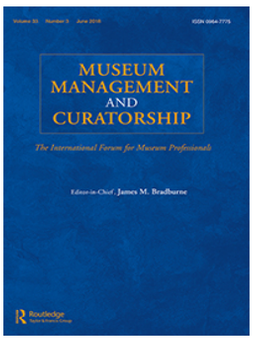

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An accounting approach to calculate the financial value of a natural history collection of mammals in Ecuador

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ABSTRACT

Biologists and economists collaborated to estimate the monetary value of the Mammal collection of the Museo de Zoología at PUCE in Quito. We analyzed the direct and indirect costs associated with collecting, preparing, and transporting mammal specimens during four 20-day trips. We determined that the average cost per specimen was $74.70. However, because the number of specimens caught in an expedition can vary, 36 expeditions varying in length between 2003 and 2016 were used, and each expedition was assigned a total cost based on the number of work days, at the baseline total cost per day obtained. The final valuation resulted in a per acquisition cost of $72.86. The total acquisition cost of the current collection is more than one million dollars. This result is a powerful argument to encourage support for research and conservation of zoological specimens.

RESUMEN

En un trabajo conjunto entre biólogos y economistas, se estimó el costo monetario de la colección de Mamíferos del Museo de Zoología de la Pontificia Universidad Católica del Ecuador en Quito. Analizamos los costos directos e indirectos asociados con la recolección, preparación y transporte de especímenes de mamíferos durante cuatro viajes de 20 días. Determinamos que, para este sub-proyecto, el valor promedio por espécimen fue de $74.70. Sin embargo, dado que el número de especímenes capturados en una expedición puede variar ampliamente, se usaron 36 expediciones con duraciones variables entre 2003 y 2016 y a cada expedición se le asignó un costo basado en el número de días de trabajo, tomando en cuenta el costo base por día obtenido. La valoración final resultó en un costo de adquisición por muestra de $72.86. El costo total de adquisición de la colección actual es de más de un millón de dólares. Este resultado es un poderoso argumento para alentar el apoyo para la investigación y conservación de especímenes zoológicos.

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Introduction

The Museum of Zoology at the Pontificia Universidad Católica del Ecuador (QCAZ) is a natural history museum belonging to the School of Biological Sciences. The museum came into being in the early seventies, initially for teaching purposes, after accessioning various vertebrate specimens, primarily birds. Ten years later, the QCAZ museum was organized into two sections, one for invertebrates and another for vertebrates, as each area began to thrive independently and grow at a steady rate. By the nineties, the collections of vertebrates and their physical infrastructure were augmented and reorganized into four divisions: Herpetology, Mammalogy, Ichthyology, and Ornithology.

The QCAZ's Mammalogy Division is currently the world's largest and most diverse collection of the mammals of Ecuador (Tirira 2014), with over 16,000 specimens from the 14 orders, 47 of the 52 families; 174 from the 207 genera and 356 from the 434 species (82%) occurring in Ecuador according to the current lists of mammals (Tirira 2017), including five holotypes. Additionally, it is the only Ecuadorian collection, and only the third collection in Latin America, to be certified by the American Society of Mammologists; it was certified in 2011, after being inspected and demonstrated to meet or exceed the curatorial standards as established by the ASM Systematic Collections Committee (2004).

Currently, the Mammalogy Division, as the other collections of the Museum of Zoology, is used mainly for research by local and foreign scientists as a reference in taxonomic, ecological, and biogeographic studies. No specimens are on display in any galleries open to the public. As a result, this museum is neither culturally iconic nor a tourism product which might be financially relevant in terms of visitation.

The Museum of Zoology is part of a private university and is funded through the university. The funds allocated to research and its annual budgets for operating, personnel, and maintenance costs come from the educational establishment itself and from external local and international funding secured by its researchers.

The scientific collections stored in the QCAZ are likely to increase the knowledge of the natural heritage of Ecuador, and, in turn, allow for a more accurate estimate of national patrimony in terms of biodiversity. As stated in Book Two of the Organic Code on the Environment – adopted in December, 2016 – Ecuador's biodiversity is an element of its Natural Heritage and, in this context, its public policy seeks to, among other things, conserve and sustainably use this biodiversity by means of the fostering and regulation of research involving the creation and use of scientific collections (Article 32) in those herbariums and museums considered as centers for documentation and recording of this heritage (Article 66).

Consequently, these collections are essential for the acknowledgment, protection and conservation of a national natural heritage. Ballart-Hernández and Tresserras (2001) argued that the *patrimonium* category is linked to the term '*patris*', or that which is inherited from one's parents. From a financial standpoint, it represents the tangible and intangible property that we, as a society, received from the past and possess for a period (i.e., an intertemporal process), which plays a socio-economic role and can therefore be valued in pecuniary terms.

In Ecuador, however, scientific collections, as heritage, have not been financially valued. Partly because museums themselves do not recognize the collections as 'assets' in their financial statements and budgets (Bradley et al. 2012) and partly because of a still

widespread misunderstanding by the governing authorities of research centers, universities, and governmental offices of their importance and potential uses.

Despite the fact that various publications discuss the scientific, cultural, and aesthetic value these collections have for nations (Allmon 1994; Lane 1996; Blackmore et al. 1997; Patterson 2002; Suarez and Tsutsui 2004; Funk et al. 2005; Phillips et al. 2009; Minteer et al. 2014; Moratelli 2014) recent literature on how to best estimate the financial value of a scientific collection is scarce.

