

## Comparative Zinc Concentrations in Tissues of Common Carp and Other Aquatic Organisms

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**Lian-Tien Sun and Sen-Shyong Jeng (1998)** Comparative zinc concentrations in tissues of common carp and other aquatic organisms. *Zoological Studies* 37(3): 184-190. Zinc concentrations in various tissues of 24 aquatic organisms were measured. Common carp and crucian carp had extraordinarily high zinc concentrations with mean values of 562 and 634  $\mu\text{g}/(\text{g fresh tissue})$  respectively, in their digestive tract tissues. They had high zinc concentrations (usually  $> 100 \text{ g}/[\text{g fresh tissue}]$ ) in kidney, gill, skeletal tissues, and spleen, which were not seen in other species. Concentrations of Cu, Na, K, Ca, and Mg in digestive tract tissues of common carp and several freshwater fish were found to be similar. High zinc was found to be specific to common carp. Common carp were reared from fry to adult fish in the laboratory for 937 d and fed on an artificial feed containing 25 ppm zinc. Zinc concentrations in the whole body and digestive tract tissue of the fish were found to be consistently high throughout the period. The anterior portion of the digestive tract tissue of common carp had the highest zinc concentration, 1590  $\mu\text{g}/(\text{g fresh tissue})$ , which decreased gradually to the posterior portion, at about 500  $\mu\text{g}/(\text{g fresh tissue})$ .

**Key words:** Zinc, Common carp, Digestive tract, Viscera of fish.

Concentrations of zinc in most tissues of several studied mammalian species, e.g., human, monkey, rat, cow, and sheep, are in the order of 10 to 100  $\mu\text{g}/(\text{g wet weight})$ , with little variation among species. Levels in tissues of birds are in the same range as mammals (Hambidge et al. 1986). The average zinc content of the edible portion of finfish is lower, at 6.5  $\mu\text{g}/(\text{g wet weight})$ , with a range of 3-24  $\mu\text{g}/(\text{g wet weight})$  (National Research Council 1979). We have found that in several freshwater fish, e.g., grass carp *Ctenopharyngodon idellus*, silver carp *Hypophthalmichthys molitrix*, and tilapia *Oreochromis mossambicus*, zinc concentrations in different tissues also approximated 10-50  $\mu\text{g}/(\text{g wet weight})$ , but levels in common carp *Cyprinus carpio* were exceptional. It was found that common carp had high zinc concentration in its viscera, i.e., 174-585  $\mu\text{g}/(\text{g wet weight})$  (Jeng and Huang 1973). Further investigation indicated that digestive tract tissue had the highest mean zinc concentration at 330  $\mu\text{g}/(\text{g fresh tissue})$ , followed by the kidney, spleen, and hepatopancreas, all of which had zinc

concentrations usually higher than 100  $\mu\text{g}/(\text{g fresh tissue})$  (Jeng and Lo 1974). Since most reports concerning zinc concentrations in fish used edible portions as samples, not much information is available for zinc concentrations in the viscera of fish. It is of interest to know whether high zinc concentration only occurs in common carp. Therefore, in this report, we further sampled 20 additional aquatic organisms and analyzed the zinc concentration in different tissues. Besides zinc, concentrations of several minerals in tissues of some freshwater fish were also investigated to determine whether zinc is the only mineral which is exceptional. Zinc concentrations in tissues of common carp from fry to adult fish (937 d) are also reported.

### MATERIALS AND METHODS

#### Aquatic organisms

Aquatic organisms (Table 1) were purchased

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from local markets in Taiwan. All the organisms surveyed were at market size.

### Preliminary treatment

After purchasing, aquatic organisms were taken to the laboratory on ice. For each species, 6 specimens were bought; for common carp, 82 specimens were used. Each specimen was analyzed individually. After measuring total length and total weight, the organism was eviscerated. Each tissue was separated, and usually the entire tissue sample was ground. However when the tissue mass was large, only part of the homogenized sample was used. For digestive tract sampling, the organ was slightly pressed to remove all contents; after longitudinal cutting, the opened gut was rinsed gently with 0.75% NaCl solution twice, and blotted with filter paper.

