# High Temperature Causes the Thornfishes Deformed in the Thermal Plume of the Second Nuclear Power Plant along Northern Coast of Taiwan

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Massive hunch-backed abnormalities of thornfishes (*Terapon jarbua*) and mullets (*Liza macrolepis*) especially juvenile and young fishes (Fig. 1) were found in the outlet area of the Second Nuclear Power Plant in the summer of 1993. A number of responsible pollutants have been suspected such as radionuclides, heavy metals, organic tin and high water temperature. In order to discover its truth to relief people's worries about the radioactivity and to be able to mitigate its ecological impact, the Environmental Protection Administration initiated a joint research project in January 1994. This paper summarized our three years field monitoring works and laboratory experiments on the effect of water temperature. The following evidences demonstrated that high water temperature (> 37°C) of thermal plum during the summer season should be the only cause which makes fishes malformed at the outlet area of the Second Nuclear Power Plant.

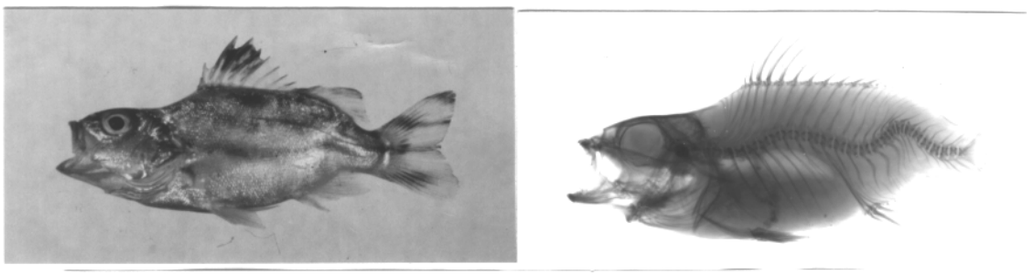

Fig 1. Specimen photo (left) and radiography (right) of the malformed thornfish (*Terapon jarbua*).

**Material and Methods**

The study can be divided into three parts:

(1) Field monitoring works -- to understand the spatial and temporal distribution pattern of malformed fishes, its rate of occurrence, degree of deformity, and the correlation with the environmental factors. In each survey, water temperature, D.O., salinity etc on the 15 stations inside and outside the outlet channel (Fig. 2) were monitored including the collection of some fish specimens by using hand-net, angling or diving observation. The field work was conducted at least once per month and more frequently in the summer time.

(2) Indoor temperature control experiments -- to determine whether the water temperature is the only cause for fish deformities. If it is, then how fast a normal fish will become malformed and how high the temperature should be. A series of tanks with different water temperatures were set up to rear different body size of normal fishes. The size classes include 1cm, 2cm, 2.5cm, 3.5cm, 4cm, 4.5cm and above 5cm. All fishes were collected from Tanshuei estuary about 10 km away from the nuclear power plant on its western side. For the constant temperature experiment, temperature was controlled on ambient (around 29°C), 34°C, 36°C, 37°C and 38°C in different tanks. For thermal amplitude experiments which simulate the temperature fluctuation of the tidal

cycle along the coast, 3～4°C fluctuation was allowed in the 36°C (highest) tank, and 4～6°C fluctuation in the 38°C (highest) tank. Furthermore, a series of flow-water tanks which used the thermal effluent directly *in situ* were arranged in a container which was installed right above the discharge channel of the power plant. This additional experiment is to prove that the temperature is the only factor which causes fish malformed. All water used for this series of tanks were the same except the temperature. In the first tank, it was adjusted to 36 or 37°C, then overflow to the following tanks with the temperature decreased naturally to about 35°C, 33°C, 32°C or 31°C.

