第 6 卷　第 5 期
2015 年 10 月

地球环境学报
Journal of Earth Environment

Vol.6　No.5
Oct. 2015

doi:10.7515/JEE201505010

# 重金属元素 Hg、Cd、Cu、Zn 和 Se 在南海东岛上的时空分布特征

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**摘　要**：重金属和其他污染物迁移转化过程中的生物传输模式在极地及高纬地区已经被广泛研究，但是生物传输模式对低纬地区重金属元素从海洋向陆地转移过程中的作用目前还不是很清楚。本研究主要分析了重金属元素 Hg、Cd、Cu、Zn 和 Se 等在南海热带珊瑚礁岛屿东岛上的时空分布。结果显示：海鸟粪是东岛表土和沉积物中元素 P、Hg、Cd、Cu、Zn 和 Se 的主要来源。同时本文还校准得到了过去千年海鸟粪中重金属元素 Hg、Cd、Cu、Zn 和 Se 的浓度变化，结果显示：海鸟粪中的重金属元素在工业革命之后均出现了快速的上升，与人类活动的加剧相对应。除了 Cd 之外，东岛表土和沉积物中的其他重金属元素浓度目前都相对较低，没有达到污染水平。但是，东岛上目前生活有超过 50000 只的红脚鲣鸟，这些鸟类会不断地从海洋中富集重金属元素，并通过鸟粪的形式输送到岛屿上。这些鸟类本身不是污染的制造者，它们只是人类排放污染物的富集和传输媒介。

**关键词**：重金属元素；土壤与沉积物；红脚鲣鸟；生物传输；污染

**中图分类号**：X53；X825　　**文献标志码**：A　　**文章编号**：1674-9901(2015)05-0330-11

## Temporal and spatial distribution characteristics of heavy metals Hg, Cd, Cu, Zn and Se on Dongdao Island, South China Sea

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**Abstract:** The biovector transport of heavy metals and other contaminants in polar areas has been widely recognized, but its role in the movement of heavy metals from marine to terrestrial ecosystems in low latitudes remains less studied. In this study, we analyzed the temporal and spatial distributions of heavy metals Hg, Cd, Cu, Zn, and Se in a tropic coral reef island, Dongdao Island, South China Sea. The results indicated that seabird droppings are the major source of elements P, Hg, Cd, Cu, Zn, and Se in the surface soils and lake sediments. The concentrations of Hg, Cd, Cu, Zn, and Se in the historical booby droppings over the past millennium were calculated and the results suggested that these heavy metals have been rapidly increasing since AD 1800, the time of the Industrial Revolution. Except Cd, the contamination levels of heavy metals in the soils and sediments of Dongdao Island are presently low; however the current 50000 red-footed boobies are generating more droppings and aggravating the heavy metal pollution on the island. These

**Received Date**：2015-09-16

**Foundation Item**：Natural Science Foundation of China (NSFC) (41522305, 41403018, 41176042); the West Light Foundation of the Chinese Academy of Sciences (29Y42909101) ; the Youth Innovation Promotion Association CAS

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seabirds are not polluters per se; they are just inadvertent vectors of the pollutants that are released to the environment by human activities.

**Key words:** heavy metals; soil and sediment; red-footed booby; biovector transport; pollution

Most of the world's oceans and seas have been under increasing pressure of anthropogenic contaminations since the Industrial Revolution as emission of atmospheric contaminants and discharge of oily wastes, ballast water, garbage, and sewage keep increasing (Fitzgerald et al, 1998; Miller et al, 2003; Elliott, 2005). Among the industrial contaminants, heavy metals Cd, Hg and Pb are nutritionally nonessential, and dietary exposure to elevated levels of these metals can be toxic to consumer (Elliott and Scheuhammer, 1997; Elliott, 2005). Cr, Cu, Zn, Fe, Mn and Se are nutritionally essential, but may become toxic if they are accumulated in tissues at excessively high levels (Elliott and Scheuhammer, 1997; Elliott, 2005).

Marine animals can concentrate heavy metals to potentially toxic levels (Ewald et al, 1998; Li et al, 2002; Christensen et al, 2005; Blais et al, 2007; Michelutti et al, 2009). Seabirds, as one of the top predators in the marine food web and the globally relevant biovectors, have received considerable attention recently (Blais et al, 2007). Many seabird species occupy high trophic positions in the marine food web; as a result, they often accumulate elevated levels of contaminants due to bioaccumulation (Blais et al, 2007). When seabirds congregate on shore, often in dense nesting colonies, they funnel a portion of their bioaccumulated contaminants to land via guano and mortality. This biovector transport process has been widely recognized in the Arctic flora and mire, in the soils with high gull density, and in the Antarctic ornithogenic lake sediments (Sun et al, 2000; Sun and Xie, 2001; Blais et al, 2005; Liu et al, 2005; Blais et al, 2007), but seabirds' role in the movement of heavy metals from marine to terrestrial ecosystems in low latitudes remains less studied (Liu et al, 2006, 2008b; Yan et al, 2010, 2011b).

