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厦门大学

硕士学位论文

西格织纹螺对天然饵料食物相金属的生物累积及毒性效应

Bioaccumulation and toxic effects of dietary metals from naturally contaminated prey to a marine predator *Nassarius siquijorensis*

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摘 要

目前，随着城市化和工业生产的迅速发展，越来越多的金属污染物被排放入海，对近岸海洋生态系统构成了极大压力，有关海洋生物金属生物累积和毒性效应也已成为生态毒理学的一个重要研究方向。相对而言，海洋潮间带又是海洋金属污染的重灾区，开展有关金属污染会如何影响潮间带生物，或者潮间带生物会如何应对日益加剧的金属污染压力的相关研究，具有重要的现实意义。

近年来，有关金属生物累积动力学研究发现食物相暴露是许多水生动物金属生物累积的主要途径，而腹足类又是其中的典型。在海洋潮间带，腹足类通常位于底栖食物链的顶端，通过食物链传递或食物相累积，海洋腹足类常可通过生物放大在其体内积累极高浓度的金属。不过，与此不相称的是，相对海洋双壳类、甲壳类和鱼类等，有关海洋腹足类金属生态毒理学的研究明显较少，还十分薄弱。

另一方面，食物相金属的生物可利用性及其毒性效应日益引起研究者的广泛关注。然而，在以往的金属食物链传递研究中，通常采用经实验室短期金属预暴露获得的不同金属负荷的饵料生物，极少关注天然饵料生物，虽然有些研究已揭示两者在金属生物可利用性方面的差异。

基于上述认识，本研究以厦门海域的常见的潮间带腹足类西格织纹螺(*Nassarius siquijorensis*)为研究对象，从金属污染较严重的厦门九龙江河口及其邻近区域选择不同金属污染程度的站点，采集具不同金属含量葡萄牙牡蛎(*Crassostrea angulata*)和白脊藤壶(*Fistulobalanus albicostatus*)，喂食西格织纹螺 7 周，以研究饵料类型、金属含量、金属的亚细胞分布等对西格织纹螺的金属累积、金属的食物链传递和潜在毒性的影响。获得研究结果如下：

1. 牡蛎和藤壶是具有极强累积能力的“超累积生物”。本研究中采用的饵料体内的 Cu、Zn、Cd 浓度极高：最高的 Zn 浓度出现在白礁的藤壶(9709 μg g^{-1})，最高的 Cu 浓度出现在白礁的牡蛎(3340μg g^{-1})，而最高的 Cd 出现在宫前的牡蛎(24.8 μg g^{-1})。不同采样点的同一物种浓度差异很大，这些饵料的浓度梯度为我们

食物相暴露提供了良好的条件。

2. 经过 7 周的累积，织纹螺内脏中，最高的 Cu 浓度可以达到 1800μg g^{-1}，Zn 可以达到 22678μg g^{-1}，Cd 可以达到 58.1μg g^{-1}，这显示出这一物种较强的累积金属的能力。

3. 饵料中的金属浓度越高，织纹螺体内累积的金属含量也往往较高。不过，作为衡量金属的生物可利用性的指标，食物链传递因子 TTF' 却与饵料中金属的浓度以及金属摄入剂量呈现明显的负相关。这表明饵料金属浓度会显著抑制西格织纹螺对食物相金属的利用率，同时，西格织纹螺摄入的金属越多，利用率也越低。这应该是其金属摄入量与金属同化效率和排出速率等的相互关系的综合反映。

4. 当饵料中的金属(本研究中可能主要是 Cu)浓度高至一定程度，西格织纹螺表现出明显的回避摄食(厌食)，这种摄食行为可显著降低其对金属的摄入，从而导致食物链传递效率的下降，同时也会使食物相暴露的潜在毒性降低。

5. 由于能进行体外消化，西格织纹螺显示了对食物相金属极强的消化能力，甚至利用那些通常认为不能被消化吸收的金属亚细胞组分(如本研究中与富金属矿体结合的 Zn 和 Cd)，表明饵料生物体内金属亚细胞分布对其生物可利用性的影响不似其他生物种类那样明显。不过，对 Cu 而言，其在饵料生物体内的亚细胞分布特征仍然会显著影响其对西格织纹螺的生物可利用性，这应该与 Cu 在生物体内形成具有特殊结构的富金属矿体有关。

我们的研究表明，在进行金属食物链传递研究时，除了饵料生物的金属含量，捕食者的摄食行为(如回避摄食)也是一个值得重视的因子，因为其可能通过改变摄食量而影响相应的金属食物链传递。

关键词：西格织纹螺；金属污染；天然饵料；食物回避；食物链传递

Abstract

As the urbanizing and industrializing of modern society, increasing metal pollution was pouring into the sea, which have a great pressure on the coastal marine ecosystem. The research on marine metal bioaccumulation and toxic effect have become an critical issue in eco-toxicology. Among the contaminated areas, the inter-tide regions are the most polluted ones. The study on the effect of metal pollution to the inter-tide animals or how these animals handle on the metal pressure have gained great significance.