Blackmore et al. (1997) proposed a method to estimate the financial value of the zoological collections of the Natural History Museum of London by considering the costs invested in acquiring, curating, and maintaining those collections based on data from yearly departmental reports, museum files, and public accounting records. This resulted in highly variable figures – thus evincing the complexity and extreme inaccuracy of this undertaking. Because of this, rather than obtain a definite amount, they produced a methodology by which a valuation estimate can be computed.

Bradley et al. (2012) and Baker et al. (2014) also performed an analysis of the Recent Mammals collection of The Natural Science Research Laboratory (NSRL) in Texas Tech University (TTU) to establish its monetary value. The first analysis examined the costs associated with the collection, preparation, and transport of mammal specimens to the museum. The methodology consisted of estimating the average cost per voucher specimen based on expenses associated with sample-gathering during a number of scientific expeditions. Thus, over an 11-year period and 61 field trips (50 regional and 11 international trips), the mean cost for specimens collected on regional field trips was $41.00, and $74.00 for international expeditions, which together produced an average cost per specimen of $56.00. Baker et al. (2014), for their part, supplemented that research by considering the costs of subsequent activities associated with specimen maintenance, such as voucher specimen curation, reception, and documentation, as well as the yearly costs associated with preservation and provision of online access to information. This study estimated an annual specimen cost of $17.51 considering a sample of six local and international field expeditions.

The research work of both Bradley et al. (2012) and Baker et al. (2014) satisfied a specific administrative requirement by TTU. In other circumstances, this type of information is also gathered for insurance reasons in the context of asset risk management of an institution. Santos-Mazorra and Rey-Fraile (2015), using all of the collections of the Museo Nacional de Ciencias Naturales de Madrid (MNCN-CSIC) as an example, devised a method to value 'for insurance purposes' natural history specimens by means of a number of parameters analogous to those considered by the Spanish public administration for the applicable accounting and valuation of various assets.

Their analysis, in addition to noting that the estimated valuation can be used to insure museum pieces during their handling and display (given their nature as cultural assets), also argued that any figures that might be worked out cannot be valued, that is, they are not market prices given that they are outside the market, and this valuation is carried out solely for the purposes of insurance. The defined parameters corresponded, on one hand, to a real, tangible financial cost (such as the costs incurred in capture permit processing, transport and import, etc.), and on the other, by means of a more complex estimation, to an intangible value, such as the scientific value or potential future value in use (Santos-Mazorra and Rey-Fraile 2015). While this work did not

provide a specific mean cost per specimen, it provides a method to determine the value of a specific piece using computed tangible costs and proposed indices of intangible values. Although these analyses assign value to research collections, the calculation methods, costs set, and proposed indices cannot be extrapolated to Ecuador (reasons for this are discussed later in this paper).

Herein, we present a combined effort between biologists and economists to put forward a reproducible calculation method to estimate the minimum monetary value of a biological collection, using the QCAZ's mammal collection as an example. After all, monetary values are well understood units of comparison when communicating and justifying the relative significance of the collections to society at large (Blackmore et al. 1997).

The accounting information for this exercise was limited to four field expeditions in 2015, each lasting three weeks, as a part of the project named '*Caracterización de la Biodiversidad del Parque Nacional Podocarpus, Parque Nacional Sangay, Parque Nacional Yacuri y Parque Nacional Llanganates* (ARCA)' authorized by the Ecuadorian Ministerio del Ambiente under the Contrato Marco MAE-DBN-ARRGG-CM-2014-002 and funded by the Secretaría de Eduación Superior, Ciencia, Tecnología e Innovación (SENESCYT). The budgets analyzed are those of the sub-project ARCA-Mamíferos 2015.

Methodology

The budget information of ARCA-Mamíferos 2015 offered ideal baseline conditions for the financial valuation of a portion of the mammal collection of the Museum of Zoology at PUCE using the cost information therein, because of its completeness, detail, and the fact that it called for the replacement of equipment and the purchase of essential supplies optimized for use for the combined eighty days of all four expeditions.

The accounting information for this study was compiled from invoices, sales notes, salary payments, and the examination of market prices for supplies at the time. In this respect, the methodology described below resembles the one by Bradley et al. (2012), while seeking to achieve more general conditions for extrapolation to other contexts.

This methodology, in addition to valuing the total cost of the expeditions of the ARCA-Mamíferos 2015 sub-project, works out a cost per specimen x, as a weighted mean of the mean cost of two groups of micromammals collected in this project, indexed as group 1 and group 2, and expressed as x_1 and x_2. Grouping is oriented by the equipment, materials, and collection techniques specific to the various orders of micromammals collected.

In this context, the order Chiroptera received independent treatment (group 1) as the equipment and supplies required to collect these specimens are specific to this group, such as headlamps, batteries, and mist nets. On the other hand, the orders Didelphimorphia, Lagomorpha, Paucituberculata, and Rodentia were grouped in another category (group 2) as these small to medium sized terrestrial mammals require supplies different to those used with bats (group 1), such as specific live traps that are baited and checked during the day. It should be noted that both groups also share supplies and equipment, and therefore, the resulting costs shared by both groups were indexed as group 0.

Larger species of mammals were not the target of these expeditions, so they were not considered in the analysis. Usually, species of primates, carnivores, xenarthrans, or

ungulates are donated or collected incidentally, thus they are not well represented at QCAZ, representing less than 2% of the specimens.

*Direct costs (**d**)*

These types of costs include the remuneration of the minimum workforce, the basic equipment and consumables that were the baseline features of the ARCA-Mamíferos 2015 field work to be performed.