In this study, we analyzed concentrations of Hg, Cd, Cu, Zn and Se in the ornithogenic sediment and surface soil samples collected from a seabird colony of a tropical coral reef island, South China Sea (Fig.1), studied the temporal and spatial characteristics of biotransport of these heavy metal pollutants, and reconstructed concentrations of these heavy metals in the historical red-footed booby droppings over the past millennium.

## 1 Materials and methods

### 1.1 Study area description

Dongdao Island (16°39'~16°41'N, 112°43'~112°45'E) is located in the east of the Xisha Islands of South China Sea, and is about 18 sea miles from Yongxin Island, the largest one of the Xisha Islands. Dongdao Island is a tropic coral reef island with an elliptical shape and a northwest-southeast orientation (Fig.1), and it is developed on an individual reef flat and formed during the period of mid-late Holocene, the primary formation period of the Xisha Islands (Liu et al, 2008a; Yan et al, 2011a). This small island has a land area of 1.55 $km^2$ and an elevation of about 3~6 m above the sea level (a.s.l.), and it is completely composed of coral sand and coral rock. The eastern, southern and western shores of this island are surrounded by 5~6 m high sand barriers; the sand barrier on the southeastern shore is slightly higher than that on the northwestern shore. The sand barriers are covered with thriving shrubs. A wide and continuous area of beach rock and unconsolidated bioclasts of Tridacna shells crop out along the northern shore. Along the northwestern shore is a sandy beach of coral and shell. In the interior of this island is an up to 3 m high flat. In the middle and about half area of this island is covered by *Pisonia grandis* woodland, providing a good and shaded nesting place for numerous seabirds. Under the *Pisonia grandis* woodland is black phospho-calc soils enriched with organic matter with a distinct smell of seabird droppings. Dongdao Island has been identified as the natural reserve area for red-footed booby (*Sula sula*) (Liu et al, 2006, 2008a).

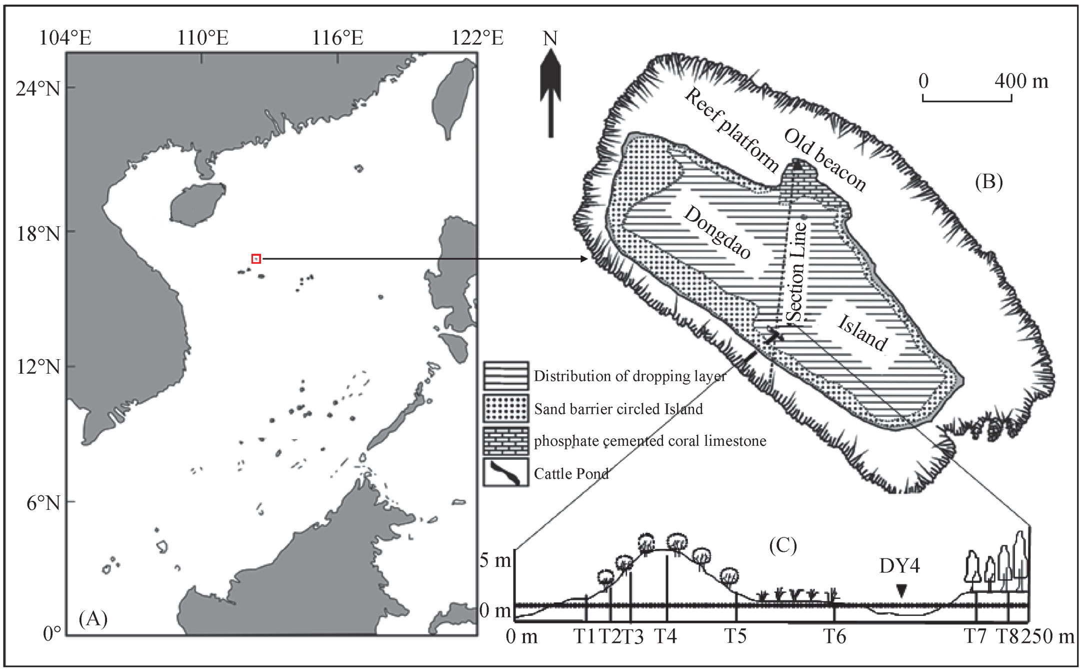



Fig.1 Maps showing the geographical location of the Dongdao Island
(A), and the distribution of morphological zones of Dongdao Island (B). The geomorphology from the beach to the center of Dongdao Island (C), Cattle Pond, sampling sites T1 to T8, and the sampling site DY4 are marked in (C)

