

Chapter 2

Research Contents and Methodology

2.1 Background and Research Significance

2.1.1 Background

With the rapid development of the human society since the Industrial Revolution, more and more global environmental problems, e.g. global warming, sea level rise, ozone depletion, frequently extreme weathers, etc., occur to unprecedented amplitudes, for which we pay a painful price. Especially since the 1960s, global change has gradually become the limitation factor in social-economic development. To promote the study of global changes and broad cooperations among countries, International Human Dimensions Programme on Global Environmental Change (IHDP), International Geosphere Biosphere Programme (IGBP), World Climate Research Programme (WCRP) and DIVERSITAS jointed together to found the Earth System Science Partnership (ESSP) in 2001. Global warming is one of the most typical issues of global changes, and has drawn increasing attentions from politics, academia and ordinary citizens worldwide. According to the 4th synthesized report of climate change study released by Intergovernmental Panel on Climate Change (IPCC) in 2007, global surface temperature over the last century has increased by 0.74 °C. Continuous increase in temperature exerts significant impacts on many aspects of natural systems and human society (IPCC 2007). Changes of eco-environments in response to climate change and anthropogenic forcing has become focus and frontier of global change studies. To better understand ecological response to global changes on a scientific basis and better adapt to those changes become urgent. Study of “Human activities and their impacts on the Earth system” and “Global change and regional response” have also been listed as Basic Research in Response to Major National Strategic Needs in “The National Medium- and Long-Term Program for Science and Technology Development (2006–2020)” in China.

Understanding the past is of great importance for predicting the future. Scientists have used a variety of natural archives, e.g. polar/alpine glaciers, marine sediments, loess deposits, speleothems (stalagmite), lacustrine sediments, etc., to study palaeoclimate and palaeo-ecology on different time-scales (Petit et al. 1999; Thompson et al. 2000; Wang 1999; Guo et al. 2002; Wang et al. 2008; Liu and Herbert 2004). Those studies provide essential information for discriminating different roles of natural and human forcing, and predicting the future. However, differences in ecosystem-type, and complexity of climate systems render future prediction quite uncertain. For example, scientists found that seabirds (penguins) in high-latitude Antarctica tended to prefer warm climate (Sun et al. 2000). In contrast, a cool climate seemed more favorable to seabirds in tropical areas (Liu et al. 2006). Some key issues remain unclear. For instance, coupling between climate and productivity, and impacts of climate dynamics on ecosystems have not been well-documented and need further in-depth discussion. To better understand these processes, scientists initiated some International research programs, including International Geosphere Biosphere Programme (IGBP), World Climate Research Programme (WCRP) and WCRP-based Climate Variability and Predictability (CLIVAR).

In terms of time scale, palaeo-climate and palaeo-ecology over the past two millennia are of particular interest (Shi 1997), as it is not only highly related to human civilizations, but also susceptible to be affected by anthropogenic feedbacks. The study of climate during this time thus provides a “key” to predict the future, and has been emphasized by international organizations. Past Global Changes (PAGES) aims at understanding the Earth’s past environment and making predictions for the future. The study of climate in the last two millennia is one of PAGES’s two focuses. National Research Council of the Nation Academies, USA (2006) also released its synthesized report namely “Surface Temperature Reconstruction for the Last 2,000 years”. The present study aims to reconstruct ecological records of the Xisha Islands, South China Sea, over the past 2,000 years. Via multi-proxy analysis and regional comparisons, it is attempted to decode possible interactions among climate change, human activity and ecosystems. This is helpful for the environmental conservation, resource exploitation and future climate prediction in the South China Sea.

2.1.2 Significance of the Present Work

Seabirds frequently move across aquatic and terrestrial ecosystem boundaries, playing an important role in exchange of matter and energy between ecosystems. Those biovectors can deliver significant quantities of nutrients, i.e., phosphorus and nitrogen, from oceans to insular islands. On the other hand, they also transport a large number of toxic contaminants, typically heavy metals and persistent organic matters (POPs), via food chains and biomagnifications, bringing about potential ecological risks (Allaway and Ashford 1984; Wendy and Polis 1999; Blais et al. 2005). Seabird population changes, foraging behaviors and dietary

compositions are essential for seabird ecology study. To date, the relationship between seabird ecology and climatic/environmental changes remains an open question and has not been well-studied. Seabird relics provide valuable information of the past, and thus enable a potential use to study changes in seabird ecology, paleoceanography and palaeoclimate. Elemental geochemical and isotopic analyses of the ornithogenic sediments from the Xisha Islands, are extensively used in the present study. From a technical perspective, this will aid in development in stable isotope ecology and island ecological geology. It will further help for examining biogeochemical cycling of some elements among geosphere, hydrosphere, biosphere and atmosphere. Under a background of global warming, our study constructs the basis of assessing the vulnerability of coral islands, as well as environmental management and resource exploitation.

According to the 4th synthesized report of IPCC in 2007, there is regional imbalance among countries. Most of reconstructed records are from developed countries, but data from developing countries are extremely deficient. The study of the Xisha Islands helps in understanding teleconnections among climate, oceans and creatures in low-latitude tropical areas, and can provide supplementary data from developing countries.