These assumptions are intended to avoid biases that might result from the inclusion of non-essential costs in the final valuation, in order to extrapolate our findings to similar expeditions.

The expression below indicates direct costs d expressed in vector notation for convenience.

$$d = \boldsymbol{sa} + \boldsymbol{fc},$$

In this context the following is proposed:

$$\boldsymbol{sa} = \begin{bmatrix} s_1 & s_2 & \dots & s_A \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_A \end{bmatrix} \quad \text{and} \quad \boldsymbol{fc} = \begin{bmatrix} f_1 & f_2 & \dots & f_M \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_M \end{bmatrix}.$$

Where $\boldsymbol{s}$ represents the hourly cost per type of professional participating during the field work and $\boldsymbol{a}$ the number of total man-hours in each case. The expression $\boldsymbol{fc}$ represents a multiplication of the unit price $\boldsymbol{f}$ by a quantity of consumables $\boldsymbol{c}$ directly used for specimen collection and delivery to the museum. The curation and maintenance processes were not considered for this analysis (see the *Discussion* for further details).

*Indirect costs (**z**)*

As regards to indirect costs, five groups that make collection viable were considered. The following expression indicates indirect costs z expressed in vector notation as well.

$$z = \boldsymbol{wb} + \boldsymbol{gy} + \boldsymbol{\varepsilon q} + \boldsymbol{th} + \boldsymbol{\tau}.$$

The first group is associated with the academic personnel needed to plan and coordinate field work, as well as to receive the specimens at the museum. The expression $\boldsymbol{wb}$ is the product of a vector $\boldsymbol{w}$ containing the man-hour costs for each academic category of personnel required during the planning (including permit processing), field coordination, and arrival to QCAZ, and the total of work hours of each category $\boldsymbol{b}$.

$$\boldsymbol{wb} = \begin{bmatrix} w_1 & w_2 & \dots & w_B \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_B \end{bmatrix}$$

The second and third group, $\boldsymbol{gy}$ and $\boldsymbol{\varepsilon q}$ respectively, represent indirect consumables – that display symmetric behavior to the direct consumables – and the equipment formally

represented by:

$$\boldsymbol{gy} = \begin{bmatrix} g_1 & g_2 & \dots & g_G \end{bmatrix} \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_G \end{bmatrix}$$

Where $\boldsymbol{g}$ is the consumable and $\boldsymbol{y}$ the quantity of that supply needed during the expedition; and,

$$\boldsymbol{\varepsilon q} = \begin{bmatrix} e_1\delta_1 & e_2\delta_2 & \dots & e_N\,\delta_N \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \\ \vdots \\ q_N \end{bmatrix} \quad \text{with } \delta_n = \frac{t_n}{v_n} \quad \text{con } n = 1,\ 2,\ \dots,\ N.$$

In the previous expression, $\boldsymbol{\varepsilon}$ represents the equipment used, e_n is the cost before taxes of the $n-th$ piece of equipment used relative to time of use, $\boldsymbol{q}$. On the other hand, $\delta_n = (t_n/v_n)$ is a ratio between the time of use of the equipment during the expedition and its entire useful life v_n. In other words, we assumed that the equipment for the expedition was either rented or that we only considered a fraction of its cost, which is subject to its use throughout the expedition relative to the expected useful life. Expected useful life estimations were based on the authors' experience.

Transport costs $\boldsymbol{th}$ (fourth group) are similarly modeled, where $\boldsymbol{t}$ represents the number of vehicles and $\boldsymbol{h}$ the total number of days of use based on just one vehicle category (i.e., model).

As regards Ecuador, a significant indirect cost is that arising from the taxes, duties and transport from abroad of direct and indirect consumables, as well as equipment, represented by τ (fifth group) and is expressed as follows:

$$\tau = \tau(\boldsymbol{gy},\ \boldsymbol{fc},\ \boldsymbol{\varepsilon q})$$

Costs per specimen

According to the above elements, x_1 will be equated with the mean collection cost of specimens of the order Chiroptera, and x_2 with the mean collection cost of the orders Didelphimorphia, Lagomorpha, Paucituberculata, and Rodentia.

To calculate the cost per specimen, let E represent the total number of specimens collected throughout the expedition, order notwithstanding, and E_1 and E_2 the total number of specimens from both groups identified by their sub-index. The weighted mean is then as follows:

$$x = \frac{E_1}{E}x_1 + \frac{E_2}{E}x_2,$$

to estimate the mean cost per order, direct and indirect costs were rearranged according to those costs shared by all of the orders d_0 and z_0 and those belonging to either group – both direct (d_1 and d_2) and indirect (z_1 and z_2). The following identities explain cost rearranging as one step prior to obtaining the mean cost per group:

$$d = d_0 + d_1 + d_2 = \boldsymbol{sa} + \boldsymbol{fc}$$

$$z = z_0 + z_1 + z_2 = \boldsymbol{wb} + \boldsymbol{\varepsilon q} + \boldsymbol{gy} + \boldsymbol{th} + \boldsymbol{\tau}$$

Lastly, a cost per specimen in each group was modeled as the sum of the ratio between those direct and indirect costs shared by the other group ((d_0/E) and (z_0/E)) and the ratio of those costs associated with its order ((d_j/E_j) and (z_j/E_j)).

$$x_j = \frac{d_0}{E} + \frac{d_j}{E_j} + \frac{z_0}{E} + \frac{z_j}{E_j} = \frac{d_0 + z_0}{E} + \frac{d_j + z_j}{E_j}, \quad j = 1, 2.$$

Valuation of the entire QCAZ mammal collection (extrapolation)

The mean results for each group using the above methodology are potentially useful to place a value on the entire collection of specimens stored at the QCAZ Mammalogy Division from the orders considered. To date, the mammal collection contains a grand total of 15,754 specimens; 11,164 from the order Chiroptera (70.86%); 347 from the order Didelphimorphia (2.20%); 30 from the order Lagomorpha (0.19%); 87 from the order Paucituberculata (0.55%); and 3850 from the order Rodentia (24.44%), amounting to 98.24% of the overall collection.