"Cattle Pond" was discovered on Dongdao Island during our field investigations in 2003 (Liu et al, 2006, 2008a; Yan et al, 2011a). Cattle Pond is a crescent-shaped freshwater lake, located within the southwestern sand barrier, it is about 150 m long, and it has a maximum width of 15 m. This pond is hydrologically closed, it is the only fresh water source for the seabirds living on the island, and the lake water is completely fed by atmospheric precipitation and lost predominantly through evaporation (Yan et al, 2011a). Field observations showed that a large number of seabirds cluster in this area and seabird droppings significantly influenced this pond. The water depth of Cattle Pond varies with the alternation of dry and wet seasons. According to field investigations, Cattle Pond never completely dries out; the water depth remains steady at about 0.5 m most of the time.

### 1.2 Sample collection

Sediment core DY4, 117 cm long, was collected from Cattle Pond during the field investigations March 10—April 11, 2003 (Liu et al, 2008a). During sampling, PVC plastic gravity pipes of 12 cm in diameter were pushed down into the soft substrate of the lake floor and then quickly retrieved. In the laboratory, the DY4 core was opened, photographed and described, and then sectioned at 1 cm intervals. Eight surface soil samples named T1 to T8 were collected from the beach to the center of Dongdao Island (Fig.1). Three fresh dropping samples were taken from different sites with breeding colonies. Five common perennial plant species in Dongdao Island, *S. sericea*, *G. speciosa*, *A. villosa*, *P. grandis*, and *S. portulacastrum*, were chosen for this study. We also collected three coral rock samples to determine the element background of Dongdao Island.

### 1.3 Analysis method

All subsamples were analyzed for inorganic elemental concentrations. The plant samples were analyzed according to the procedure by a previous study (Xie and Sun, 2003). They were cleaned from soil deposits, washed separately and thoroughly with tap and deionized water, and dried at 60℃ for 12 h. Root tissues of these plant samples were discarded to avoid possible soil contamination, and only the above ground plant parts (stems, leaves) were analyzed. These dried plant tissues were blended and powdered. The powder sample (0.5 g) was fused with NaOH and $Na_2O_2$ at 650℃ in a covered nickel crucible. The residue was extracted by 50 mL deionized water at 90℃ , and the filtrate was diluted to 100 mL using deionized water. The soil, feces, coral rock and sediment samples were air-dried in the clean laboratory first, ground and passed through a 120-mesh screen, and then dried again at 60℃ for 12 h. About 3 g of each dried powder sample was taken, precisely weighed, and then digested by multi-acid (high purity grade $HNO_3$, HF, $HClO_4$) in a Pt crucible with electric heating. Atomic absorption spectrophotometry (AAS) was used to determine concentrations of Ca, Cu, Zn, Pb, Cd, Fe, and Mn. For details of these analytical methods, see Liu et al (2006). Abundance of $P_2O_5$ was determined by ultraviolet visible spectrophotomety (UVS). Concentrations of As and Hg were determined by atomic fluorescent hydrogenation (AFS). For quality control purpose, the national standard sediment and soil samples of GBW07120 and GBW07108 (2 replicates) were measured as "unknowns" with every batch analysis. The analytical values for the major elements and heavy elements are within ±0.5% and ±5% of the certified ones, respectively.

Radiocarbon analyses for the DY4 core were performed on terrestrial organic matter (plant caryopsis) after HCl treatment with the Accelerator Mass Spectrometer facility at Institute of Heavy Iron Physics in Peking University. The dating results and detailed description of the equipment and method were given by Liu et al (2008a) and Yan et al (2011a).

### 1.4 Method for reconstruction of heavy metal concentrations in the historical red-footed booby droppings over the past millennium

Previous study by Zhao et al (2007) analyzed the ratios of Sr/Ca and Mg/Ca in the plant, coral sand, and seabird dropping samples from Dongdao Island and found that these ratios were distinct and could be used to identify the material source. Using three end-member mixing model, we calculated relative contribution of seabird dropping, coral sand, and plant remains in DY4 (Fig.2).