2.2 Research Objectives

Based on rationale of ecological geology, this study focuses on ecological responses of seabirds from a specific region. Study area of the present study is the Xisha archipelago located in the central South China Sea. We will attempt to investigate palaeoecology from ancient bird remains by elemental geochemical, stable isotopic and biochemical analyses. Seabird ecology in the past of this area is the core of the present study, and the principal objectives are specified as follows:

1. By high-resolution ^{210}Pb - ^{137}Cs and radiocarbon (^{14}C) dating techniques, establish reliable chronologies for the sediment cores collected from five individual islands.
2. Via biomarker analysis (bio-elements and reflectance spectroscopy), reconstruct relative seabird population size over the past two millennia on the Xisha Islands, identify the overall trends in seabird population dynamics, and construct evolution model of coral island ecosystem.
3. From proxy-based analysis (including heavy metal mercury and black carbon, which reflects human metallurgy civilization and energy structure changes, respectively), seek for possible evidence of past anthropogenic activity.
4. Through stable isotopic analysis of ancient bird remains, reconstruct seabird palaeo-diet and examine interactions among seabird diet, foraging behavior and population changes.
5. From a historical perspective, demonstrate impacts of climate, ocean productivity and human activity on seabird population, investigate the reason for the

rapid decrease in seabird population in recent times, and assess ecological risks from human activities on the coral islands.

The ultimate objective of our study is providing useful data for future prediction of ecological response to climate change, on the basis of regional comparison.

2.3 Research Contents

1. Establishment of chronology for the collected sediment cores

Accurate and reliable chronology is the basis of palaeoecology study. There are several kinds of dating techniques to choose from, depending on the type of material and its age. Because the Xisha Islands were formed during middle to late Holocene (~6 ka), and there are lots of carbon-bearing biological materials (bird/fish bone, eggshell etc.) in the sediments, we attempt to take radiocarbon analysis as the main dating technique (upper limit ~50 ka years). To examine possible influences of recent human activity on the island ecosystems, high-resolution chronology within the past ~150 years is indispensable. As radiocarbon (^{14}C) has a half-life approximately 5,730 years, it cannot well-resolved chronology of post-industrial sediments. For such deposits, ^{210}Pb - ^{137}Cs dating is an ideal chronological analysis tool. Joint use of ^{14}C analysis and ^{210}Pb - ^{137}Cs dating can yield more precise chronology. Detailed chronological analysis of the sediment cores will be given in following chapters.

2. Seabird population reconstruction

Population is an important part of seabird ecology, and also a critical research topic in study of ecological responses to climate change and human activity. In an earlier study, record of seabird population since 1,300 years before present on Dongdao Island of the Xisha archipelago has been reconstructed. We have collected new sediment cores from the study area. On the basis of biomarker identification (avian bio-elements and characteristic spectrum), the present study attempt to reconstruct seabird population record over the past 2,000 years on the Xisha Islands. Based on bottom-up changes in source materials of the cores, we also infer the developmental model (i.e. gradual development) of such coral island. The influence of seabird activity on plant development and its feedback will also be discussed.

3. In-depth discussion of the causes for seabird population changes

On the foundation of chronology analysis and seabird population reconstruction, our next step it to discuss the possible reasons for seabird population variability. Both natural and anthropogenic forcing can exert significant impacts on seabird abundance. Proxy-based climatic and environmental records have been reconstructed by scientists. These include historical SST, ENSO, monsoons and solar irradiation records, which may affect seabird directly or indirectly. We will compare our seabird population records with climatic dynamics and attempt to identify key factors affecting seabirds. It is expected to formulate

a theory explaining the mechanism of past seabird population changes in the Xisha Islands.

4. Reconstruction of seabird dietary compositions during the past 2,000 years

Generally, alterations in diets and foraging behavior of seabird lead to changes in stable isotope compositions. Thus, the palaeo-dietary record of seabirds can be obtained by stable isotope analysis of well-preserved bird remains, including organic matrix of eggshell, guano particle and bone collagen. As foraging strategy is closely related with population size, and seabird population changes may affect their dietary compositions. Potential linking among changes in climate, seabird foraging behavior and their population will be examined.

5. Records of past human activity from the ornithogenic sediments

Strength of human activity over the past 200 years has surpassed that of any other epoch. Heavy metal mercury and black carbon are closely related to human metallurgy civilization and energy structure. We will attempt to examine the levels of these proxies in ancient bird tissues, as well as bulk ornithogenic sediments. A potential correlation between anthropogenic activity and their levels will also be examined.

6. Preliminary study of ancient DNA extraction from subfossil guano particles

So far, little is known about the correlation between evolution and environmental changes on the Xisha Islands. Whether climate change impacts on evolution, or DNA structure, remains unclear. Bird droppings are remains of swallowed food. Such materials contain information about host organism, as well as prey. Ancient guano has a potential use to study temporal changes in DNA structure of both host and prey organisms. In the present, it will be attempted to perform DNA isolation from ancient guano particles.

2.4 Methodology

The overall idea of the present study is to clarify possible mechanism of seabird ecology changes in response to climate change and anthropogenic activity. We attempt to reconstruct records of seabird ecology in a tropical environment via biomarker identification. The basic principles of multi-disciplines, i.e. ecology, geology, oceanography, geochemistry etc., will be incorporated in the present study. Techniques that we employ include elemental geochemical, isotopic geochemical and biochemical analyses. “Macro” changes in seabird population/diet and “micro” alterations in trace elements and isotopic compositions will be evaluated by geochemical analyses. Proxy-based records and modern observations will also be compared to infer time-series evolution. Regional characteristics and differences of our records in tropical island ecosystems are also considered.

In short, our first step is to collect ornithogenic sediment cores from typical islands the Xisha archipelago. Then, accurate and reliable chronology of the sediment profiles will be established via radiocarbon and ^{210}Pb dating techniques.

After that, we will attempt to reconstruct developmental processes of the coral islands, seabird population and their dietary records over the past 2,000 years. Ultimately, it is expected to conceive a hypothesis explaining interactions among climate system, marine environments, seabirds and coral islands.

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