The ARCA-Mamíferos 2015 offers insight for calculating the required minimum personnel, materials and equipment, as well as their costs, for expeditions. However, the number of specimens may vary due to a number of factors, most of which cannot be controlled (i.e., length of the expedition, type of habitat, environmental conditions, accessibility to sampling sites, search for a specific taxonomic group, permit requirements, released individuals, among others). Likewise, the individual costs of each specimen may vary considerably due to considerations such as the type of preparation, associated material extracted from each specimen (tissue samples, fur, ectoparasites, etc.), and size, which ultimately determines the amount and type of material used in its preparation.

Taking these issues into consideration, a group of 36 expeditions conducted by the QCAZ over a 14-year period (since 2003) was used to arrive at a mean cost per specimen. Each expedition was assigned a total cost based on the number of work days, at the baseline total cost per day of the ARCA-Mamíferos 2015 findings with the following quotient ($d + z/80$). After working out the total cost, each expedition was then divided by the number of specimens collected which resulted in a mean cost, including the ARCA numbers, to value the QCAZ's collection of these orders in its entirety. This is formally expressed as:

$$v = \frac{\sum_{i=1}^{36} ((d + z/80)h_i/E_i)}{36}$$

Results

Sampling efforts during four field trips, lasting 20 days each, of the ARCA-Mamíferos 2015 sub-project resulted in the preparation of 456 museum specimens from the orders Chiroptera (264), and Didelphimorphia, Lagomorpha, Rodentia and Paucituberculata (192 between the four orders of terrestrial micromammals). Some pregnant females, infants, and juvenile individuals were released.

Direct costs (d)

Salaries (sa)

After a thorough examination of the ARCA-Mamíferos 2015 sub-project, a group comprising three professionals (biologists) and a native field guide was considered to be the required minimum for expeditions of this nature (university personnel are considered separately under indirect costs). The field leader is a more experienced professional than the technicians, ideally a researcher with a higher academic degree, who handles the coordination of the expedition on-site, permit processing, allocation of resources in the field, sampling organization, sampling execution, and specimen preparation. The field technicians are less experienced professionals who provide support in specimen collection and preparation tasks. Man-hour costs for undergraduate students and volunteers who joined the research groups during these trips were not considered. For this specific analysis, we considered a minimum workforce, with different salaries, for a period of 80 days and 8 h of daily work. This total direct cost was $18,659.60. Considering the collection of 456 specimens, the cost per sample was $40.92 USD (Appendix 1).

Materials (fc)

Appendix 2 shows the items used during field trips, as well as the quantities required. Those materials needed to capture specimens, such as bait, as well as the material used to prepare captured specimens (cotton, string, steel wire, corn flour, labels, ethanol, formaldehyde, among others) were considered direct materials.

The amounts shown are the total and per specimen costs separated in terms of whether the materials used were exclusive to group 1 (bats), group 2 (rodents, marsupials, rabbits and marsupial mice) and those shared by both groups. For example, the materials used to bait traps are specific to group 2. Cotton, string, labels, cryotubes or chemicals were materials used in both groups.

Summation of direct costs ($d = sa + fc$)

The total direct cost d and the cost per collected specimen during the ARCA-Mamíferos 2015 amounted to $20,297.56, with a total direct cost per specimen of $44.51 (Table 1). The differences between groups reflect the differential use of equipment, materials and techniques for collection and preparation, and d_0, represents the direct costs shared by all of the orders.

Table 1. Summation of costs from direct material used for the collection of specimens from the groups analyzed, used to estimate an average cost per specimen collected.

Groups of orders	Total direct cost	Total direct cost per specimen
d_0	$20,183.88	$44.26
d_1	$0.00	$0.00
d_2	$113.68	$0.59
d	$20,297.56	$44.51

Indirect costs (z)

Salaries (wb)

We also analyzed the costs of remunerations for minimum personnel: these professionals are ideally made up of the Mammal Collection Curator and the Collection Manager (university faculty). Their involvement, as well as that of the personnel directly involved in the fieldwork, constitutes the requisite minimum for an expedition to take place.

The daily cost was calculated considering the hourly remuneration schedule for the PUCE's teaching personnel since 2015 – $16.25/hour for principal professors and $13.75/hour for associate professors. A cost was not assigned to undergraduate students and unpaid volunteers. We estimate, as per our experience, that these personnel dedicated to each expedition of the ARCA-Mamíferos 2015 sub-project, in addition to their other duties, approximately 20 h to both logistics and administrative planning (80 h in total). So, for the matter of this specific analysis, we considered, as a minimum workforce, two faculty members (curator and collection manager). The total indirect cost was $2400.00, and a $5.26 cost per sample collected (Appendix 3).

Materials (gy)

These materials included food and travel expenses for the personnel during the field trips, spare parts, cleaning, and office supplies, among other materials itemized in Appendix 4. The total cost for indirect materials summed $4929.18, with a total indirect cost per specimen of $10.81.

