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Forum

The importance of guano birds to the Inca Empire and the first conservation measures implemented by humans

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The Inca Empire was the largest ancient civilization in South America, extending across almost 4000 km of distinct environments from the Pacific coast to the Andes, and throughout most of the arid desert between. The present study highlights the importance of guano birds (Guanay Cormorant *Leucocarbo bougainvillii*, Peruvian Pelican *Pelecanus thagus* and Peruvian Booby *Sula variegata*) for the expansion and prosperity of the Inca Empire. The use of guano as a fertilizer was fundamental to sustain the agricultural development of the empire and, it has been argued, was the basis for its rapid growth. The access to guano on coastal islands and its subsequent transportation to highlands provided food security for a population of more than 8 million. The importance of guano birds to the Inca Empire led to the development of management plans based on a penal code aiming to preserve these species and their natural habitats. These protective actions may represent the first conservation measures ever implemented by humans based on the importance of species protection for human activities and livelihoods.

Keywords: conservation measures, fertilizer, guano birds, Inca Empire.

The Inca Empire was the largest and last native empire in pre-Columbian America and extended throughout much of South America. Its territory comprised diverse environments, extending from the Atacama Desert to the highest mountain range in the South American continent, the Andes, and to the tropical lowlands of the upper Amazon Basin (Covey 2008). The success of this vast empire relied on a collective labour force founded on agriculture, the basis for economic productivity, to which every citizen was required to contribute as described in the *Commentarios Reales* by de la Vega (1609). As a good part of the Inca territory was infertile, the Incas used techniques developed by previous civilizations, such as irrigation and the fertilization of fields, to sustain agricultural practice across its vast territory (Snyders 2011). The use of seabird guano was the main source of manure used by coastal indigenous civilizations in modern Peru. As such, it was collected in huge quantities, as described by Alexander von Humboldt during his travels across South America (Nuñez & Petersen 2002).

Before the arrival of the Spanish and the introduction of the Latin alphabet, the Quechua language had no written form. Everything that it is known about Inca history is based on the analysis of bibliographic texts derived from early Spanish colonizers that documented several Inca oral traditions, especially in relation to indigenous coastal people who collaborated with the colonizers (Cushman 2013) and as obtained from archaeological and anthropological studies and from guano industry reports.

The present study highlights the importance of seabirds to the expansion of the Inca Empire and the importance of their guano as a fundamental key to sustaining Incan agriculture and economic development, plus providing food security to support an increasing population. The Inca developed a management system for accessing natural habitats where guano birds breed, as on several islands and coastal rocky formations across the South American Pacific coast. Alongside this, they developed and enforced a penal code. The main argument presented in this paper is that these measures were among, or actually were the first habitat conservation measures implemented by humans to achieve a sustainable use of seabird guano as a natural resource.

COMPOSITION OF THE PERUVIAN SEABIRD GUANO AND THE KEY SPECIES PRODUCING IT

Guano is a highly effective organic fertilizer, formed by the deposition of faeces from some animal species, mainly birds (Dedenbach-Salazar 1985). The shortage of rainfall and the variable humidity levels typical of the Pacific coast of South America, combined with the age of the deposits, play a decisive role in the chemical composition of guano, containing 8–21% nitrogen, phosphate (12.5%) and potassium (2.5%) in addition to other mineral elements (Julien 1985, Brooks *et al.* 2004, Szpak *et al.* 2012a). This abundant and inexpensive compost is

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deposited by seabirds across the South American Pacific coast, including almost all the rocky outcrops and islets of the otherwise arid coastline between Peru and northern Chile (Fig. 1), but especially on the offshore islands of Lobos, Guanape and Chincha in Peru (Snyders 2011), as well as Tarapacá and Mejillones in Chile (Zolezzi 1993, Pujante & Pollet 2016). As the coast of Peru and northern Chile only seldom receives precipitation (during El Niño events), guano accumulates at these seabird nesting sites in a series of sedimentary layers (Szpak *et al.* 2012b).