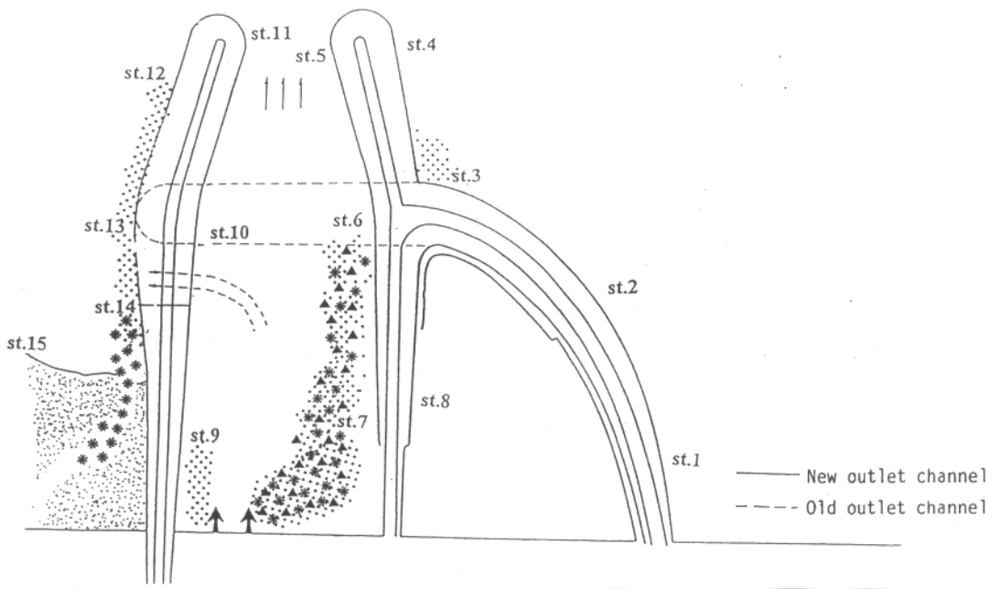


Fig 2. Locations of the fish skeletal deformities found along the new and old outlet channels of the Second nuclear power plant. * Fish skeletal deformities found in summer 1993: ▲ found in summer 1994; found in summer 1995 after reconstruction of new outlet channel.

(3) The mechanisms -- why heat will cause fish deformity. The deficiency of ascorbic acid (Vitamin C) was firstly suspected because of its unstable and sensitivity to degradation in higher water temperature. Thus, thornfish fries (2.5～3.5cm) were cultured at 28°C, 32°C, and 36°C separately and fed with or without vitamin C-supplemented diet.

All fish specimens collected from the field or the fishes sampled from the cultured tanks were examined through X-ray photography to get the morphological data and the occurrence ratio of deformity as well as to calculate the degree of deformity. One "curvature index" for the latter was designed as the vertebrae actual linear length divided by the straight-line length between the 1st to the 25th vertebra. Thus, larger the index value, more serious the deformity is. The precision of the all measurements were all up to 0.1mm.

**Results and Discussion**

Figure 2 summarizes the locations where the malformed fishes most frequently occurred in the summer of 1993, 1994 and 1995. High percentage (80-100%) of malformed fish fries collected near the bottom on the left side of discharge channel in 1993 was because the mouth of old channel was open to the left direction. Consequently, the heat waters could not disperse well. The hot water stagnated at this corner make the daily temperature remain 37-40°C high during middle June to early September. On the contrary, after the mouth of outlet had been reconstructed and shifted to north-eastern direction since April 1994, the warm effluent has been no longer hugging along the

shoreline (Fig.3) (Chious et al., 1995). Henceforth, the malformed fishes mostly occurred inside the channel and scattered along the outside wall of the channel. After the ambient water temperature dropped below 26-27°C from middle of September to the June of next year, the water temperature of thermal plume also dropped below 36-37°C ($\triangle$T=10-11°C). Consequently, no more malformed fish fries could be collected. Only some larger malformed fishes (>3 cm SL) which were grew up and survived from the summer could be found. Thus, we can predict that the malformed fishes will have seasonal recurrence in the summer in the future, just like the coral bleach in the thermal plume region of the Third Nuclear Power Plant in the southern tip of Taiwan.

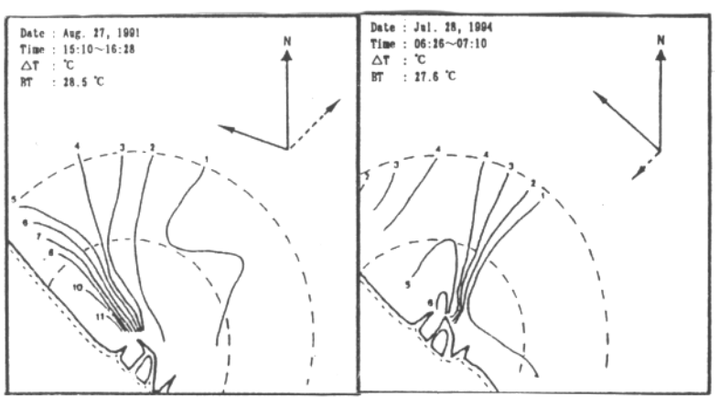


Fig 3. Surface dispersion of thermal effluent in relation to the speed and direction of the wind and current near the outlet of the Nuclear II Plant. (number, $\triangle$T; BT, surface temperature of the background station). Note that the discharge channel was shifted since April 1994 on the right figure. (After Chiou et al., 1995)