Seabird droppings and coral sands make up 90% of the DY4 sediments (Fig.2). The sediments in the top 45 cm of DY4 are composed of roughly 50% feces, 40% coral sands, and 10% plant remains. Because of the steady and abundant seabird droppings input, the sediments in the top 45 cm were used to estimate the Hg, Cd, Cu, Zn, and Se concentrations in the historical red-footed booby droppings using the following mass equation:

$$(M)\times[(x\%)\times(C_x)+(y\%)\times(C_y)+(z\%)\times(C_z)]=(M)\times(100\%)\times(C_m) \quad (1)$$

Where

$M$ = total weight of sediment,

$x\%$ = percentage of booby droppings in lake sediments,

$y\%$ = percentage of coral sands in lake sediments,

$z\%$ = percentage of plant remains in lake sediments,

$C_x$ = concentration of elements (Hg, Cd, Cu, Zn and Se) in booby droppings,

$C_y$ = concentration of elements (Hg, Cd, Cu, Zn and Se) in coral sands,

$C_z$ = concentration of elements (Hg, Cd, Cu, Zn and Se) in plants,

$C_m$ = concentration of elements (Hg, Cd, Cu, Zn and Se) in sediments.

We assumed that the Hg, Cd, Cu, Zn, and Se concentrations in coral sands and plants remain constant during the studied time period and used the Hg, Cd, Cu, Zn, and Se concentrations in coral sands background and modern plant as $C_y$ and $C_z$.

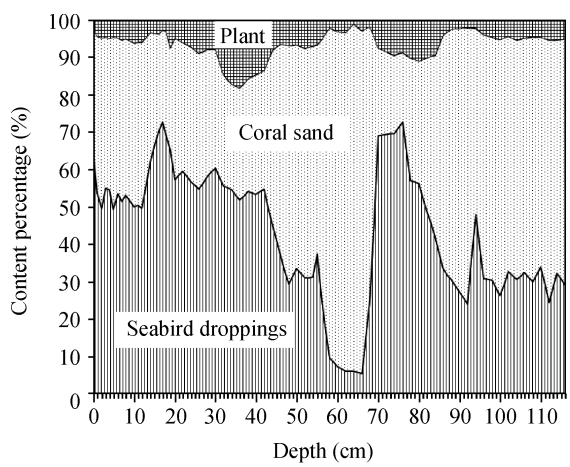



Fig.2 Relative contributions (%) of seabird droppings, coral sand, and plant remains in the DY4 lake sediments (Zhao et al, 2007)

## 2 Results and discussions

### 2.1 Concentrations of P and heavy metals in seabird droppings, plants and coral sand background

The levels of nine heavy metals (Hg, Cd, Cu, Zn, Se, Pb, As, Fe, Mn, Ni, and Sr) and nutrient element P in the red-footed booby droppings and the coral sand background of Dongdao Island are given in Tab.1 together with the ratios of element concentration in feces to that in coral sand. P has the highest level of up to 15% in the red-footed booby droppings, almost a thousand times higher than that in the coral sand background. The concentrations of Cd, Cu, Zn, and Se in the seabird droppings are tens of times higher than those in the coral sands (Tab.1). The level of Hg in the fresh seabird droppings is more than fifty times higher than that in the coral sand background (Tab.1). One likely explanation for this is that red-footed boobies (*S. sula*) have fish as its main diet; they accumulate Hg through biomagnification in the food chain (Burger and Gochfeld, 2000). Pb has comparable levels in the seabird droppings and the coral sands, indicating a lack of bioaccumulation in the food chain; and this is consistent with the earlier observation (Ancora et al, 2002). The Cu concentration in the seabird droppings is 18 times that in the coral sands.

Tab.1 Concentrations of P and heavy metals in seabird droppings, coral sand background, plants, DY4 sediments, and surface soil

| | $P_2O_5$ (%) | Hg ($\mu g \cdot kg^{-1}$) | Cd ($mg \cdot kg^{-1}$) | Cu ($mg \cdot kg^{-1}$) | Zn ($mg \cdot kg^{-1}$) | Se ($mg \cdot kg^{-1}$) | Pb ($mg \cdot kg^{-1}$) |
|---|---|---|---|---|---|---|---|
| Fresh seabird droppings (FSD) (*n*=3) | 15.081 | 88.3 | 6.62 | 39.8 | 489 | 3.05 | 2.61 |
| Coral sand background (BG) (*n*=3) | 0.015 | 1.59 | <0.2 | 2.2 | 6.92 | 0.035 | 2.08 |
| FSD/BG | 986.86 | 55.53 | >33.1 | 18.09 | 70.66 | 87.14 | 1.25 |
| Plant average (*n*=5) | 0.319 | 7.63 | 0.38 | 12.17 | 35.72 | 0.26 | 1.59 |
| Sediment average (*n*=117) | 1.65 | 14.34 | 2.34 | 6.63 | 28.5 | 1.55 | 3.26 |
| T1—T8 average (*n*=8) | 3.28 | 17.98 | 4.71 | 16.125 | 154.36 | 1.46 | 3.3 |

