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Heavy metal concentrations in water and tiger prawn (*Penaeus monodon*) from grow-out farms in Sabah, North Borneo

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Abstract

Concentrations of a number of heavy metals, including Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb and Zn were determined in samples of water and muscle tissue of tiger prawn (*Penaeus monodon*) from two farms. One farm was located in Tuaran (farm-A) and the other in Likas (farm-B) near Kota Kinabalu. While Co, Cr, Cu, Fe, Mo, Pb and Zn concentrations were higher in the water from farm-A, other metal concentrations (Cd, Mn and Ni) were higher in farm-B. Tiger prawns raised in farm-A had comparatively higher concentrations of Co, Cr, Cu, Ni and Pb. Those grown in farm-B had higher levels of Cd, Fe, Mn, Mo and Zn. No general correlation between metal levels was discernible in the prawn tissue. The data suggested complexities in uptake and retention of metals in tiger prawn. This animal seemed to resist the build-up of certain metals whereas it allowed the entry of others to the extent of exceeding the proportion that occurred in the environment. Some of the controlling factors include the nature of the metals, environmental factors, the body's reaction, physiological tolerance, tissue thresholds and regulatory mechanisms.

Keywords: Heavy metals; Water; Tiger prawn; Farms

1. Introduction

Consumption of seafood is a significant pathway to metal exposure in the human population living in coastal areas. Increased levels of minerals in the coastal zone enhance the metal load of inshore waters and of aquatic animals, resulting in greater health risk from seafood consumption. Marine fauna can acquire metals from food, suspended matter, or directly from seawater. Some marine organisms concentrate certain metals above the level found in the surrounding environment. The process of biological magnification, in which a chemical increases in concentration in the bodies of organisms, with succeeding trophic levels (through food chains), magnifies the effects of metals in the body.

Water quality is a major factor in sustainability of aquaculture. Large-scale mortality in marine hatcheries and grow-out farms, poor growth and anatomical aberrations in cultured animals are often attributed to water contamination. Marine shrimp aquaculture is facing an increasing threat from water pollution. This is potentially serious because shrimp is a high value seafood commodity whose consumer demand far exceeds the supply. Aquaculture meets most of the market requirement. The sensitivity of crustaceans to heavy metals is well documented (Ahsanullah, Negilski, & Mobley, 1981; Migliore & Giudici, 1990) and is known to be influenced by stage of life, reproductive cycle, molting stage and nutritional condition (McGee, Wright, & Fisher, 1998). Small amounts of absorbed trace metals are either stored in a metabolically available form for essential biochemical processes or detoxified into metabolically inert forms and held in the body either temporarily or permanently.

We report the results of our investigation of heavy metals in edible tissue (muscle) of the giant tiger prawn (*Penaeus monodon*) and in estuarine water from two grow-out farms from Sabah. Interest in this species was motivated by the fact that it is the most extensively

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cultured, forming some 90% of the total shrimp harvest from aquaculture in southeast Asia.

2. Materials and methods

Live specimens of tiger prawn and samples of water were collected from two commercial farms, one situated in Tuaran (farm-A) and the other in Likas (farm-B) near Kota Kinabalu, the capital of the east Malaysian state of Sabah on north-east Borneo. Water samples collected with the help of samplers were transferred to reagent bottles and acidified by a measured volume of concentrated nitric acid. The samples were filtered through a 0.45 μ micropore membrane filter. Prawn specimens were caught by nets and wrapped in polyethylene bags for transfer to the laboratory in an ice-box. At the time of analysis, the test individuals were taken out and a known weight of muscle was removed from a fixed location behind the cephalo-thorax. Samples were processed according to the technique of Campbell and Plank (1998). The procedure involved drying of the tissue sample in oven at 80 °C for 24 h and digesting 2 g of the dried sample in 10 ml of concentrated nitric acid at 60 °C for 30 min. Subsequently, the tubes were cooled to room temperature and 2 ml of hydrogen peroxide were added. The contents were then heated until the solution became clear, after which they were diluted to 100 ml with deionized water. All the samples were analyzed for heavy metals using a Flame Atomic Absorption spectrophotometer (Perkin Elmer). The concentrations of heavy metals were calculated using standard curves prepared by taking a series of working standards in the detectable range for each metal. Metal concentration in the water was expressed as parts per million (ppm) and that in the muscle tissue of prawn as μg/g (fresh weight basis).