The Humboldt Current, with its cold waters rich in nutrients, particularly nitrogen (Vogt 1942), is an additional important factor in the formation of the Peruvian seabird guano deposits, as it flows north along the western coast of South America (Montecino & Lange 2009). The natural upwelling phenomenon resulting from this current is the cause of the geographical location of numerous seabird colonies in the south-east Pacific (Snyders 2011). Deeper-lying waters, rich in decomposing organic matter, reach the surface, filling the deep-water depression resulting from the interaction of coastal winds with the coastline's topography. When this organic matter reaches the surface, it is consumed by pelagic fishes supporting numerous shoals of

Figure 1. Map of the Inca Empire (grey), with the geographical distribution of guano birds (black delineated line) and the principal guano deposits (black dots) along the western coast of South America.
[Correction added on 24 August 2020, after first online publication: 'Inca Empires' has been corrected to 'guano birds' in this version.]

gregarious species, mainly anchovy, which in turn support entire seabird colonies from the north of Peru to central Chile (Pujante & Pollet 2016). During the breeding season, huge numbers of birds congregate to lay their eggs and roost with their hatchlings on offshore islands such as Lobos, Guanape and Chincha in the south-east Pacific, in proximity to upwelling areas, probably due to the profuse abundance of rich decomposing matter (Snyders 2011).

The most important Peruvian guano-producing bird species are: Guanay Cormorant *Leucocarbo bougainvillii*, Peruvian Pelican *Pelecanus thagus* and Peruvian Booby *Sula variegata* (Duffy 1994, Pujante & Pollet 2016). These species form the group of 'guano birds' due to the large amount of guano they generate (Tovar & Cabrera 2005), which Cushman (2013) referred as the 'Billion-dollar birds' owing to their important economic value in the mid-19th century. Such species breed along the coast of Peru and Chile (Fig. 1) and their populations were so large that the guano they produced comprised piles tens of metres thick (Brown 2016). Barbraud *et al.* (2018), based on more than 40 years of data, estimated that the current populations of guano birds make up some 4 million individuals living on 29 islands and headlands of coastal Peru.

An important factor in the fluctuation of guano bird populations across the coast of Peru and Chile is the warming of the ocean surface temperature, known as El Niño, or the Southern Oscillation (ENSO; Philander 1990). ENSO reduces the upwelling of nutrient-rich water that sustains fish populations such as the anchovy which, in turn, sustain the top seabird predator populations, resulting in the crashes of the latter species (Schreiber & Schreiber 1984).

Leucocarbo bougainvillii

The Guanay Cormorant (Fig. 2) is a resident species on the coasts of Peru and Chile. It has been identified as the most abundant avian species resident on the Peruvian Coastal Current, with an estimated population of 3.7 million individuals (Zavalaga & Paredes 1999). It breeds on offshore islands and coastal headlands (Weimerskirch *et al.* 2012), from the north on Isla Lobos de Tierra, Peru (6°23′08″S, 80°51′01″W), to the south on Isla Mocha, Chile (38°26′50″S, 73°54′19″W). Breeding is year-round, with two peaks of reproduction occurring in July and September/October (Passuni *et al.* 2016). Cormorants form large colonies, exceeding 1000 pairs, with densities of up to 3 nests/m^2, and usually lay three eggs (Orta 1992). Nests are scraped on the ground and created from guano, feathers and other debris, with a diameter of 32 ± 4 cm (Duffy 1983).

Pelecanus thagus

The Peruvian Pelican (Fig. 3) is a resident species of the Humboldt Current across the coast of Peru and Chile. It breeds in large colonies on small coastal islands, on cliff ledges and on rocky ground, feeding in shallow offshore coastal waters on small schooling fish communities (Carboneras 1992, Jeyasingham *et al.* 2013). It breeds from the north on Isla Foca, Peru (5°12′13″S, 81°12′28″W), to the south on Isla Pupuya, Chile (33°58′24″S, 71°53′39″W), mainly from July to October (Passuni *et al.* 2016).

Sula variegata

The Peruvian Booby (Fig. 4) is most abundant in the area of the Humboldt Current, breeding on small coastal islands on either cliff ledges or bare ground, from northern Peru to Isla Santa Maria (37°02′40″S, 73°31′29″W) and Isla Mocha (38°26′50″S, 73°54′19″W), Chile (Carboneras 1992). It breeds year-round, with a peak reproduction phase from July to September (Passuni *et al.* 2016).