### 2.2 Seabird droppings' influence on spatial distributions of P and heavy metals in surface soil of Dongdao Island

We collected 8 surface soil samples (T1—T8) from beach to the center (Fig.1), analyzed the concentrations of P and Hg, Cd, Cu, Zn, and Se, and observed a clear concentration gradient of P, Cd, Cu, Zn and Se from beach to the center (Fig.3). This is understandable. Due to the great difference in the concentrations of P, Hg, Cd, Cu, Zn and Se between seabird droppings and local background, a large amount of seabird droppings input will dramatically change the characteristics of the surface soil. The T1—T4 samples were collected from the seaward side of the coral sand, the place that is an unfavorable area for seabird activities due to strong wind from sea; thus seabird droppings input is very limited. Additionally, waves may flush away the seabird droppings on the surface of the coral sand barriers. On the contrary, the T7—T8 samples were collected from the *Pisonia grandis* woodland with approximately 35000 breeding pairs of red-footed booby (*S. sula*)(Cao et al, 2005) and a large amount of excrement. The average concentrations of P, Cd, Cu, Zn, and Se in T7—T8 are 31, 71, 5, 11 and 29 times higher than those of T1—T4, respectively. Unlike Cd, Cu, Zn, Se and P, Hg does not have a clean concentration gradient between T1—T4 and T7-T8, and this could be attributed to its vaporizable nature (a low enthalpy of vaporization as 59.15 $kJ \cdot mol^{-1}$). Mercury could evaporate from seabird droppings (with high mercury concentration), and this evaporation process is more intense on Dongdao Island due to the warm (strong tropical sunlight) and windy climate (Gustin et al, 2002). The T5—T6 samples were collected form the transition belt with shrubs and small trees, the place unfit for seabird nesting but suitable for recreation. Therefore, the concentrations of P, Cd, Cu, Zn, and Se concentrations in T5—T6 are between those of T1—T4 and T7—T8.

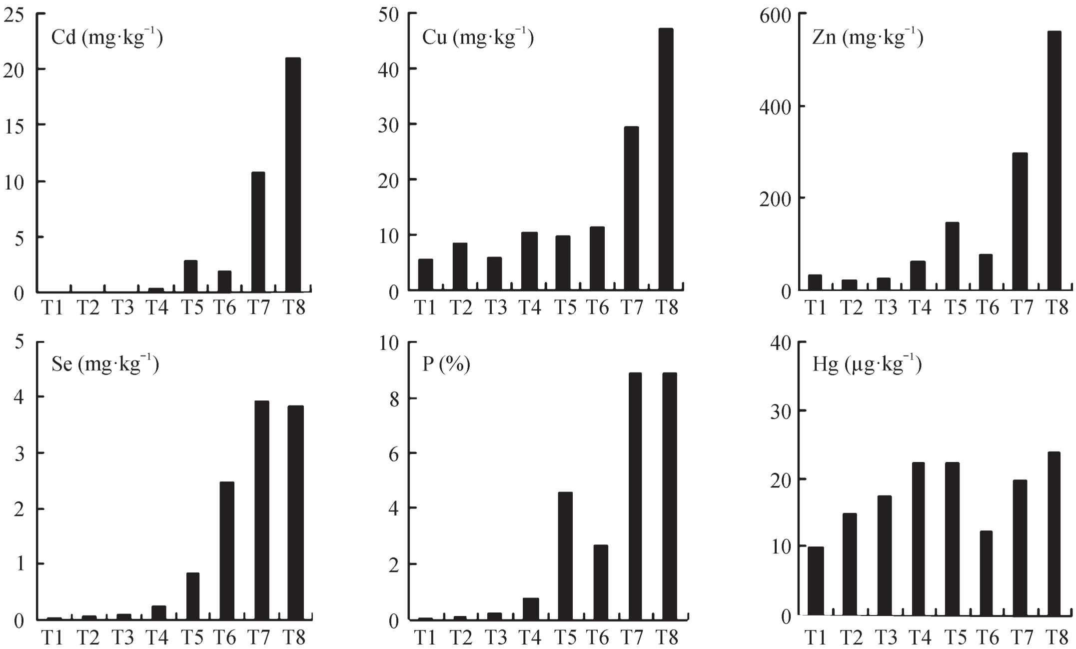
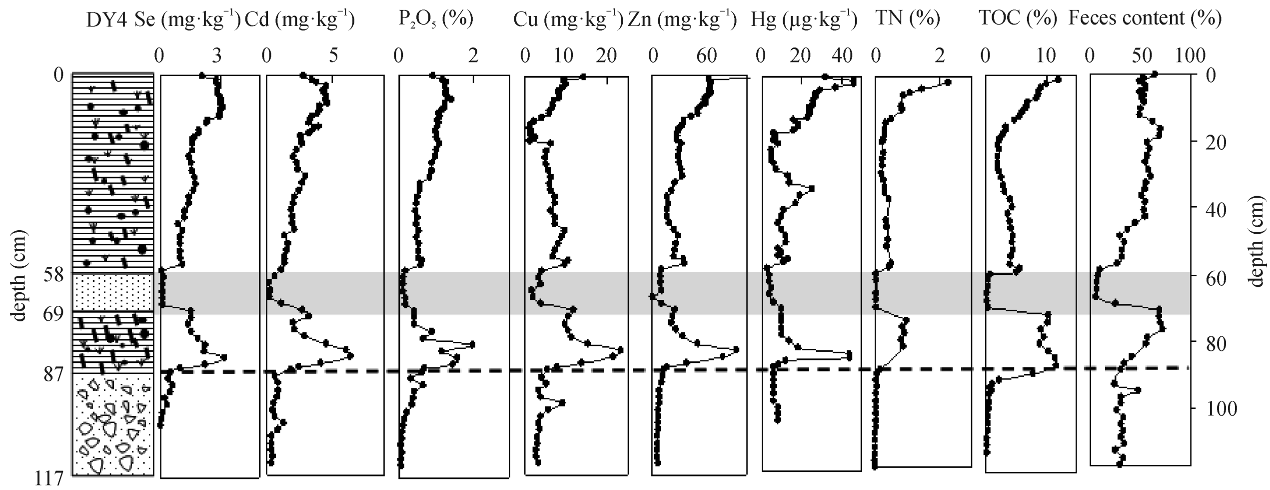