### Analyses of Zn, Cu, Na, K, Ca, and Mg

All samples were initially digested with  $\text{H}_2\text{SO}_4\text{-HNO}_3$ . Then concentrations were determined by the following methods: a. Zn: measured with the AOAC method (Helrich 1990) using a Hitachi Model 170-10 type atomic absorption spectrophotometer (AAS); b. Cu: the digested samples were further extracted with APDC (ammonium pyrrolidine-N-dithiocarbamate)-MIBK (methyl isobutyl ketone), then measured with AAS (Tsutsumi 1972); c. Ca and Mg: measured with a AAS; d. Na and K: measured with a flame photometer (Hsu et al. 1979). The detection limits of Zn, Cu, Na, K, Ca, and Mg are 0.05, 0.05, 0.05, 1.0, 1.0, and 0.5  $\mu\text{g/g}$  fresh tissue.

### Zinc concentrations in whole body and digestive tract tissue of common carp from fry to adult fish

Fry of common carp were produced in our laboratory by induced spawning; the fry were fed artificial feed for 120 d. The methods of induced spawning, rearing of fish, the composition of the diet, and the feeding method are the same as previously reported (Jeng and Sun 1981). Zinc concentration of the artificial feed was kept around 25 ppm. Before day 120, fish were too small to remove the digestive tract, therefore, only the zinc concentration in the whole body of the fish was measured. About 50 or 100 fish larvae during days 1 and 25, 10 fry during days 28 and 31, and 2 fry during days 32 and 120, respectively, were pooled

as 1 sample for the measurement. Three to 6 samples were collected for each sample date. After day 121, 6 fish at a time were randomly selected, and the digestive tract of each fish was removed. The digestive tract tissue (without contents) and the fish body (without digestive tract) were homogenized separately, and each portion analyzed for zinc concentration.

### Zinc concentrations in different portions of digestive tract tissue of common carp

Digestive tract tissue, without contents, of randomly sampled common carp (mean body weight of  $177 \pm 118$  g, range of 50 to 428 g; mean length of digestive tract of  $24.3 \pm 6.4$  cm, range of 15.0 to 35.5 cm), was evenly divided into 10 parts from the anterior to the posterior portion. Zinc concentration in each portion was then determined.

## RESULTS

### Zinc concentrations in different tissues of some aquatic organisms

In all 24 aquatic organisms sampled from the market in this study, including 9 freshwater and brackish-water fish, 7 marine fish and 8 invertebrates; zinc concentrations in different tissues of the organisms are shown in Table 1. Table 1 shows that the concentrations of zinc in most tissues are in the order of 10 to 100  $\mu\text{g}/(\text{g}$  fresh tissue) with little variation among freshwater and brackish-water fish, marine fish, and invertebrates. However, there are several exceptions. The most distinctive exception is that the digestive tract tissues of common carp and its closely related species, crucian carp *Carassius carassius*, have extraordinarily high zinc concentrations (mean values of 562 and 634  $\mu\text{g}/[\text{g}$  fresh tissue], respectively) which are not seen in other species or other tissues. Besides digestive tract tissue, common carp has higher zinc concentration in almost every tissue as compared to other organisms. This is especially true for kidney, gill, skeletal tissues, and spleen, in which concentrations are usually larger than 100  $\mu\text{g}/(\text{g}$  fresh tissue). Table 1 also shows that the concentration of zinc in ovary of common carp (mean concentration of 118  $\mu\text{g}/[\text{g}$  fresh tissue]) is much higher than that in sperm (mean concentration of 21  $\mu\text{g}/[\text{g}$  fresh tissue]). This kind of difference in zinc concentration between sperm and ovary is also seen in several other fish.