3. Results and discussion

The results of the quantitative analysis of heavy metals (Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb and Zn) are presented in Figs. 1 and 2. Water fed to the ponds from estuaries obviously contained a higher load of several metals. This kind of situation, seen in Sabah, is typical of developing coastal areas where interaction between inshore waters and land-based activities is intense. Generally, the ocean margin is a critical land–sea interface at the boundary of which several sources may affect the chemical characteristics of the waters and bring pollutant materials (Kotté-Krief, Guieu, Thomas, & Martin, 2000). Continental sources (river runoff and atmospheric transport), oceanic sources (upwelling) and diagenetic exchanges at the water–sediment interface have been identified as the main factors. Carbon compounds, nutrients and heavy metals, that are delivered to the ocean margin, are important in the living processes of marine organisms but they are a potential source of contamination as well. Marine animals are sensitive to metals when the concentrations of these substances reach a certain level in the water. This is especially so in the case of shrimp for the reason that invertebrates tend to accumulate more metals than fish as a result of differences in the evolutionary strategies adopted by various phyla (Phillips & Rainbow, 1993). Exact levels of tolerable metals in solution that are safe for aquatic organisms are a subject of debate and disagreement because the concentration of a metal required to produce toxicity may differ according to the

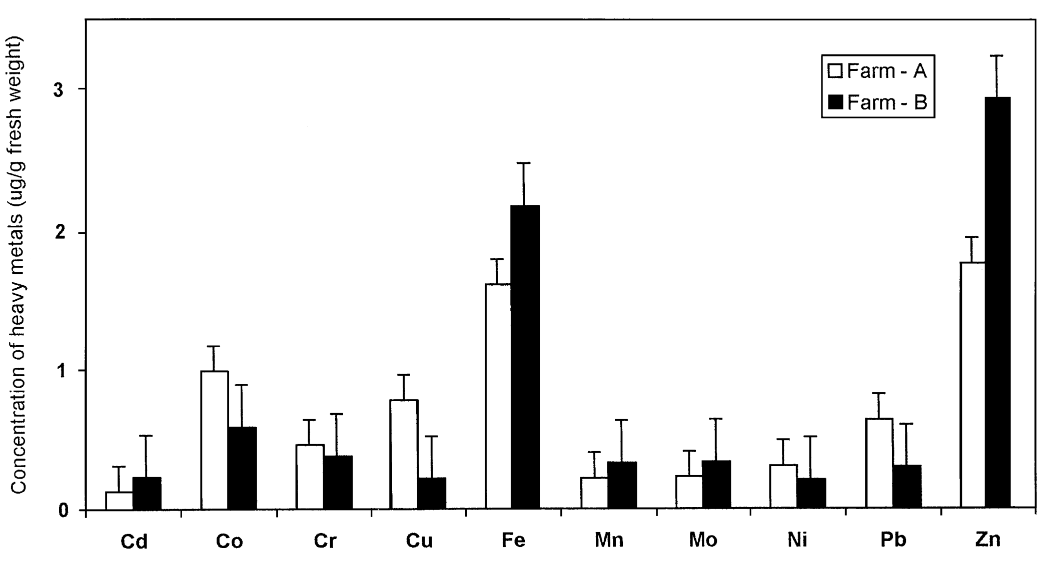

Fig. 1. Concentration of heavy metals in tiger prawn from two grown-out farms.