Equipment (εq)

Appendix 5 shows the cost of equipment, or a fraction of its cost relative to the total time of use, as well as the cost per collected specimen in the ARCA-Mamíferos 2015 sub-project, which ascended to $533.62, and an indirect cost of equipment per specimen of $1.17. This category includes mist nets (group 1) and traps (group 2), as well as, and unlike Bradley et al. (2012), other ancillary and standard sampling equipment, such as cloth bags for collection, tools for dissecting, scales, calipers, skins and skeletons preparation equipment, camping gear, flashlights or lamps and personal field equipment.

Transportation (th)

The transportation costs were obtained following a similar process as that used to determine those of equipment, where the cost per use of a rental vehicle possessing the adequate characteristics to access sites not easily reached. Taking our own experiences and the current values of renting a car (~$60.00 a day) or buying fuel, we estimated that a total value of $4800 in transportation, throughout the project, is adequate. This resulted in a value per specimen of $10.53.

Taxes, duties and shipping (τ)

This section also contains value added taxes and import duties as well as the standard costs of equipment and materials shipping for a standard courier service. These results are supported with information compiled from invoices and sales notes for a final cost of $1104.01 for the sub-project, and a per specimen cost of $2.42 (Appendix 6).

Summation of indirect costs ($z = wb + gy + \varepsilon q + th + \tau$)

Table 2 shows the total indirect cost *z* and the total indirect cost per specimen collected in the ARCA-Mamíferos 2015 sub-project (refer to appendices 3–6). The difference between groups 1 and 2 lies, as evinced by the results above, in those costs associated with taxes, duties and shipping of specific equipment for rodents, marsupials, rabbits and marsupial mice.

Summation of direct and indirect costs ($d + z$) and mean costs

Table 3 shows the total costs, per group and specimen, as a result of the sum of the costs in Tables 1 and 2.

Costs per specimen

Likewise, the mean cost for each group was calculated as per the methodological elements above and the weighted mean of the total number of specimens collected.

$$x_1 = \frac{d_0 + z_0}{E} + \frac{d_1 + z_1}{E_1} = 74.18 + 0.26 = \$74.44$$

$$x_2 = \frac{d_0 + z_0}{E} + \frac{d_2 + z_2}{E_2} = 74.18 + 0.88 = \$75.06$$

$$x = \frac{E_1}{E}x_1 + \frac{E_2}{E}x_2 = \frac{264}{456}\ 74.44 + \frac{192}{456}75.06 = \$74.70$$

Valuation of the entire QCAZ mammal collection (extrapolation)

As stated initially, the above results can be used to value the remaining specimens of the collection of vertebrate mammals of the QCAZ, whose orders are a 98.05% match with those valued using ARCA-Mamíferos 2015 information.

Table 4 shows that the total cost to assemble the QCAZ-PUCE collection of these orders amounts to $1,154,845.16. However, as mentioned in the description of the methodology, a mean cost for a larger group of expeditions limits the distinctive particularities

Table 2. Summation of indirect costs used for the collection of specimens from the groups analyzed, used to estimate an average cost per specimen collected.

Order classification	Total indirect costs	Total indirect costs per specimen
z_0	$13,640.08	$29.91
z_1	$69.36	$0.26
z_2	$57.37	$0.30
z	$13,766.81	$30.19

Table 3. Summation of direct and indirect costs for the collection of specimens from the groups analyzed, used to estimate an average cost per specimen collected.

Order classification	Total aggregate costs	Total aggregate costs per specimen
$d_0 + z_0$	$33,823.96	$74.18
$d_1 + z_1$	$69.36	$0.26
$d_2 + z_2$	$171.05	$0.88
$d + z$	$34,064.37	$74.70

Table 4. Extrapolation of the cost of the Mammals Collection of the Museum of Zoology at PUCE, taking into account the total number of stored voucher specimens of the groups analyzed.

Order	Number or specimens	Unit cost	Total cost
Chiroptera	11,164	$74.44	$831,049.06
Didelphimorphia	347	$75.06	$26,044.80
Paucituberculata	87	$75.06	$6529.96
Lagomorpha	30	$75.06	$2251.71
Rodentia	3850	$75.06	$288,969.63
Total			$1,154,845.16

(exogenous and endogenous) that could arise during the expedition as regards collected specimens.

Variation is expected with different conditions in different expeditions. Information from 36 other expeditions with different numbers of work days, and different capture results is depicted in Appendix 7 (distance variation was not considered). As mentioned in the Methodology, each expedition was assigned a total cost based on the number of work days, at the baseline total cost per day of the ARCA-Mamíferos 2015 (Appendix 8). The mean cost obtained was $72.86 with a standard deviation of $29.46. This cost multiplied by the total number of specimens studied yields a total collection cost of $1,125,541.28.

Discussion

The conditions of the ARCA-Mamíferos 2015 sub-project were particularly good, as the budget available was higher than normal. The budget structure, the number of professionals involved, and the information on equipment and materials helped to establish the minimum requirements needed to conduct a standard field trip.

For this type of accounting procedure, the workforce directly involved in the capture of specimens and the materials that were used for their preparation until its arrival to the QCAZ were considered direct costs. Thus, an adequate work team is made up of three professionals and, at least, one field guide for each trip with their salaries covered either by the project budgets or by the academic entities responsible, in this case, the university. No salary costs for undergraduate students, volunteers, and other local professionals, important for the success of the expeditions, were considered as they did not receive monetary compensation. However, travel expenses for the entire group were considered as an indirect cost.