**Table 1.** Zinc concentrations ( $\mu\text{g}/[\text{g}$  fresh tissue]) in tissues of some aquatic organisms

Aquatic organism <sup>a</sup>	Digestive tract tissue <sup>b</sup>	Liver	Spleen	Kidney	Air bladder	Heart	Gonad <sup>c</sup>	Gill	Muscle	Skeletal tissues
<b>1. Freshwater and brackish-water fish</b>										
<i>Anguilla japonica</i> (Japanese eel)	20±2	54±8	17±7	19±4	9±2	25±5	–	15±4	17±4	21±1
<i>Aristichthys nobilis</i> (Bighead carp)	19±1	18±3	15±3	17±2	16±4	11±2	68±13	21±5	7±2	28±5
<i>Carassius auratus</i> (Crucian carp)	634±126	32±6	23±8	173±12	45±9	26±5	♀ 40±7	109±9	17±1	103±3
<i>Cirrhina molitorella</i> (Mud carp)	36±8	27±12	36±13	16±8	22±3	12±2	–	21±7	8±2	46±9
<i>Ctenopharyngodon idellus</i> (Grass carp)	39±10	31±5	74±45	36±6	25±11	31±13	–	23±1	15±6	45±13
<i>Cyprinus carpio</i> (Common carp)	562±287	96±63	134±70	191±112	91±49	71±33	♂ 21±12 ♀ 118±49	186±108	34±18	139±56
<i>Hypophthalmichthys molitrix</i> (Silver carp)	18±6	33±7	14±2	12±5	15±6	12±3	26±16	20±2	6±1	31±5
<i>Oreochromis aureus</i> (Tilapia)	42±9	17±7	57±15	62±15	44±14	25±7	–	5±1	24±7	60±8
<i>Chanos chanos</i> (Milkfish)	16±2	20±5	17±2	20±3	28±4	16±2	7±5	20±5	5±1	33±5
<b>2. Marine fish</b>										
<i>Acanthopagrus latus</i> (Yellowfin seabream)	20±4	31±17	20±4	23±4	11±2	20±2	♂ 46±8 ♀ 168±41	30±7	5±1	60±7
<i>Decapterus maruadsi</i> (Scad)	14±1	30±4	16±6	27±10	11±2	9±2	202±5	21±5	2±1	54±12
<i>Lateolabrax japonicus</i> (Japanese seaperch)	17±1	16±4	48±9	119±28	7±2	17±3	–	13±1	3±1	32±4
<i>Mugil cephalus</i> (Striped mullet)	19±4	17±4	12±3	9±2	12±6	10±2	♂ 30±7 ♀ 229±57	11±2	2±1	27±4
<i>Priacanthus macracanthus</i> (Red bulleye)	14±3	41±23	16±4	18±3	13±2	14±2	♂ 13±4 ♀ 173±17	13±1	2±1	36±9
<i>Scomber australasicus</i> (Spotted chub mackerel)	19±4	22±4	14±5	14±3	9±2	9±2	♂ 15±2 ♀ 115±17	15±7	2±1	46±14
<i>Chiloscyllium indicum</i> (White spotted cat shark)	11±4	10±5	9±3	11±1	21±4	18±2	14±3	8±1	6±2	13±3
Aquatic organism	Digestive tract tissue	Liver	Ink	Gonad	Gill	Muscle	Shell			
<b>3. Invertebrates</b>										
<i>Macrobrachium rosenbergii</i> (Giant river shrimp)	18 ± 5	46 ± 5		17 ± 4	18 ± 7	9 ± 7	35 ± 5			
<i>Penaeus japonicus</i> (Kurma prawn)	28 ± 7	83 ± 10		62 ± 13	16 ± 2	13 ± 1	13 ± 3			
<i>Penaeus monodon</i> (Giant tiger prawn)	31 ± 7	61 ± 10		–	22 ± 8	13 ± 1	19 ± 6			
<i>Portunus pelagicus</i> (Pelagic crab)	18 ± 4	42 ± 9		72 ± 20	7 ± 1	16 ± 1	7 ± 2			
<i>Portunus sanguinolentus</i> (Red-spotted swimming crab)	18 ± 6	33 ± 8		26 ± 16	32 ± 3	6 ± 1	12 ± 3			
<i>Meretrix lusoria</i> (Hard clam)	8 ± 1	20 ± 5		8 ± 1	9 ± 2	8 ± 2	84 ± 17			
<i>Loligo chinensis</i> (Neritic squid)	23 ± 8	20 ± 4	17 ± 5	41 ± 13	14 ± 1	10 ± 2	99 ± 27			
<i>Sepia esculenta</i> (Cuttlefish)	25 ± 3	420 ± 102	11 ± 2	18 ± 6	21 ± 5	14 ± 1	50 ± 18			

<sup>a</sup> For each organism, 6 samples were measured and expressed as mean  $\pm$  SD, but for *Cyprinus carpio* (common carp), 82 samples were measured.