The morphology of wild malformed fishes were also not so uniform, comparing to those specimens cultured under the constant high temperature. This is because the fish inhabits in the outlet area where they can freely swim around to avoid too hot water. Thus, the deformity of fishes varied from very slight, only a little curve on the first few vetebrae, one obvious wave-like curve, up to 3 curves. The rate of occurrence and average curvature index values of each sampling time fully coincide with the distribution pattern of water temperatures both on spatial and temporal (seasonal) scale. Climate changes and the operational conditions of power plant can also play in role. For instances, low rate of malformed fishes and less serious of deformity in the summer 1994 compare to that of 1993 and 1995 was because several typhoons passing by all together in the summer of 1994, and the power generators shut down more frequently in that particular summer.

The occurrence of malformed fishes restricted only in the outlet area not in other vincity areas also indicating that it is the juveniles stage not the planktonic fertilized eggs or larval stage to be affected by the thermal plume. Otherwise, the occurrence of malformed fishes should occur in a very broad region. In other words, when juveniles of these two warm water fish species swim into the outlet region, they will stay in this warm region because both thornfishes and mullets are thermal tolerant species. The lethal high water temperature of their juveniles can up to 41-42°C (Chen and Shao, 1987). Thus, after a certain period of time, probably few days to one or two weeks, stay in this area, make the fishes become malformed.

The results of ichthyoplankton sampling in the waters outside the outlet area also demonstrated that there was no eggs or larva of thornfishes near shore, only juveniles with swimming ability could be collected when they were migrating to the shoreline. This result has been fully agreed with the life cycle and migration pattern of these two species proposed by Tzeng and Wang (1993).

No malformed fish was found while rearing below 34°C tank (Table 1). In 36°C, it wll take half a year to make fish 100% malformed. But it only needs 2 weeks to reach 100% malformed in 37°C and 38°C tanks. Nevertheless, the mortality is high when rearing in the tanks above 37°C. In 38°C tank, all fish were died after 1-2 months. The order of growth rate from high to low is 34°C > 36°C

> room temperature > 37°C > 38°C. Figure 4 shows that the abnormalities could happen no matter which body sizes of the fish were started to be rear. But the curvature is getting more serious if the fish is in faster growing juvenile or young stage (Fig. 5). The morphological comparisons of malformed fishes showd that the curvature will get more serious when fish grow up. Though the variation of curvature in 36°C is greater than in 37°C and 38°C, their variations were all smaller than that of the fish caught from wild. So far our malformed fishes reared indoor has lasted longer than 10 months and body size larger than 9cm. Although it is unlikely to 100% simulate the natural environment in the tank, our reproduced malformed fish in the tanks no matter on body shape or spinal curvature, they are hardly to be distinguished from the wild malformed fishes.

Table 1. The percentage and degree of deformity of thornfishes after rearing in different constant water temperatures.

| constant temperature | days | sample size | percentage of deformity | curvature index |
|---|---|---|---|---|
| room temperature | 116 | 115 | 0% | -- |
| 34 | 116 | 114 | 0% | -- |
| 36 | 116 | 192 | 34% | 1.079±0.017 |
| 38 | 61 | 90 | 68% | 1.139±0.015 |

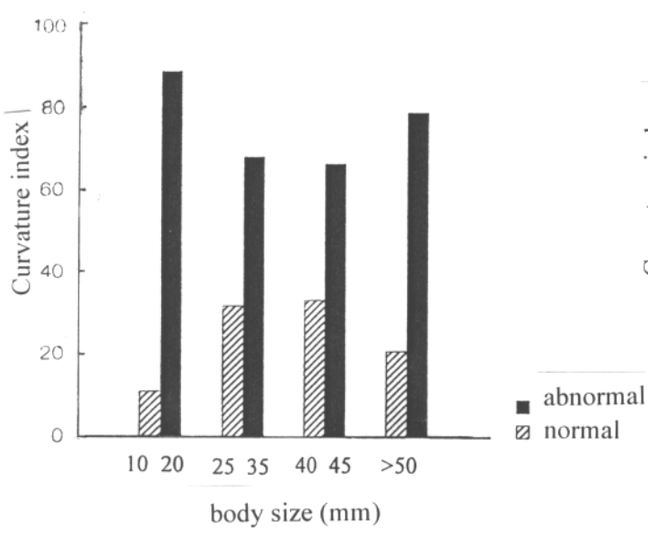


Fig 4. The percentage of deformity for rearing different body size of thornfishes in 37°C tank.

