	5
La Té	Esmeraldas	0.419625	-79.19861	5
Las Golondrinas	Esmeraldas	0.320575	-79.212177	5
Las Mercedes	S. Domingo de los Tsáchilas	-0.183417	-79.023083	12
Las Pampas	Cotopaxi	-0.43488	-78.963893	5
Los Laureles	Pichincha	0.141136	-78.970621	11
Mashpi	Pichincha	0.177113	-78.90609	5
Pachijal	Pichincha	0.161123	-78.936928	12
Palo Quemado	S. Domingo de los Tsáchilas	-0.374722	-78.991083	14
Paraíso Escondido	Pichincha	0.061091	-79.138397	5
Pedro Vicente Maldonado	Pichincha	0.085361	-79.050738	13
Playas de Lindiche Alto	S. Domingo de los Tsáchilas	-0.250194	-79.013306	10
Puerto Nuevo	Esmeraldas	0.465334	-79.241141	5
Puerto Quito	Pichincha	0.127252	-79.253159	9
Reserva Canandé	Esmeraldas	0.45139	-79.20111	5
Río Blanco	Pichincha	0.003698	-78.916822	5

Table 1. Continued.

Location	Province	Latitude	Longitude	Number of interviews
San Bernabé	Pichincha	-0.013149	-79.092141	8
San Miguel de Lelia	S. Domingo de los Tsáchilas	-0.361174	-79.024959	9
San Miguel de los Bancos	Pichincha	0.023114	-78.894836	9
San Vicente de Andoas	Pichincha	0.075653	-78.997343	12
Santa Rosa de Lima	S. Domingo de los Tsáchilas	-0.351114	-78.923199	16
Santo Domingo	S. Domingo de los Tsáchilas	-0.255557	-79.17325	12
Tinalandia	S. Domingo de los Tsáchilas	-0.297611	-79.052861	5
Unidos Venceremos	Pichincha	0.081364	-79.19579	5
Unión del Toachi	S. Domingo de los Tsáchilas	-0.31802	-78.953954	10
Zapallo	Esmeraldas	0.414302	-79.24803	5

10 ANNEXES

Annex 1. Collections where *C. argenteola* locality records were obtained.

Acronym	Museum
BCRC	Brett C. Ratcliffe personal collection.
EPN	Mueso de la Escuela Politécnica Nacional, Quito-Ecuador.
MECN	Museo Ecuatoriano de Ciencias Naturales, Quito-Ecuador.
MXAL	Miguel A. Morón personal collection.
NHMUK	Natural History Museum, London-UK.
QCAZ	Museo de Zoología de la Pontificia Universidad Católica del Ecuador, Quito-Ecuador.
RBINS	Royal Belgian Institute of Natural Sciences, Brussels-Belgium.
UNSM	University of Nebraska State Museum, Lincoln-Nebraska-USA.
USNM	National Museum of Natural History, Washington DC-USA.

Annex 2. Interview sheet concerning *Chrysina argenteola*.

Entrevistador:

Número de entrevista:

Lugar:

Coordenadas:

Sexo:	MASCULINO	FEMENINO		
Edad:	ADOLESCENTE	ADULTO	3RA EDAD	
Identidad:	COLONO	NATIVO/ ETNIA:		
Ocupación:	AGRICULTOR	GANADERO	COMERCIANTE	ESTUDIANTE

¿Conoce usted a este escarabajo?

SI	NO

¿Conoce usted a este escarabajo?	¿Conoce usted a este escarabajo?	¿Conoce usted a este escarabajo?

¿Qué ha hecho cuando encuentra un escarabajo?

¿Alguna a vez lo ha vendido?

SI	NO

¿Cómo obtiene los escarabajos que vende?

¿A cuánto lo vendió?:

¿A quién o dónde lo vendió?:

¿Cuántos escarabajos vende por semana/mes?:

El entrevistado ofreció vender el escarabajo durante la entrevista

SI	NO

¿En qué tiempo del año cree que se ve más al escarabajo?

Observaciones:

PONTIFICIA UNIVERSIDAD CATÓLICA DEL ECUADOR

DECLARACIÓN Y AUTORIZACIÓN

Yo, Luis Felipe Camacho Cárdenas, C.I. 171000749-1 autor del trabajo de graduación intitulado: "Vulnerability of a jewel scarab (Coleoptera, Scarabaeidae, Rutelinae) in a highly fragmented light-polluted landscape in Ecuador", previa a la obtención del grado académico de **MAGISTER EN BIOLOGÍA DE LA CONSERVACIÓN** en la **Facultad de Ciencias Exactas y Naturales**:

1.- Declaro tener pleno conocimiento de la obligación que tiene la Pontificia Universidad Católica del Ecuador, de conformidad con el artículo 144 de la Ley Orgánica de Educación Superior, de entregar a la SENESCYT en formato digital una copia del referido trabajo de graduación para que sea integrado al Sistema Nacional de Información de la Eduación Superior del Ecuador para su difusión pública respetando los derechos de autor.

2.- Autorizo a la Pontificia Universidad Católica del Ecuador a difundir a través de sitio web de la Biblioteca de la PUCE el referido trabajo de graduación, respetando las políticas de propiedad intelectual de la Universidad.

Quito, 8 de abril de 2015

Sr. Luis Felipe Camacho Cárdenas

C.C. 171000749-1