<sup>b</sup> Digestive tract tissue without contents.

<sup>c</sup> When the sex of the organism could be identified visually, testis (♂) and ovary (♀) were measured separately, otherwise they are combined; – means the gonad was too small to be measured.

**Table 2.** Zn, Cu, Na, K, Ca, and Mg concentrations ( $\mu\text{g}/[\text{g fresh tissue}]$ ) in digestive tract tissues of common carp, grass carp, silver carp, and tilapia<sup>a</sup>

Fish	Zn	Cu	Na	K	Ca	Mg
Common carp	454 $\pm$ 214	3 $\pm$ 1	1416 $\pm$ 96	3203 $\pm$ 126	42 $\pm$ 10	134 $\pm$ 12
Grass carp	18 $\pm$ 1	4 $\pm$ 1	1596 $\pm$ 158	2976 $\pm$ 91	47 $\pm$ 11	140 $\pm$ 18
Silver carp	18 $\pm$ 6	2 $\pm$ 1	1292 $\pm$ 131	3070 $\pm$ 209	25 $\pm$ 6	175 $\pm$ 46
Tilapia	25 $\pm$ 3	4 $\pm$ 1	2086 $\pm$ 62	2946 $\pm$ 196	74 $\pm$ 3	133 $\pm$ 4

<sup>a</sup> For each fish, 6 samples were measured and expressed as mean  $\pm$  SD.

### Zinc, Cu, Na, K, Ca, and Mg concentrations in digestive tract tissues of common carp and several freshwater fish

Table 2 compares concentrations of Zn, Cu, Na, K, Ca, and Mg in common carp, grass carp, silver carp, and tilapia. It is very clear that zinc was the only mineral which had extraordinarily higher concentrations in the digestive tract tissue of common carp than was found in that of other fish.

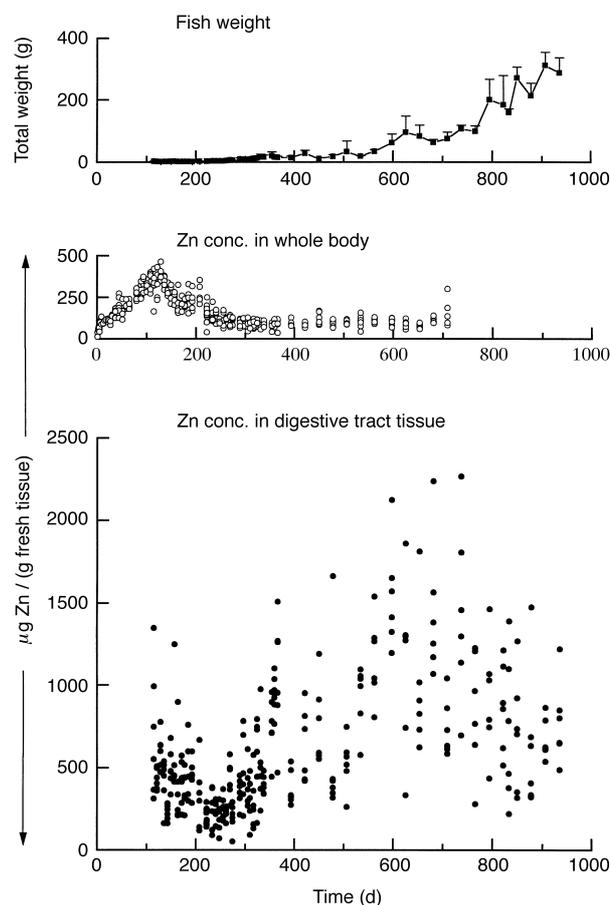
### Changes of zinc concentrations in whole body and digestive tract tissue of common carp from fry to adult fish