THE USE OF GUANO AS FERTILIZER IN PRE-INCA CIVILIZATIONS

At the beginning of the Era of Incipient Agriculture (10 000–8000 years ago), farming was supplementary to hunting and gathering and therefore social groups were small and probably semi-nomadic (Steward 1949, Smith 2001). Cultivation played only a minor role in the subsistence of human societies. By the end of this era, *ca.* 4000 years ago (Mangelsdorf *et al.* 1964), agriculture became the primary activity for subsistence, supporting permanent communities and increases in population growth (Steward 1949). For example, the introduction of maize in the Virú Valley of Peru, between 600 and 200 BC, gave rise to a rapid demographic expansion (Gordon 1953, Tykot *et al.* 2006). A similar pattern of population growth occurred when the introduction of a new crop thrived. For example, when cold climate changes halted the production of maize, the potato–quinoa sequence became dominant and boosted population growth (Kelly 1965).

In addition to temperature and rainfall variation, the soils of the western coastal region of South America are poor. The desert–coastal zone comprising a narrow, gently sloping, plain that varies in width from 20 to 100 km forms one of the world's driest deserts – the Atacama (McEwan 2006). As a consequence, agricultural productivity in such an arid region could only be sustained by resorting to the use of fertilizers. The use of manure to either maintain or improve soil fertility is therefore probably as old as agriculture itself (Denevan 1995).

Figure 2. Guanay Cormorant *Leucocarbo bougainvillii* (Lesson 1837). (Photograph by Marcelo Flores, www.avitrek.com). [Colour figure can be viewed at wileyonlinelibrary.com]

Figure 3. Peruvian Pelican *Pelecanus thagus* Molina 1782. (Photograph by Marcelo Flores, www.avitrek.com). [Colour figure can be viewed at wileyonlinelibrary.com]

In South America, guano (derived from the Quechua word *huanu* meaning dung) not only was used for centuries to sustain agricultural needs across coastal fields but was also transported to the Andean mountains by llama caravan (Julien 1985, Paracka & Silva 2012). Andean civilizations used all animal dungs as manure, but seabird guano was especially valued due to its highly effective fertilizing power and as a major contributor of nitrogen to agricultural production (Szpak *et al.* 2012a, 2012b). The importance of guano to the subsistence of different South American civilizations over the past 4000 years, that is, from the Archaic period (*c.* 2300 BC) to the Late Intermediate period (1476 CE), was confirmed by the identification of extremely heavy concentrations of the stable isotope $\delta^{15}N$ (+17.8 to + 33.1‰) in the dental calculus of human skeletons from coastal and valley archaeological sites in northern Chile (Poulson *et al.* 2013).

The Paracas civilization (*c.* 900 BC to 400 CE) is an example of an Andean society that prospered in the desert almost 3000 years ago due to the use of guano as fertilizer (Brown 2016). Coastal Moche civilization (1–450 CE) artefacts from *c.* 2000 years ago have been found in guano deposits from Islas Guañapes (northern Peru). Moreover, Moche drawings illustrate ancient reed boats used to reach the islands and transport guano to the mainland coast for agricultural use (Brooks *et al.* 2004), and several pottery pieces depict the birds known to produce guano (Kidder 1967).

The Wari and Tiwanaku (300–1150 CE) and Chimor (850–1470 CE) were the largest civilizations that preceded the Incas, with empires extending more than 1000 km along the South American Pacific coast (Moseley 2001). Such civilizations developed and subsisted on agriculture, technology and the transfer of knowledge from their predecessors. The continuous progress in the development of agriculture and technology eventually led to the rise of the Inca Empire, which flourished between *c.* 1400 and 1533 CE (Moseley 2001).

In the absence of bibliographic texts contemporary to the Pre-Inca era, there is no evidence of any conservation measures developed by such pre-Inca civilizations to protect the guano bird species and their habitats.

EXPANSION OF THE INCA EMPIRE

The Inca Empire extended across *c.* 4000 km, from near the modern Colombia–Ecuador border south through the

Figure 4. Peruvian Booby *Sula variegata* (von Tschudi 1843). (Photograph by Marcelo Flores, www.avitrek.com). [Colour figure can be viewed at wileyonlinelibrary.com]

highlands and coastal plains of Peru, part of Bolivia, to the extreme northwest of Argentina and to the Maule River in central Chile (Fig. 1). This vast empire comprised a population of 8–10 million individuals divided into a multitude of tribal groups, each with its own customs and language (McEwan 2006, Chepstow-Lusty *et al.* 2009).

State expansion is usually motivated by economic prosperity. During the Inca Era, access to agricultural land and to valuable resources such as guano, as well as access to trade routes, were key factors in state expansion (Algaze 1993, Kosiba 2018). As a consequence, the arid coastal desert of today's Peru and Chile was made fertile by irrigation and the use of seabird guano as a fertilizer, which became a highly valuable resource (Sandweiss & Reid 2016).