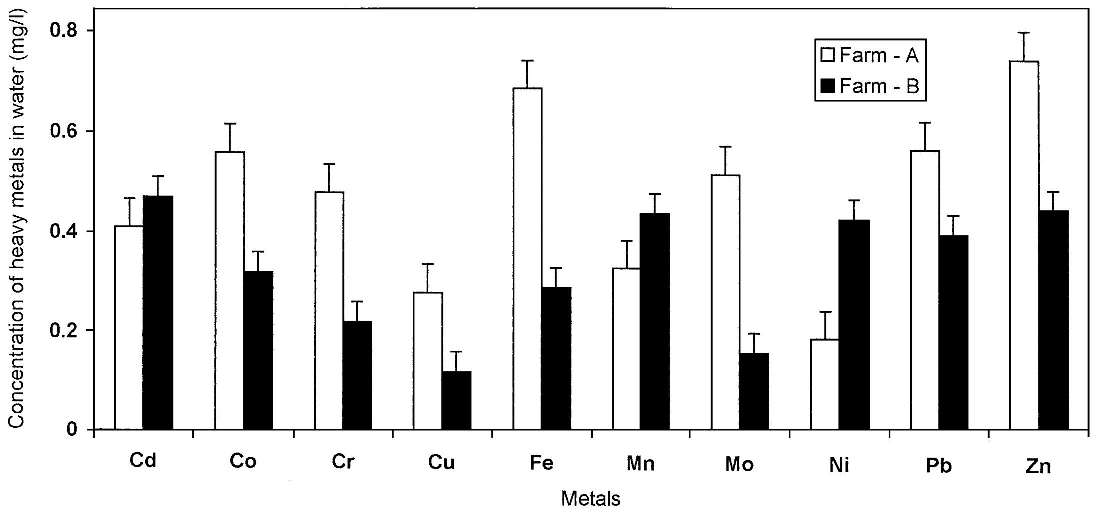

Fig. 2. Concentration of heavy metals in water from two tiger prawn grown-out farms.

overall water chemistry (Parker, 1995). Except for Al, As, Ba and Fe, other metals, such as Be, Cd, Cr, Co, Pb, Mn, Hg, Mo, Ni, Se and Zn should be considered potentially harmful if their individual concentrations exceed 0.1 ppm (Parker, 1995). Concentrations of the individual analyzed metals in water from both the tiger prawn farms were <1 ppm. The metal load in the water was higher than what is considered optimum for penaeid shrimp culture. Optimum values available for certain metals as described by Stickney (2000) in terms of parts per million include: <0.15 (Cd), <0.1 (Cu), <0.01 (Fe), <0.25 (Zn). Barring Pb in farm-B, concentrations of all the other heavy metals observed in this investigation were higher than those reported earlier (Mokhtar, Awaluddin, & Guan, 1994) from this region of Sabah: Cd (0.05 ppm), Co (0.17–0.19 ppm), Cr (0.04–0.05 ppm), Fe (0.13–0.21 ppm), Mn (0.08–0.11 ppm) and Pb (0.38–0.44 ppm). The recommended safe level of dissolved Pb is <0.05 ppm (Krenkel & Novotny, 1980). High values of Pb in both farms indicated pollution of the water bodies. According to Waite (1984), Pb normally exists in an undissolved form and in low concentration, except when water is polluted by exogenous inputs. Co concentration, in the farms, also exceeded the normal range for natural waters (0.012–0.03 ppm; Surmani, 1985). Cr too occurred in a quantity higher than the normal value for natural water (0.04–0.05 ppm). In tiger prawn, concentrations of most metals were <1 μg/g except for Fe and Zn (both >2 μg/g).

Variation in heavy metal concentrations in inshore waters accounted for differences in these metals in the tiger prawn farms A and B. Since both the farms are situated near the river mouths, the concentrations of dissolved metals are influenced mainly by the water quality of the river discharge. Changes in the total dissolved metal concentration correspondingly change the free metal ion concentration, and thereby lead to an increase in the rate of metal uptake (Rainbow, 1995). When the rate of metal excretion does not follow a parallel increase, a net accumulation of metal in the body is to be expected.