On the other hand, indirect costs are those that do not explicitly pertain to the collection, but are essential to the performance of the process, that is, wages of research and management personnel coordinating the field work, as well as procedures relating to specimen accessioning upon their arrival to the museum. In this case, additional activities associated with processing and curation of specimens and their associate information, their storage, and the long-term care and preventive conservation costs are not taken into account.

As indirect costs, in addition to the management staff of the operation, some materials and field equipment are also included, as well as personal gear that, despite being important during the collection and preparation processes, is not included in the direct costs per specimen collected. This accounting approach differs from that of Bradley et al. (2012) and

seeks to develop a highly general methodology that could be used in other contexts; to this effect, accounting identities for each calculation have been formulated. In this respect, based on their experience, Bradley et al. (2012) estimated an average replacement cost for the loss of a certain amount of traps and nets, and disregarded the cost of other standard field trip supplies and equipment. Our approach differs in that we have not excluded these costs because we consider them to be a substantial contribution to the final cost per voucher specimen; therefore, we have calculated a fraction of their cost in respect to their entire useful life, which was estimated based on the authors' professional experience. This same scenario was applied to the cost of transportation, assuming the day rental of a 4×4 twin cab vehicle. The amounts for taxes and duties considered in this case were gathered from detailed records and actual receipts for 2014 and 2015. The amounts corresponded to current duties mainly on imported equipment, such as traps, nets, calipers, scales, and bat bags, among others.

The summation of direct and indirect costs yielded a final cost per specimen of $74.70, higher than that obtained by Bradley et al. (2012) of $41.00 for specimens collected locally or regionally, and similar to $74.00 for specimens collected internationally, including Ecuador. In that same paper, just those specimens collected in Ecuador were estimated at a cost of $52.00, during a 71-day trip in 2004, and where 1473 specimens were collected. Despite the large number of specimens collected (more than twice the number considered in this study), this comparison is not practical given the direct and indirect costs borne by foreign researchers to travel to Ecuador (airfare, lodging, legal documents, salaries of an American faculty, etc.), as well as the exclusion of other expenses, such as standard field trip supplies, equipment and salaries for local collaborators.

The amounts obtained herein correspond to those estimated solely for micromammals. For example, the cost of shared materials shown in Appendix 2 and estimated at $3.59 is similar to that of Bradley et al. (2012) estimated in $3.00. While the cost of materials does, as they state, vary greatly given that the size of an individual affects the quantity and type of material used, in our case, it is a reference cost as the QCAZ Mammal collection is comprised of local fauna, dominated by the orders Rodentia (120 of the 434 mammal species of Ecuador) and Chiroptera (170 of the 434), which is reflected in the collection composition of 98.05% of its specimens belonging to the orders of micromammals considered in this work. Therefore, extrapolating this cost obtained from the ARCA-Mamíferos 2015 to the rest of the micromammal collection is both appropriate and informative. Larger species of mammals would have, in addition to collection costs, much higher processing and maintenance costs than small mammals. Consequently, the results of this evaluation should be considered as minimal costs, and the total value of the collection imagined to be greater than the one established herein.

The approach proposed to extrapolate daily direct and indirect costs obtained from this accounting exercise (Appendix 8) to 36 expeditions carried out by personnel associated to the QCAZ Mammal collection during the 2003–2016 period, including ARCA-2015, resulting in a mean cost per specimen of $72.86 USD and a total collection cost amounting to $1,125,541.28, is also informative.

This amount does not include the cost of curating, storing, preserving, and documenting information on each specimen, or maintaining the museum facilities and its environment for a proper preventive conservation. It also does not include salaries for curator assistants, curatorial and identification efforts, specimen-based research activities, and development of

innovative mechanisms to provide access to this collection around the world. The present analysis should be considered as an underestimate since it has taken into account only the costs related to the collection and accession of specimens to the museum; the costs of storage and long-term maintenance of the specimens, a fundamental aspect of the mission of a museum of natural history, deserves special consideration, since the annual cost of these factors increases with the growth of the collection. It is evident then that any attempt to assign a financial value to biological collections is extremely complex and, as has been the case with prior initiatives, is far from well-represented, given that the scientific, historic, educational and aesthetic values are still prohibitively difficult to quantify.

Conclusions

Our approach, similar to that used at the Museum of Texas Tech University, estimates an average cost per specimen, but goes one step further in that it considers and discriminates between the direct and indirect costs, and proposes calculation formulas that may be easily reproduced by other national collections, public or private, and could potentially be used at the regional level.

Million-dollar figures such as those obtained in this paper can be powerful arguments used to persuade not only the scientific community, but, as in our case, university authorities, the relevant government entities (i.e., the Ministry of Environment), as well as national and international funding agencies and trusties, regarding the importance of systematic collections and that the cost of acquiring and caring for said collections is low in comparison with the potential cost of not having them.

The continued investment in the growth and conservation of scientific collections is essential for assessments now and in the centuries that follow, given that the real value of these resources lies in their potential to provide knowledge opportunities for the future: that value is indeed priceless.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendices

Appendix 1. Minimum required personnel participating directly during field trips and associated costs.

Type of personnel	Number of days	Hours per day	Total number of hours	Hourly wage*	Total cost
Field leader 1	80	8	640	$9.38	$6003.2
Technician 1	80	8	640	$8.13	$5203.2
Technician 2	80	8	640	$8.13	$5203.2
Guide	75	8	600	$3.75	$2250.0
Total cost					$18,659.60
Total cost per specimen					$40,92

*Hourly wage is based on that determined by the Pontificia Universidad Católica del Ecuador.