As a consequence, high levels of food security, based on food surpluses of between 3 to 7 years, was achieved through the use of innovative irrigation methods and the practice of guano fertilization (Snyders 2011). There were massive seabird guano accumulations on several islands in the valleys of Chincha and Ballestas under the control of the Chincha society and within reach of their boats (Curatola 1997). The Incas collected substantial volumes of seabird guano from nearby islands such as the Chincha Islands (13°38′24″S, 76°24′0″W), 21 km off Peru's southwestern coast, for use in its vast empire. The guano was even transported along trails to higher altitudes such as Machu Picchu (Rubio 1988), a distance of more than 600 km from the coast (Martínez 2009). These rocky islands, mostly comprising granite, are all less than a mile wide and are surrounded by cliffs up to 34 m high (Chisholm 1911).

The Chincha was strategically important in the commercial relationships of the Inca due to their guano and guano managers (Sandweiss & Reid 2016). The interactive network of the Chincha ranged from the Titicaca Altiplano (Peru and Bolivia) to Manta Bay (Ecuador) (see Curatola 1997 to understand Chincha prosperity). Ultimately, however, the Incas conquered the Chincha territory. This was possibly forcibly peaceful, most probably due to acknowledgement by the Incas of a valuable resource that could only be obtained by Chinca seamen able to construct and manoeuvre vessels in cold and difficult Pacific coastal waters (Rostworowski 1988). According to Curatola (1997), in 1630, Vázquez de Espinosa described that between the Majes Valley and Arica (16°16′S, 072°13′W and 18°28′S, 070°18′W, respectively) everything that was seeded was fertilized with seabird guano, and this was also used in many coastal valleys. The supply came from the so-called guano islands that were, thus, central to the survival and prosperity of resident sequential civilizations. These were also the islands that fuelled the guano boom of the mid-19th century (Snyders 2011).

Highland colonization was only evident when Wari and Tiwanaku societies established coastal colonies, or enclaves, particularly in regions of intensive agriculture sustained by guano, as in the piedmont of the Osmore Valley (Sutter 2000). Similar to earlier empires, the Incas wanted to extend their control over the entire regional economic system, consolidating their control in the piedmont area to exploit all major maize production regions, but, especially, to control access to coastal guano and its transportation, as this was vital for the maintenance and development of their agricultural production (Covey 2000).

Agriculture was the most important economic activity of the Incas (Chepstow-Lusty *et al.* 2009). The majority of the empire's population were farmers, and large areas of terraces and associated irrigation systems were constructed for agricultural purposes (Donkin 1979). In such agricultural terraces, up to three harvests per year could be obtained. The most important crops were maize, potatoes, quinoa, Andean amaranth, oca, ulluco, mashua and achira (Zimmerer 1993). At that time, a larger expanse of land was cultivated in contrast to what happened in the post-Inca occupation. The Incas relied on the agriculture, technology and knowledge of their predecessors, but expanded upon this to a scale never before attained (Zimmerer 1993). Such

agricultural productivity in arid areas across the majority of the Inca territory could only be sustained with the use of fertilizers (Denevan 1995). The extension of the Inca Empire was, thus, conditioned by the distance to seabird guano clusters and, consequently, to the natural distribution of the guano birds. The importance of guano to the Inca Empire led to the protection and management of guano birds and the principal offshore islands where they breed (de la Vega 1609).

INCA CONSERVATION MEASURES

To show their gratitude for the extracted guano, both the Moche and the Chincha societies had a tradition of providing offerings to the seabird guano clusters of the islands of Chincha (Kubler 1948). This worship was of a ritual and symbolic character for the guano islands identified as 'the ones that give birth to the birds' (Rostworowski 1992). These types of connections to Nature were more spiritual than representative of some form of protection of natural resources for the benefit of human society.

The Incas venerated the goddess Urpi Huáchac (a divinity of sea life and shore birds), due to the important role that guano played in their life in providing food security (Snyders 2011). According to Curatola (1997), Urpi Huáchac was also named the 'Lady of Guano'.