It was difficult to establish a general pattern of progressive relationship between heavy metals in water and prawn tissue. While Co, Cr, Cu, Fe, Mo, Pb and Zn concentrations were higher in farm-A, the other metals (Cd, Mn and Ni) were more concentrated in farm-B. Prawn from farm-A had higher concentrations of Co, Cr, Cu, Ni and Pb. Those sampled from farm-B exhibited higher levels of Cd, Fe, Mn, Mo and Zn. Evidently, Co, Cr, Cu, Ni and Pb concentrations were higher in the water, as well as prawn tissues, while Cd and Mn were higher in water and in tissues of prawn from farm-B. Interestingly, other metals, such as Fe, Mo and Zn, that maintained a higher profile in farm-A, were distributed in lower amounts in the prawn tissue. With the studies that were designed to compare the heavy metals in water and tissue of prawn from the two farms, it was not intended nor is it correct to seek quantitative interrelationships among the metals based on the data that show high or low levels of metals in the same habitat or prawn of the same farm. A reasonably cautious conclusion is that there is no general correlation between the various metals from the present data. Some authors have sought to establish correlations between various metals but the scientific views and interpretations continue to be at variance. Thus, for example, the Cd–Zn relationship was attributed to a commonality in the uptake–mineralization cycle rather than similarity in environmental levels of the two minerals (Bruland & Franks, 1983). Kang, Choi, Oh, Wright, and Koh (1999), who worked on Asian periwinkle, *Littorina brevicula*, noticed that certain toxic metals, Cd and Pb, in the tissue, reflected environmental levels, whereas Cu and Zn were regulated by this marine gastropod. This phenomenon was also seen in other species of the periwinkle by Young (1975), Bryan, Langston, Hummerstone, Burt, and Ho (1983), Langston and Zhou (1986), Marigomez and Ireland (1989, 1990) and Nott, Bebianno, Langston, and Ryan (1993). That the differences in regulatory mechanisms account for differences in the loads of essential and non-essential metals in the body of periwinkle and other mollusks has been discussed by Mason, Simkiss, and Ryan (1984). In an interesting study, Soto, Ireland, and Marigomez (1997) reported that a regulatory mechanism for essential metals existed following exposure to low levels, but Cu and Zn regulation did not occur in specific tissues of the periwinkle after a certain threshold value was attained. For two metals (Cd and Pb), the bioaccumulation in the case of sea urchin (*Paracentrotus lividus*) larvae has been known to be independent on the metal concentration in the water (Radenac, Fichet, & Miramand, 2001). Such a situation suggests a balance between uptake and excretion rates (Connel, 1998). In adult sea urchins, the accumulation of Cd and Pb is proportional to metal concentration in the surrounding water (Temara, Aboutboul, Warnau, Jangoux, & Dubois, 1998). In the light of the present observations, enormous amounts of interspecific variations, and lack of adequate information on metal metabolism in prawns, it is not possible to relate the tissue levels of heavy metals to the environmental contamination, or to conclude that the tiger prawn is a suitable indicator of heavy metal pollution of the aquatic habitat. It is becoming obvious that tissue levels of metals such as Cd, Pb and Ni are not regulated by marine decapods (Depledge & Rainbow, 1990; Rainbow, 1985) but these animals effectively regulate the levels of essential heavy metals within certain constant limits (Chan & Rainbow, 1993). The freshwater prawn (*Macrobrachium malcolmsoni*) has been shown to lack the capacity to regulate tissue levels of essential heavy metals (Cu, Cr) (Vijayram & Geraldine, 1996). Data obtained in our investigations on tiger prawn indicated accumulation of Ni in prawn from farm-A, and that of Fe, Mo and Zn in specimens from farm-B. The literature reviewed above suggests considerable interspecific variability in the rate of uptake of individual metals. These results further demonstrate the intraspecific variations in metal uptake and elimination. Because some of the heavy metals are associated with fatal anatomical, reproductive and physiological abnormalities, the topic of metal concentration in prawns requires investigation, particularly since these animals are an expensive and popular human food. Concentrations of metals in marine organisms can increase several times over the environmental levels (Förstner & Wittmann, 1983; Furness & Rainbow, 1990; Peerzada, Nojok, & Lee, 1992), which demonstrates their potential as accumulators of heavy metals (Phillips, 1980; Soule & Kleppel, 1988).