Zinc concentrations in whole body and digestive tract tissue of common carp from day 0 to adult fish are shown in Fig. 1. It can be seen that zinc concentrations in both whole body and digestive tract tissue were rather high throughout the period, although there are individual differences. In whole body of common carp, zinc concentration was highest around day 130, at about 400  $\mu\text{g}/(\text{g fresh tissue})$ ; after day 250, the zinc concentration was rather constant throughout the experiment, i.e., at about 100  $\mu\text{g}/(\text{g fresh tissue})$ . In digestive tract tissue of the fish, the lowest period was around day 250, the higher zinc concentration appeared at days 600-700, and the highest zinc concentration measured was 2300  $\mu\text{g}/(\text{g fresh tissue})$  on day 740. Zinc concentrations in whole body and digestive tract tissue of common carp were compared with length, weight, or sex of the fish, and no correlation could be found.

### Zinc concentrations in different portions of digestive tract tissue of common carp

Digestive tract tissue of common carp was divided into 10 regions and zinc concentrations in different portions are shown in Fig. 2. It was found that the zinc concentration was highest in the most

anterior 10% portion (mean concentration of 1590  $\mu\text{g}/[\text{g fresh tissue}]$ ), and decreased sharply within the initial 30% portion. Lower concentrations were observed in the middle and terminal portions (mean



**Fig. 1** Total weight and zinc concentration in whole body and digestive tract tissue of common carp from fry to adult fish. Each point represents the combination of 50 to 100 individual larvae during days 1-25, 10 fry during days 28-31, and 2 fry during days 32-120. Every sampled date consists of 3-6 samples. After day 121, each point represents 1 fish. Fish were fed on artificial diet with an approximate zinc concentration of 25 ppm.

concentrations of about 600 and 450  $\mu\text{g}/[\text{g}$  fresh tissue], respectively). Similar much higher zinc concentrations in the anterior portion of digestive tract in common carp were not found in grass carp, silver carp, or tilapia.

## DISCUSSION

Based on the measurements of zinc concentrations in different tissues of 24 aquatic organisms (Table 1), it is clear that exceptional high concentrations of zinc occurred in common carp and crucian carp. Table 2 indicates that concentrations of Cu, Na, K, Ca, and Mg in common carp are similar to those of other fishes. Zinc seems to be the only mineral which was found in much higher concentrations in common carp.

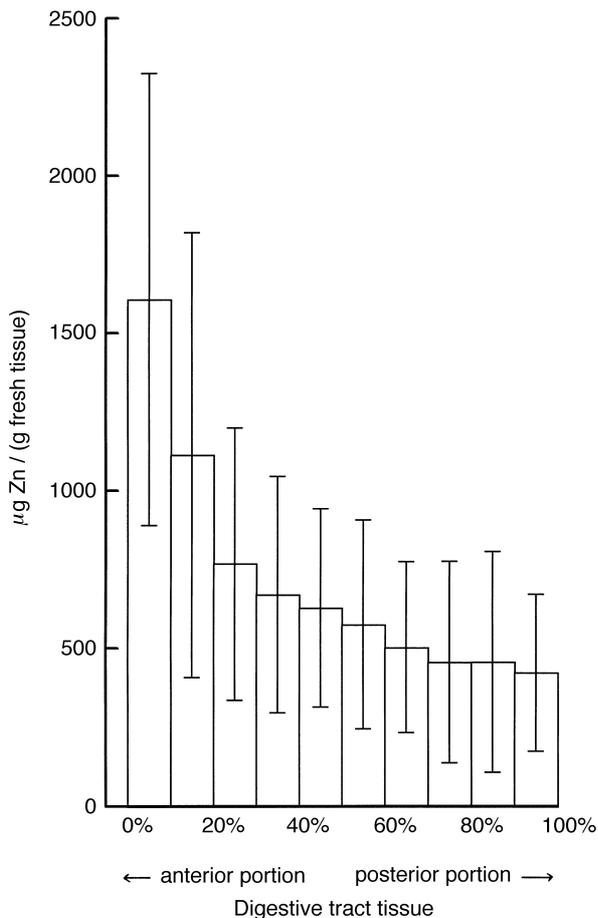
Although common carp has much more zinc concentrations in most of its visceral and skeletal