The Inca society was well aware of the value of guano, which was central to both its culture and its religion (Rostworowski 1989). To ensure the continued use of this natural resource, conservation measures emerged. De la Vega (1609) described how the Incas formulated a comprehensive management system with rules to protect the guano supply from an island, or portion of an island, that was attributed to each province, and quantities were rationed. Landmarks were used so that one province did not enter that of another, and an appropriate penal code was established to outlaw disturbance of the birds and prevent egg theft. During the breeding season it was not permitted to land on the islands, so that the birds would not be disturbed and fly away from their nests. The penalty for anyone who killed any bird, at any time or in any place, or disturbed them on the nest, was death (de la Vega 1609).

Inca policy thus conserved the natural resources and tried to ensure the continued use of the environment for the benefit of human society (Rostworowski 1981, Hughes 1999). To the authors' knowledge, these were the first conservation measures implemented by humans, at least in South America, to protect animal species and their natural habitats, based on the importance of species protection for human activities – one of the current premises for the implementation of national parks (Jongman 1995).

There are several indigenous communities on all continents that provide some form of protection for the natural heritage, related to a spiritual connection with Nature and ethnography passed down through generations, which could be considered a form of conservation. The profound knowledge kept for generations by these communities is being used for several projects aimed at native species and habitats (Tidemann & Gosler 2010). For example, in New Zealand, spiritual guardianship by Māori indigenous people has played a key role in the conservation of wildlife populations and their habitats. Several New Zealand native birds were recognized as 'treasure species' by Māori tribes, from which the people derived part of their identity and which represented highly valued sources of food and feathers, as stressed by Liver and Moller (2010). The spiritual context consisted, for example, in the idea that it was considered 'shameful' to receive visitors of importance and not serve a meal of these birds. This spiritual guidance might have played an important role in increasing the chances of 'treasure species' chicks fledging and minimizing overharvesting and wastage. Nevertheless, these 'forms of protection' did not embody specific laws focusing on management and/or preservation of a specific species and/or habitat, let alone economic interests, being more similar to the pre-Inca civilization forms of protection based solely on cultural and spiritual aspects.

The Inca conservation and protection measures could explain the geographical range of the guano birds across the Inca Empire area, supported by the low genetic differentiation of the Peruvian Pelican across its range and possibly explaining its recent range expansion (Jeyasingham *et al.* 2013). The preservation of the guano islands by the Incas could also explain the high abundance of the three most important guano bird species, leading to the guano boom of the 19th century, when guano became a valuable resource with millions of tonnes being exported to North America and Europe, leading to overexploitation of the Peruvian guano deposits (Duffy 1994). Overharvesting and an increased human presence on the guano islands were responsible for the seabird colony declines (Cushman 2005), with thousands of young animals being killed just to facilitate access for guano diggers (Murphy 1927).

The Compañia Administrativa del Guano, an initiative from the beginning of the 20th century, reported some management actions taken to increase bird numbers and, thereby, sustain the Peruvian guano harvest:

- The protection of fish stocks to increase food availability to guano birds
- Disinfection and use of toilets by workers on the islands to avoid transmission of possible diseases by humans
- Improvement of the landscape on the islands to provide larger areas for nesting and to allow better air circulation, using dynamite for controlled explosions (Vogt 1942)

- Several measures to either reduce or eliminate the natural predators of the guano birds (Cushman 2013).

Clearly, the meaning and value of seabird guano for the Incas, where the guano islands were central to the survival of a whole civilization (Snyders 2011), differ substantially from what those in the 19th–20th century of Western societies (Szpak *et al.* 2012b).

CONCLUSIONS

The prosperity of the Inca civilization was due to an economic system based not only on agricultural production but also on the organization of an integrated system to support food supply by encompassing access to guano sources, its transportation across the empire and the protection of guano birds and their natural habitats. The dependence on guano to fertilize the vast arid land across the empire turned the guano birds into one of the most important pillars of Inca development and expansion.

Although pre-Inca civilization's spiritual connection with Nature represented some 'form of protection', there is no evidence that such actions were embodied within a penal code with specific laws focused on management and/or preserving a specific habitat, similar to other indigenous civilizations across the Earth.

To achieve sustainable use of a natural resource such as the seabird guano, which was of major economic importance for the development of the Inca Empire, management plans, based on a penal code aiming to preserve these species and their natural habitats, gradually emerged and could be among, or indeed represent, the first habitat conservation measures ever implemented by humans. These conservation measures allowed not only the sustainable use of seabird guano as a resource, but also the guano bird species to thrive due to protection and habitat conservation.

The efficacy of the management plan developed by the Incas is especially evident when compared with and contrasted with the overexploitation of Peruvian guano during the 19th century, which led to the huge decline of these seabird populations.

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