As explained above, the metals can enter the body of marine organisms directly through physical processes, such as absorption, but the body load is strongly influenced by uptake through food and metabolic capacity of the animal. The authors are not aware of any such data on tiger prawn but studies conducted on marine turtles have established the role of marine prey items in transferring exogenous metals into the body (Francesconi & Edmonds, 1993; Hanaoka et al., 1999). Shift in food preferences, feeding rates and metabolic processes, such as absorption through the gastrointestinal tract, are known to cause alterations in body concentration of metals in some animals (Saeki, Sakakibara, Sakai, Kunito, & Tanabe, 2000). The effect of heavy metals on cellular enzymes is a conspicuous physiological disturbance. Modification of enzyme activity within the cells causes disruption in normal metabolism, as reflected at higher levels of organization. An effect of sublethal metal exposure is an energy-requiring chronic demand for compensatory induction of enzymes, or blocking of sensitivities by which enzyme reaction rates are regulated (Sindermann, 1996). Such biological conditions lessen the metabolic flexibility necessary for an animal's adaptation and survival during environmental challenge. The physiology of crustaceans, especially that related to hormonal control of molting, has been a subject of investigations in the past. The role of heavy metals in manipulating metabolic pathways involved is of course an area of concern. As an example, abnormal production of the steroid-molting hormones may inhibit shell synthesis, whereas hormonal insufficiency may delay or prevent molting, thus affecting growth and survival (Sindermann, 1996). Some of these metal effects are expectedly similar in prawn but scientific evidence is grossly inadequate.

Our findings suggest complexities in uptake and retention of metals. Tiger prawn resists accumulation of certain metals and promotes that of others under particular conditions. Loading of Ni in one farm and resistance against it in the other farm, and circumstances under which Fe, Mo and Zn are allowed entry in excess of their relative proportions in the medium in one environment but not in the other, can be interpreted in this context. In the light of our present level of understanding, it is difficult to find exact answers for the variations in body's affinity for heavy metals. Apparently, the nature of metals, a multitude of environmental factors and the body's reaction to heavy metals determine the level that can be accumulated in the tissues. The body's threshold for the metal residues is linked to the range of tolerance, and loading can occur if physiological processes are not impaired. However, physiological processes alone cannot serve as a protective barrier between tissues and elevated levels in the environment. Exposure to certain doses can alter the physical processes of metal influx in the body and modify the internal environment of the prawn.

4. Conclusions

The results of this study demonstrate that the water in tiger prawn farms is contaminated by heavy metals. The most likely source of contamination is the river that flows nearby. Since some of these metals have the ability to adversely affect growth and development of aquatic animals and action is therefore necessary to monitor quality of the estuarine water that is pumped into the aquaculture ponds. For a sustainable tiger prawn culture, control of water quality is necessary, even though it might require sourcing the water away from the coast where quality might be better and metal concentrations are within the normal range. Such a measure is especially important because the coastal zone of Sabah is a complex region comprising numerous semi-enclosed bays, open shores and estuaries, and where there is a dense human population and industrial activities. The other factor that also requires serious consideration is the large volume of run-off that results from a high precipitation related to the rainforest climatology of Sabah that can potentially bring land-based contaminants to the coastal sea.

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