Fig.3　Concentrations of Cd, Cu, Zn, Se, $P_2O_5$ and Hg in the surface soil of Dongdao Island from T1 to T8

### 2.3　Heavy metal concentrations in the historical red-footed booby droppings over the past millennium and possible causes

The lake sediment core DY4 has three sediment units (Sun et al, 2007; Zhao et al, 2007; Liu et al, 2008a) (Fig.4). The bottom unit (Unit 3, from 117 cm to 87 cm) consists of fragments of grey-white coral, shell and sandy gravels. The sediments in the bottom unit probably represent deposition in a lagoon environment, and they do not contain any plant remains. The top unit (Unit 1) consists of ornithogenic sediments and is influenced by guano; it contains bone remnants of seabirds and their dietary fish and discharges a strong and unpleasant smell, similar to the smell of modern seabird excrements. The interbedded coral sand layer (Unit 2, 58~69 cm) has distinctly different lithology from the overlying and underlying sediments, and it possibly corresponds to a precipitous marine sedimentation event happened at about 926 AD (Sun et al, 2007). The seabird droppings content in DY4 (Fig.4) is consistent with the lithology analysis result. For example, the seabird droppings content in the interbedded coral sand layer (Unit 2) is much lower than that in the ornithogenic sediments (Unit 1).

The high phosphate (as $P_2O_5$) content of 1.63% (means of all subsamples) in DY4 (Fig.4) also confirmed the lithology analysis result that a large amount of guano was transported and deposited in the Cattle Pond. The important role of seabirds in the transportation of nutrient nitrogen and phosphorus of marine origin to terrestrial ecosystems has been well recognized (Anderson and Polis, 1999). Phosphate deposits have been shown to occur in the islands of the Pacific and Indian Oceans as the result of phosphate being leached from the superficial coating of avian guano and subsequently the re-precipitation in underlying calcareous sands (Trichet and Fikri, 1997; Baker et al, 1998). The levels and depth distributions of As, Cd, Cu, Zn, Pb, Hg, Fe and Mn in sediment core DY4 have been analyzed by Liu et al (2008b) and the results demonstrated that the seabird droppings are probably the main source of these elements in lake sediments (Fig.4). This result is consistent with numerous studies in the remote islands of Antarctica and Arctic (Sun et al, 2000; Blais et al, 2005; Liu et al, 2005; Blais et al, 2007).




1 2 3 Legend: 1. Middle to fine grained coral sandy mud with brown-red color, containing seabird droppings; some yellow-white coral silts and plant remains are intermingled in the sediments. 2. Well-sorted coral sand. 3. Grey-white coral, shell, and sandy gravel. Broken lines marked in the figure indicate the transition of sedimentary environment. The shadow area indicated the interbedded coral sand sediment layer with sharp stratigraphic contacts.