Appendix 2. Details of consumable supplies used in the Mammal collection of the Museum of Zoology at PUCE for capture, preparation, and transportation of voucher specimens and tissues. Costs of these supplies were considered for a period of 80 days (four 20-days field trips). These costs information was compiled from invoices, sales notes, and market costs.

Material	Group	Quantity (80 days)	Unit cost	Total cost
Powder free-nitrile gloves, several sizes (box)	0	12	$10.40	$124.80
Surgical gloves (box)	0	12	$6.83	$81.96
5 ml syringe, 100-unit box	0	4	$9.42	$37.68
10 ml syringe, 100-unit box	0	4	$13.23	$52.92
Dust masks, 20-unit box	0	4	$23.40	$93.60
Cotton thread	0	4	$14.29	$57.16
1.5 ml Eppendorf tubes, bags of 500	0	8	$11.25	$90.00
96% potable alcohol, national gallon	0	16	$13.15	$210.40
96% potable alcohol, national liter	0	4	$3.03	$12.12
Box of big Ziplock® bags (20 × 20)	0	16	$3.84	$61.44
Box of small Ziplock® bags (7 × 5.5)	0	16	$2.95	$47.20
500 gr rolled cotton	0	12	$6.63	$79.56
Synthetic cotton	0	4	$1.00	$4.00
Cornmeal	0	4	$1.75	$7.00
1 × 1 m expanded polystyrene foam sheets	0	8	$0.35	$2.80
3.6 cm sewing pin (units)	0	160	$0.10	$16.00
Needle set	0	40	$0.08	$3.20
Brown thread	0	4	$0.75	$3.00
Black thread	0	4	$0.75	$3.00

(*Continued*)

Continued.

Material	Group	Quantity (80 days)	Unit cost	Total cost
36.5% formaldehyde, 5 l	0	4	$26.25	$105.00
Gauze, 0.60 cm × 100 m	0	4	$27.89	$111.56
Plastic material (rope, containers, bags)	0	1	$73.64	$73.64
Duct tape	0	8	$12.00	$96.00
Synthetic rope	0	12	$7.20	$86.40
Marking tape	0	48	$1.35	$63.84
72.5 m galvanized wire roll	2	4	$8.50	$34.00
Peanut paste	2	16	$2.00	$32.00
Oatmeal, 500 g	2	4	$0.96	$3.84
Vanilla extract, 500 ml	2	4	$0.96	$3.84
Sunflower seeds	2	80	$0.35	$28.00
Fruit (banana)	2	40	$0.30	$12.00
Duct tape	0	8	$12.00	$96.00
Synthetic rope	0	12	$7.20	$86.40
Marking tape	0	48	$1.35	$63.84
Group 1				$0.0
Group 2				$113.68
Group 0				$1524.28
Total cost				$1637.96
Total cost per specimen				$3.59

Appendix 3. Minimum required personnel participating indirectly during field trips and associated costs. These indirect activities may involve organizing field trips, as well as accessioning the voucher specimens.

Type of personnel	Number of days	Hours per day	Total number of hours	Hourly wage	Total cost
Principal Professor – Full time	10	8	80	$16.25	$1300.00
Associate Professor – Full time	10	8	80	$13.75	$1100.00
Total cost					$2400.00
Total cost per specimen					$5.26

Appendix 4. Details of indirect supplies and materials utilized for collection, preparation, and transportation of voucher specimens and tissues. Costs of these supplies were considered for a period of 80 days (four 20-days field trips). These costs information was compiled from invoices, sales notes, and current market costs.

Materials	Quantity	Unit cost (USD$)	Total (USD$)
Daily food for the collection team	80	$56.22	$4497.60
A4 three-ring folder, 3 × 25 mm	4	$3.87	$15.48
N600 18 × 20 mm adhesive tape, transparent	12	$1.40	$16.80
Pencils / ballpoint pen	8	$0.51	$4.08
Edding® indelible markers – 0.1	24	$1.73	$41.52
Edding® indelible markers – 0.3	24	$1.73	$41.52
Package of 8 AA batteries	20	$5.35	$107.00
Package of 8 AAA batteries	20	$6.42	$128.40
Package of garbage bags	8	$1.34	$10.72
Small lighter	12	$1.00	$12.00
Package of candles	16	$1.00	$16.00
22 × 25 cm reusable towels	20	$0.28	$5.60
Field notebook	4	$8.11	$32.44
Total cost			$4929.18
Total cost per specimen			$10.81

Appendix 5. Details of equipment and personal gear used by the team of researchers for collection, preparation, and transportation of voucher specimens and tissues. The useful lifetime of each piece of equipment was estimated based on the collecting experience of authors and colleagues.