In the past decades, investigation on metal bioaccumulation kinetic have found that dietary exposure is the dominant pathway of metal bioaccumulation in aquatic organisms, among which gastropods are the typical. In marine inter-tide shores, gastropods are usually the top predators in benthic food chain. Through trophic transfer, marine gastropods can accumulate extremely high metal concentration by bio-magnification. However, the study on metal toxicology of marine gastropods is obviously not enough compared with that on marine bivalve, mollusk and fish.

On the other hand, metal bioavailability of prey its toxic effect have gained increasingly focus. Most previous studies investigated the trophic transfer and potential toxicity of metals by using the ‘artificial’ prey with a range of metal burdens, which were achieved by pre-exposing prey to different concentrations of waterborne metals for a relatively short period of time. Very few studies have focused on metal bioavailability and/or potential toxicity from naturally contaminated prey to aquatic predators. This may result in differences in metal bioavailability between natural prey and short-term artificially enriched prey.

Nassarid snails are important opportunistic scavengers widely found in marine intertidal shores and trophic transfer is a predominant source of metal accumulation in these species, thus there is a significant need to understand the controls of metal trophic transfer. Barnacles and oysters are main preys for Nassarid snails, which can accumulated high concentration of metals in contaminated areas. In the present study, we took advantage of a severely contaminated estuary and collected two prey organisms (oysters

Crassostrea angulata and barnacles *Fistulobalanus albicostatus*) with different contaminated histories. These naturally contaminated prey were then fed to a marine neogastropod *Nassarius siquijorensis* for a period up to 7 weeks. We then investigated the influences of prey type, metal burden and subcellular distribution in the prey on the metal accumulation, trophic transfer, and potential toxicity on *N. siquijorensis*.

We demonstrated the results as following:

1. Oysters and barnacles are recognized as 'hyperaccumulator',which can accumulate extremely high concentration of metals. In present study, the highest Zn concentration occurred in Baijiao Barnacles, which can reach 9709 μg g^{-1}, and highest Cu in Baijiao Oysters (3340μg g^{-1}), highest Cd in Gongqian Oysters (24.8 μg g^{-1}).

2. After 7-week dietary exposure, the viscera of snails accumulated high metal concentration, among which the highest concentration of Cu is 1800μg g^{-1}, Zn is 22678μg $g^{-1}$and Cd is 58.1μg g^{-1}. This results indicated the great potential of metal bioaccumulation.

3. We used trophic transfer factors (TTFs and TTF' s) to evaluated the bioavailability and trophic transfer of the metals in natural preys, and we demonstrated an obvious negative relationship between the tropic transfer and the metal concentration in prey or the metal dosage. This suggested that metal concentration in prey could effect the bioavailability to *N. Siquijorensis*, which could be a comprehensive reflect of metal ingestion amount, assimilation and efflux rate.

4. When the metal concentration in prey (especially copper in present study)reached a high level, *N. siquijorensis* exhibited food avoidance behavior to the contaminated food, which effectively reduced the metal ingestion and resulted in a decrease of tropic transfer, as well as reduced the potential toxic effect from dietary exposure.

5. Because of its extra digestion, *N. Siquijorensis* showed a powerful digestion to the dietary metal, even to the subcellular fractions which were considered trophic

unavailable such as Zn and Cd bounding to metal-rich granules. Our results also implied the metal specific impact of subcellular metal distribution in prey on the bioavailability of *N. Siquijorensis*. Different metals shows different bioavailabilities to the predator. Zinc and cadmium have higher bioavailability than copper, and metal-rich granules associated with zinc and cadmium can also be assimilated by *N. Siquijorensis.*

Our study suggested that the metal burden and feeding avoidance should certainly be considered in understanding the trophic transfer of metals in marine benthic food chain.

Keywords: *Nassarius siquijorensis*; metal-contaminated prey; food avoidance; trophic transfer.