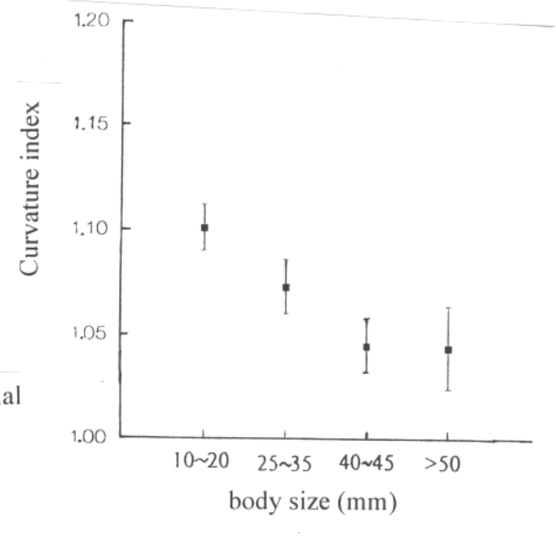


Fig 5. The curvature index values decreases when the body size of rearing fishes are larger.

From the rearing experiment of thermal amplitude which simulating the natural tidal cycle, the curvature could be recovered if the low limit of amplitude is below 35°C. No matter the malformed fishes were caught from *in situ* or cultured in the tank, they could gradually recovered after move back into the waters of room temperature. Nevertheless, the recover rate is slower if the body size of fish larger.

Table 2 is the results of the flow-water rearing experiment. Again, it demonstrates that it should have no other pollutants in the effluent waters which could make the fish malformed except the temperature. Otherwise, the fishes cultured in lower temperature tanks should be malformed as well.

Table 2. The percentage of deformity and curvature index of flow-water rearing experiment *in situ.*

| | Temperature | days | sample size | percentage of deformity | curvature index |
|---|---|---|---|---|---|
| First experiment | 37±1.5°C | 51 | 7 | 100% | 1.09810±1.1274 |
| | 35±1.5°C | 51 | 27 | 0% | -- |
| | 32±2.0°C | 51 | 18 | 0% | -- |
| Second experiment | 36±1.0°C | 52 | 32 | 47% | 1.0234±1.0653 |
| | 33±1.0°C | 52 | 53 | 0% | -- |
| | 31±1.5°C | 52 | 13 | 0% | -- |

The level of ascorbic acid (vitamin C) and the ratio of hydroxyproline/proline in thornfish and mullet collected from the outlet area were found to be less either in deformed fish than in normal fish or in warmer seasons than in colder seasons. Thornfish were separately cultured at 28°C, 32°C and 36°C tanks, and fed diet with or without vitamin C-supplement. Deformed fish only appeared at 36 °C , but did not occurred when fish fed diet with vitamin C-supplemented diet (Fig.6). Therefore, high water temperature can make the vitamin C deficient both in fish body or in their food, so that the content of hydroxyproline (collagen) is not enough for normal growth of fish vertebrae. Our experiments also suggested that the skeletal abnormality is mainly occurred in fast growing juvenile or young stage since they need more supply of vitamine C than adults. When rearing the fish in 36 °C tank, the ratio of hydroyproline/proline for skin and bone which significantly lower in the 4th week, then becoming normal after the 8th week. This also reveals that the abnormalities could be relieved since its growth rate will slow down or the larger fish might be able to synthesis the vitamine C by itself.

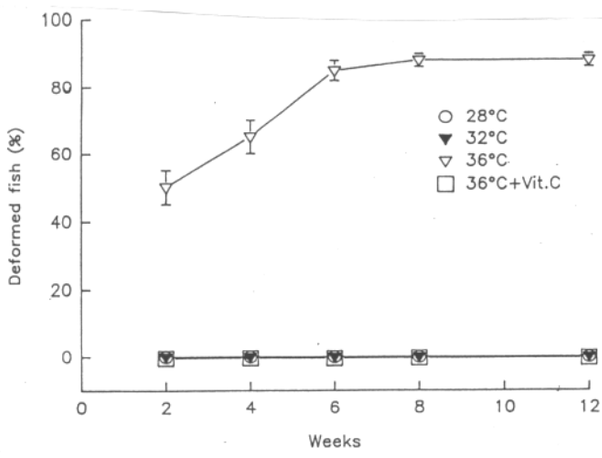


Fig 6. Percentage of deformed thornfishes after rearing 12 weeks in different temperature tanks vit.C supplemented diet was treated in one 36°C tank.

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