Fig.4 Lithological characters and down-core variation profiles of Se, Cd, $P_2O_5$, Cu, Zn ,Hg, TN, TOC, and feces content in the DY4 core

Using three end-member mass equation (1), we calculated the Hg, Cd, Cu, Zn, and Se concentrations in the historical booby droppings and the results are plotted in Fig.5. The Hg, Cd, Cu, Zn, and Se concentrations in seabird droppings over the past millennium fall into two distinct periods (Fig.5). Under 15 cm of DY4, they kept at stable relatively low levels. In the top 15 cm, they increased rapidly and fluctuated drastically; the Hg, Cu, and Zn concentrations increased from 27 μg·kg$^{-1}$, 2 mg·kg$^{-1}$, and 47 mg·kg$^{-1}$ to 90 μg·kg$^{-1}$, 16 mg·kg$^{-1}$, and 116 mg·kg$^{-1}$, respectively. From 15 cm to 13 cm, the Cd and Se levels increased from 3 mg·kg$^{-1}$ and 2 mg·kg$^{-1}$ to 8 mg·kg$^{-1}$ and 6 mg·kg$^{-1}$, respectively, and then stayed relatively stable. The reconstructed concentrations of these heavy metals for the booby droppings of the surface sediments are not differentiable from those in fresh booby droppings.

Seabird droppings contain diet-derived and non-biologically available heavy metals, these metals are accumulated in different organs and excreted via different physiological routes (Pastor et al, 1994; Furness and Camphuysen, 1997), and the concentrations of these heavy metals in the seabird excreta closely reflect those in their diets (Pastor et al, 1994; Furness and Camphuysen, 1997; Elliott, 2005). Based on our investigation, flying fish makes up a large proportion of red-footed booby's diet (more than 80%), and squid the rest. Flying fish is plentiful near the studied area due to the good coral inhabits in Xisha Islands. Thus red-footed booby's diet is mainly determined by its feeding habits and expected to be stable over the studied time span. As reported in our previous study (Liu et al, 2008a), each 1 cm sample in DY4 represents about 15 years of sediment accumulation on average based on AMS $^{14}C$ age model. The Hg, Cd, Cu, Zn, and Se concentrations in the top 15 cm, roughly spanning the recent two centuries, are several times higher than those in the 15～45 cm. It is difficult to explain such large and rapid variations by the changes in natural marine environment, and increased anthropogenic emissions in recent centuries are most likely the main contributor (Elliott and Scheuhammer, 1997; Fitzgerald et al, 1998; Miller et al, 2003). For example, Hg is a well known global contaminant and has a long atmospheric residence time of over one year, a long range atmospheric transport, and a global distribution. Human mercury consumption experienced sustained and rapid growth since about AD 1650 in corresponding to beginning of the large-scale gold mining activity in South Central America, which left an unparalleled legacy of massive mercury pollution (Nriagu, 1994; Camargo, 2002; Hylander and Meili, 2003). In this study, the reconstructed Hg profile also revealed a sustained increasing since about AD 1650, similar to the reported sediment records from the other parts of the world (Nriagu, 1994; Martinez-Cortizas et al, 1999; Biester et al, 2002; Sun et al, 2006).

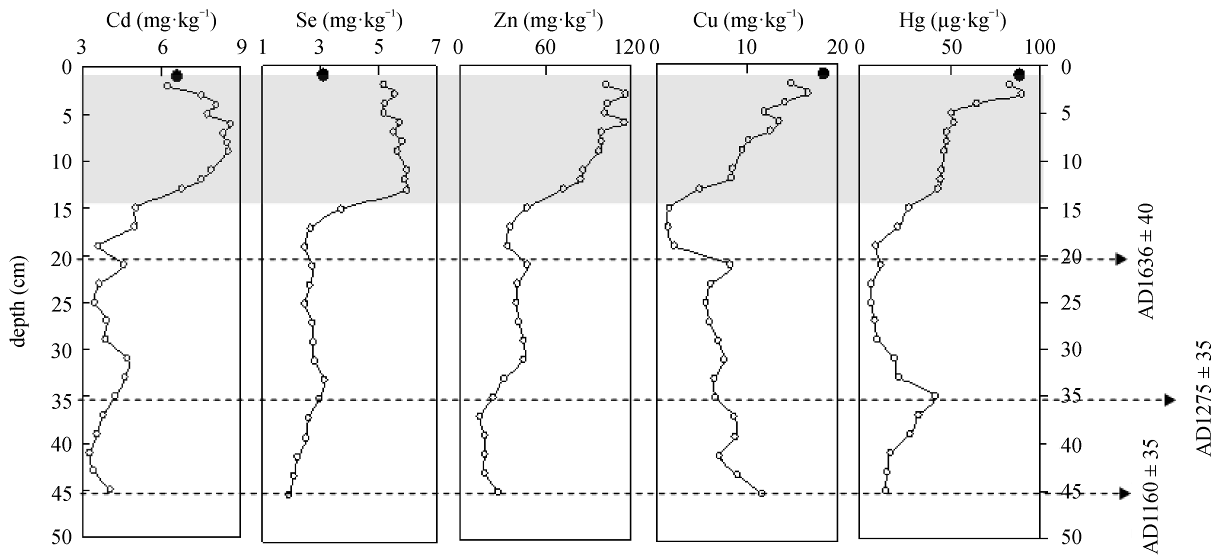



Fig.5 Down-core concentration variation profiles of calibrated Se, Cd, Cu, Zn and Hg in top 45 cm of the DY4 core. Solid dots mark heavy metals concentration in seabird droppings