tissues than do other aquatic organisms, usually several times higher, and much higher zinc concentrations in its digestive tract tissue, usually more than 10 times higher, this has not attracted much attention. This may be because the muscle of common carp, which is the main consumed part, has a relatively low zinc concentrations, i.e., similar to those of other fish at only about 30  $\mu\text{g}/(\text{g}$  fresh tissue) (Table 1). For adult common carp, the weight percentages of muscle, skeletal tissues, digestive tract tissue, and all other visceral tissues, were about 49%, 45%, 0.2%-0.6%, and 5% respectively; but for small fish (< 3 g), the weight percentages were 40%, 53%, 2%, and 5% respectively. When fish are very small, the relative weight percentage of muscle is also very small, and this made the zinc concentration in the whole body higher; but as the fish grow, the weight percentage of muscle increases, thus lowering the zinc concentration in the whole body (Fig. 1).

In a review of other publications, only 1 species, juvenile Atlantic salmon, had higher zinc concentrations in body tissue, especially intestine (Maage and Julshamn 1993). Low zinc contents in body tissues such as intestine, liver, kidney, and spleen were also found in most fish species such as yellow tail, black seabream (Takeda and Shimizu 1982), rainbow trout (Wekell et al. 1986), turbot (Overnell et al. 1988), goldfish, sardine, sea bass (Carpene et al. 1990), and menhaden fish (Scott and Latshaw 1993).

The U. S. Fish and Wildlife Service collected 7 species of fish including common carp at 112 monitoring stations for 2 yr and analyzed 7 elements including zinc (Lowe et al. 1985). They found that mean zinc concentration in whole body of common carp (63.4  $\mu\text{g}/[\text{g}$  wet weight]) was significantly higher ( $p \leq 0.0001$ ) than was the mean concentration for all other fish samples (17.7  $\mu\text{g}/[\text{g}$  wet weight]). These data are consistent with our results in Fig. 1 which show that the zinc concentration in whole fish of adult common carp was around 100  $\mu\text{g}/(\text{g}$  fresh tissue).

For marine animals, the National Research Council (1979) reported that the edible portion of organisms examined had zinc concentrations of 3-30 ppm (wet weight) except for oyster. It is well known that oysters usually contain high zinc concentrations. Pringle et al. (1968) reported that the Atlantic oyster *Crassostrea virginica*, had a value of 1428 ppm (range of 180-4120 ppm), and Pacific oyster had 86-344 ppm of zinc (wet weight). Since oysters very easily accumulate zinc from surrounding water, and the accumulated zinc is released



**Fig. 2** Zinc concentrations in different portions of digestive tract tissue of common carp (Each bar represents the mean  $\pm$  SD of 22 fish.).

when the oyster is put in clean water (Ikuta 1968), it is very likely that the high zinc concentration in oyster is just the result of accumulation from water rather than a physiological need of the oyster (Wolfe 1970). In this report, common carp were reared from fry to adult in a controlled system, i.e., the zinc in the diet was maintained at around 25 ppm and the zinc concentration in the culture water was between 0.2-0.9 ppm with a medium value of 0.5 ppm. Under this controlled system, zinc concentrations in the whole body and digestive tract tissue of common carp still remained very high (Fig. 1). This means that high zinc concentrations in common carp could be due to a physiological mechanism. We reported earlier that differences in absorption rates of zinc from diet between common carp and other fish might play a role (Jeng and Sun 1981). By adding  $^{65}\text{Zn}$  to the diet, we proved that common carp could absorb 3 to 6.8 times more zinc from their diet than could tilapia, grass carp, or silver carp (Jeng and Lian 1994). It seems that the digestive tract tissue may act as a storage site for zinc in common carp. A similar situation was also indicated in juvenile Atlantic salmon (Maage and Julshamn 1993).