Equipment	Group	Useful lifetime (days)	Unit cost	Total cost of use
12 × 3 m mist nets	1	200	$80.00	$32.00
Live traps	2	400	$1.00	$0.20
Buckets for pitfall traps	2	200	$5.20	$2.08
Meters of black plastic	2	200	$1.34	$0.54
Shovel	2	720	$18.95	$2.11
Container to prepare bait	2	200	$4.50	$1.80
Folded Sherman traps	2	400	$19.90	$3.98
Packaging plastic boxes	0	720	$130.00	$14.44
Dissection equipment	0	200	$19.32	$7.73
Dry bag, 15 1	0	400	$30.35	$6.07
Tent	0	200	$280.35	$112.14
Insulator	0	200	$11.04	$4.42
Inflatable insulator	0	200	$39.05	$15.62
45 1 backpack	0	200	$161.25	$64.50
GPS Garmin 60CSx	0	800	$518.89	$51.89
Photo camera	0	800	$546.98	$54.70
Blue plastic container with dispenser	0	200	$25.00	$10.00
Plastic trays	0	200	$4.20	$1.68
Glass alcohol lamp	0	100	$3.10	$2.48
Wire cutter	0	720	$2.38	$0.26
Tulle (1 m)	0	100	$2.50	$2.00
Plastic bucket to preserve whole specimens in fluid, 22 L	0	200	$9.74	$3.90
Plastic bucket to preserve bodies, 5 gallons	0	200	$6.00	$2.40
7″ × 12-1/2 cloth bags (package of 100)	0	100	$93.75	$75.00
5″ × 7″ cloth bags (package of 100)	0	100	$57.50	$46.00
Digital gauge	0	400	$28.75	$5.75
10 g Pesola spring scale	0	800	$33.95	$3.40
50 g Pesola spring scale	0	800	$33.25	$3.33
100 g Pesola spring scale	0	800	$32.25	$3.23
Group 1				$32.00
Group 2				$10.70
Group 0				$490.92
Total cost				$533.62
Indirect cost per specimen				$1.17

Appendix 6. Cost of taxes, duties, and shipping values for the importation of direct and indirect material used for the collection of specimens from the groups analyzed, used to estimate an average cost per specimen collected.

Groups of orders	Taxes, duties and transport – direct costs	Taxes, duties and transport – indirect costs	Total cost of taxes, duties and transport
0	$233.61	$786.37	$1019.98
1	$0.00	$37.36	$37.36
2	$13.64	$33.03	$46.67
Total tax			$1104.01
Total cost per specimen			$2.42

Appendix 7. Estimated value of voucher specimens collected in 36 field trips in a period of 14 years.

Location (Province, Location/Name of the expedition)	Year	Valuation of collection per specimen
1. Pichincha, Tandayapa.	2003	$102.19
2. Napo, Sierra Azul.	2005	$47.31
3. Napo, Bermejo.	2005	$36.42
4. Napo, Sumaco National Park.	2007	$75.83
5. Pastaza, Río Villano, Villano B Camp. AGIP 2008	2008	$47.66
6. Pastaza, Río Villano, K4 Camp. AGIP 2008	2008	$60.83

(*Continued*)

Continued.

Location (Province, Location/Name of the expedition)	Year	Valuation of collection per specimen
7. Pastaza, Río Villano, Villano B(2), Camp. AGIP 2008	2008	$73.60
8. Pastaza, Río Villano, K10 Camp, AGIP 2008	2008	$99.66
9. Pastaza, Río Villano, K10(2) Camp. AGIP 2008	2008	$77.42
10. Pastaza, Río Villano, K32 Camp. AGIP 2008	2008	$114.64
11. Pastaza, Río Villano, Kurintza Community. AGIP 2008	2008	$75.14
12. Pichincha, Santa Eulalia.	2008	$7.89
13. Pastaza, Río Villano, Kurintza Community. AGIP 2010	2010	$106.45
14. Imbabura, Santa Rosa.	2010	$43.25
15. Chimborazo, Atillo Grande Sangay National Park.	2010	$55.10
16. Napo, Wildsumaco Lodge.	2011	$50.69
17. Pastaza, Río Villano, AGIP Oil Installations Block 10	2012	$55.20
18. Pastaza, Río Villano, Villano B Camp. BAP 2012	2012	$77.42
19. Pastaza, Río Villano, Kurintza Community. BAP 2012	2012	$101.38
20. Pastaza, Río Villano, Oglán. BAP 2012	2012	$102.19
21. Pastaza, Río Villano, Tarangaro Community. BAP 2012	2012	$114.24
22. Cotopaxi, San Francisco de las Pampas.	2012	$28.20
23. Orellana, Yasuní Scientific Station	2013	$36.42
24. Pastaza, Río Villano, AGIP Oil Installations Block 10	2013	$101.82
25. Pastaza, Río Villano, AGIP Area of Operations. BAP 2013	2013	$127.74
26. Pastaza, Río Villano, Tarangaro Community. BAP 2013	2013	$67.74
27. Pastaza, Lorocachi. BIOYAS 2013	2013	$73.00
28. Orellana, PNY, Tambococha. BIOYAS 2013	2013	$64.88
29. Carchi, San Francisco, Guandera	2014	$56.58
30. Pastaza, Río Villano, K10 Camp. BAP 2015.	2015	$85.16
31. Pastaza, Río Villano, K10 Camp. BAP 2015.	2015	$131.02
32. Arca-Mamíferos 2015	2015	$74.70
33. Napo, Yanayacu Scientific Station	2016	$60.83
34. Orellana, Yasuní Scientific Station	2016	$53.23
35. Loja, Jimbura, Parque Nacional Yacuri	2016	$37.98
36. Pastaza, Río Villano, K10 Camp. BAP 2016.	2016	$99.02
Mean		$72.86
Standard deviation		$29.46

Appendix 8. Baseline costs structure per day of the ARCA-Mamíferos 2015 project.

Budget Information		Total for 80 days (USD$)	Total per day (USD$)
1. Direct costs	Wages (***sa***)	18,659.60	233.25
	Materials (***fc***)	1637.96	20.47
2. Indirect costs	Wages (wb)	2400.00	30.00
	Materials (***gy***)	4929.18	61.61
	Equipment (εq)	533.62	6.67
	Transportation (***th***)	4800.00	60.00
	Taxes (τ)	1104.01	13.80
		Total	425.80