## 2.4 Potential heavy metal pollution on Dongdao Island

It is difficult to accurately evaluate the contamination level of heavy metals in the soils and sediments of Dongdao Island. First, few data about the historical heavy metal levels in this island are available. Second, the guano-derived element concentrations are closely related to the degree of the influences by seabirds (Otero and Fernandez-Sanjurjo, 2000; Sun et al, 2000; Blais et al, 2005, 2007). Here we give a tentative estimation for the environment quality in Dongdao Island using the determined levels of heavy metals in the bird-influenced materials, the national environmental quality standards, and the published thresholds of heavy metal levels that may affect wild animals and plants (Tab.2).

For the soils in Dongdao Island, the concentrations of Cu and Hg in the bird-influenced samples were lower than the critical levels given in Chinese Environmental Quality Standard (No. GB15618—1995) (threshold: Cu 100 mg·kg$^{-1}$, Hg 1.0 mg·kg$^{-1}$), but the concentration of Zn in T7—T8 samples, which are strongly influenced by seabird droppings, is above the critical level (Zn 300 mg·kg$^{-1}$). The concentrations of Cd in T5—T6 and T7—T8 samples are far above the critical level (0.6 mg·kg$^{-1}$).

For the lake sediments, the corresponding national standard is not available, so we used the marine sediment standard instead (No. GB181668—2002, threshold: Cu 35 mg·kg$^{-1}$, Zn 150 mg·kg$^{-1}$, Hg 0.2 mg·kg$^{-1}$, Cd 0.5 mg·kg$^{-1}$). Like in the soils, the concentrations of Cu, Zn, and Hg in the sediments are below the critical levels, but the concentration of Cd is above. We also compared the concentrations of Cd, Cu, Zn, and Hg in the sediments of Dongdao Island with the threshold effect level (TEL) from Canadian ecological database for sediment baseline (Cu 36 mg·kg$^{-1}$, Zn 123 mg·kg$^{-1}$, Hg 0.173 mg·kg$^{-1}$, Cd 0.6 mg·kg$^{-1}$) (Ni et al, 2005). Again Cd is the only element exceeding TEL. In summary, as a whole, the contamination levels of heavy metals Cu, Zn and Hg in the soils and sediments of Dongdao Island are low, but the concentration of Cd greatly exceeds the critical level.

Tab.2 Comparison of concentrations of heavy metals Cd, Cu, Zn and Hg in surface soil and sediment on Dongdao Island with accepted standard ones

| | | Cd (mg·kg$^{-1}$) | Cu (mg·kg$^{-1}$) | Zn (mg·kg$^{-1}$) | Hg (μg·kg$^{-1}$) |
|---|---|---|---|---|---|
| Surface soil | T1—T4 average | 0.225 | 7.625 | 36.875 | 21.25 |
| | T5—T6 average | *2.385 | 10.75 | 112.25 | 17.5 |
| | T7—T8 average | *16 | 38.5 | *431.5 | 21.9 |
| | No. GB15618—1995 | 0.6 | 100 | 300 | 1000 |
| DY4 Sediment | Min | *1.38 | 1.15 | 16 | 5 |
| | Max | *6.43 | 23.3 | 63 | 46 |
| | average | *3.07 | 7.83 | 39.6 | 17.04 |
| | No. GB181668—2002 | 0.5 | 35 | 150 | 20 |
| | TEL | 0.6 | 36 | 123 | 173 |

*: concentrations are higher than accepted standard ones.

## 3 Conclusion

Seabird droppings are the major source of heavy metals Hg, Cd, Cu, Zn, and Se in the surface soils and sediments of Dongdao Island. The concentrations of these heavy metals in pure seabird feces have been rapidly increasing since AD 1800, the time of Industrial Revolution; apparently the increase is caused by recent anthropogenic activities. Except Cd, the contamination levels of heavy metals in the soils and sediments of Dongdao Island are presently low; however the current 50000 red-footed booby are generating more droppings and aggravating the heavy metal pollution on the island. Seabirds are not polluters per se; they are just inadvertent vectors of these pollutants released to the environment by human activities.

**Acknowledgments:** We wish to thank JIA Nan, LIU Xiaodong, YIN Xuebin and LUO Honghao for their help in sampling and analyzing.

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