In animals, higher zinc concentrations occur in some structures or organs: eyes, prostate, prostatic secretions, and sperm (Williams 1984, Vallee and Falchuk 1993). The highest zinc concentrations known to exist in living tissues occur in the choroid layer of the eye of some species. Zinc levels in the choroids of the dog, fox, and marten have been given as 14 600, 69 000 and 91 000  $\mu\text{g}/(\text{g dry matter})$ , respectively (Hambidge et al. 1986). High zinc concentrations in the prostate gland of the rat, rabbit, and man, and in human seminal fluid and spermatozoa were reported (Underwood 1977). The spermatozoa of some marine animals also have a distinctly high zinc content. In the starfish *Asterias amurensis*, Fujii et al. (1955) found 210  $\mu\text{g zinc}/(\text{g dry weight})$  of sperm and a similar value was recorded by Mizuno (1956) in mussel *Mytilus* spermatozoa. Martin et al. (1973) reported that the spermatozoa of the giant octopus *Octopus dofleini martini*, contained 1850-9500  $\mu\text{g zinc}/(\text{g dry weight})$ .

Since the dry weight of digestive tract tissue of common carp is approximately 20%, it follows that, on a dry weight basis, the mean zinc concentration of the whole digestive tract tissue of common carp will be 2810  $\mu\text{g zinc}/\text{g}$ . The mean zinc concentration in the most anterior 10% portion of the digestive tract tissue of common carp was 1590  $\mu\text{g}/(\text{g fresh tissue})$ , or 7950  $\mu\text{g}/(\text{g dry weight})$  (Fig. 2). It

can be said that zinc concentrations in the digestive tract tissue of common carp are among the highest values reported in living tissues.

Common carp and crucian carp are not unusual fish. Why their zinc concentrations are so extraordinary and why zinc concentrations in their digestive tract tissues are so uniquely high are very interesting subjects. We have tried to extract zinc and zinc binding substances from the digestive tract tissue of common carp, and we found that only about 40% of the zinc in the digestive tract tissue of common carp could be extracted by water. Metallothionein and metallothionein-like substances are compounds which have high proportions of zinc and are soluble in water (Roesijadi 1992). Since most of the zinc in the digestive tract tissue of common carp could not be extracted by aqueous solutions, it would seem that the high zinc in common carp can not be due to metallothionein content. Recently, we have studied the subcellular zinc distribution in the digestive tract tissue, kidney, hepatopancreas, and spleen of common carp, and digestive tract tissue of silver carp, grass carp, and tilapia. We found that mean zinc concentrations in the cytosol, microsomal, and mitochondrial fractions were approximately the same for all 4 species, being very low; but zinc concentrations in the nuclei/cell debris fraction of common carp tissue were higher (data not shown). Biochemical properties of zinc in the nuclei/cell debris fraction of digestive tract tissue of common carp were studied, and preliminary results suggest that the zinc might associate with membrane proteins.

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## 鯉魚與其他水產生物組織中鋅濃度之比較

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分析 24 種水產生物不同組織之鋅含量，結果發現僅有鯉魚和鯽魚消化道組織含有非常高之鋅濃度，平均值各為 562 和 634  $\mu\text{g/g}$  新鮮組織；另外，其腎、鰓、骨骼及脾臟之鋅濃度亦常高於 100  $\mu\text{g/g}$  新鮮組織，此為其他魚種所未曾見到。鯉魚及數種淡水魚消化道組織中之銅、鉀、鈣及鎂之濃度相近。高鋅似為鯉魚所特具。將鯉魚幼苗以含鋅 25 ppm 之人工飼料飼養至成魚，在飼養之 937 日中，鯉魚消化道組織之鋅濃度皆維持甚高。在鯉魚消化道組織中，其前段鋅濃度最高為 1590  $\mu\text{g/g}$  新鮮組織，隨往後段，其鋅濃度則逐漸降低至約 500  $\mu\text{g/g}$  新鮮組織。

**關鍵詞**：鋅，鯉魚，消化道，魚之內臟。

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