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REGIONAL DIFFERENCES IN OYSTER (*CRASSOSTREA GIGAS* THUNBERG) SIZE AND SHAPE IN TAIWAN[1]

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Keryea Soong, Li-Lian Liu, Jau-Luren Chen and Chang-Po Chen (1992) Regional differences in oyster (*Crassostrea gigas* Thunberg) size and shape in Taiwan. *Bull. Inst. Zool., Academia Sinica* **31**(2): 111-119. Size characteristics of oysters, *i.e.*, meat weight, shell length, and shell width, were measured in *Crassostrea gigas* Thunberg at eight sites along the west coast of Taiwan and the Penghu Islands. The mean, median, and "prime" (top 5%) for each characteristic in the population, as well as the ratio between characteristics correlation, and regression among the characteristics were calculated.

These parameters differed significantly across various populations. In addition, Penghu oysters were larger than those collected at other sites in all size parameters measured. We also found that Penghu oysters produce more meat per unit of shell (in terms of length and width), and have a different shell form compared with oysters from other sites.

Differences between the Penghu oyster population and those collected along the west coast of Taiwan may be attributable to environmental factors, whereas differences among populations collected along the west coast of Taiwan are probably caused by both environmental and genetic factors.

Key words: Taiwan, Oyster, Size, Regional differences.

Two approaches, environmental or genetic, may be adopted to increase production of a cultured species. The first thing to determine, however, is what variation is available for an existing population; determining the cause(s) of the variation would then help decide the better approach.

The Pacific oyster, *Crassostrea gigas* Thunberg, has been introduced to many regions (Gosling, 1982). It has been known to exhibit regional variations in New Zealand (Pridmore *et al.*, 1990), and in Japan—its place of origin—regional differences have been found between Hokkaido in the north and Kumamoto in the south; four populations have been distinguished (Ahmed, 1975; Buroker *et al.*, 1979; Cahn, 1950).

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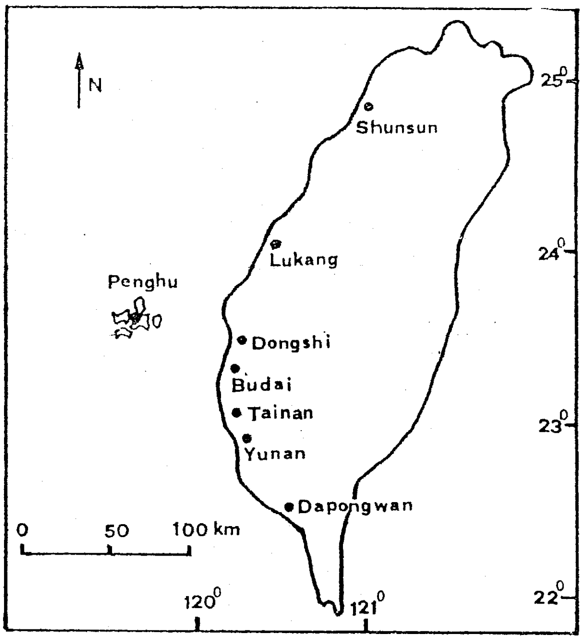

Fig. 1. Collection sites.

Crassostrea gigas is the most economically important cultured shellfish in Taiwan. Production officially registered in the *Fisheries Yearbook Taiwan Area* (1986; 1990) ranged between 15-30 thousand tons of meat per year between 1977 and 1989. Oyster farms with an estimated total culture area of about 14,000 hectares are located along the west coast from Shunsun in Shintsu county to Dapongwan in Pintung county (Fig. 1) (Taiwan Fisheries Bureau, 1989).

Growing oysters in Taiwan basically involves maintaining artificial substrata —usually sticks or strings of oyster shells—in intertidal or subtidal zones. Spat settles and grows on these substrata which may either be exposed when tides are low, or continuosly immersed in subtidal waters. In subtidal zones, strings of cultch may be hung under racks anchored to the bottom, or suspended by surface flotsam. Oyster spat has been successfully collected in Taiwan, but Penghu oyster farms depend on importated spat (on oyster shells as cultch) from Taiwan, since no local spat is available.

Natural predators of cultured oysters differ regionally. Oyster drills (*Thais clavigera* Kuster) are the principal predators along Taiwan's coast (Hwang and Huang, 1971; Lin and Hsu, 1979). In Penghu, however, significant oyster mortality is caused by oyster leeches, *Stylochus orientalis* Bock (Shu and Lin, 1980; Chen *et al.*, 1990; Lee, 1990).

Presumably, environmental factors also vary regionally. For example, Dapongwan is an inner bay with low water circulation and almost no exposure to wave action, whereas other sites are more exposed. Terrigenous nutrients may be lower in Penghu (an archipelago) than along the Taiwanese coast where a significant amount of sediment is deposited (Shih, 1980). Water temperature also varies along the coast; a surface water deviation of over 6°C between Shunsun (north) and Dapongwan (south) has been recorded (Tang and Chen, 1990).

Other practices may also affect oyster growth; for example, farmers in Dapongwan move strings of oysters to different habitats according to season, presumably to hasten production. Penghu farmers occasionally wash oyster strings with fresh water to inhibit oyster leech populations (Lee, 1990). Artificial selection due to these various practices may exist; it is unknown whether or not this selection is beneficial in the long run.

For this study we compared shell lengths, shell widths and meat weights, as well as relationships among characteristics of oyster populations harvested at various sites in Taiwan (including one non-culturing site, Yunan). We aimed to find out if oysters from various regions differ in growth characteristics. If they do further research can determine if the differences are mostly genetic or environmental—thus helping to devise better culture methods.

MATERIALS AND METHODS

Crassostrea gigas specimens were collected from eight sites along the west coast of Taiwan and the Penghu archipelago between September and November, 1990 (Fig. 1). Whole oyster aggregates still attached to artificial substrata, or baskets of separated and unsorted oysters were procured either on-site or directly from oyster farmers. Specimens from Yunan—where oysters grow on unattended substrata—were collected by divers.

Specimens were frozen at -20°C. Leng thand width of the left shell (Fig. 2) was measured with vernier calipers; meat weight was determined with an electronic balance. Samples included 106 to 358 randomly chosen individuals from each site.

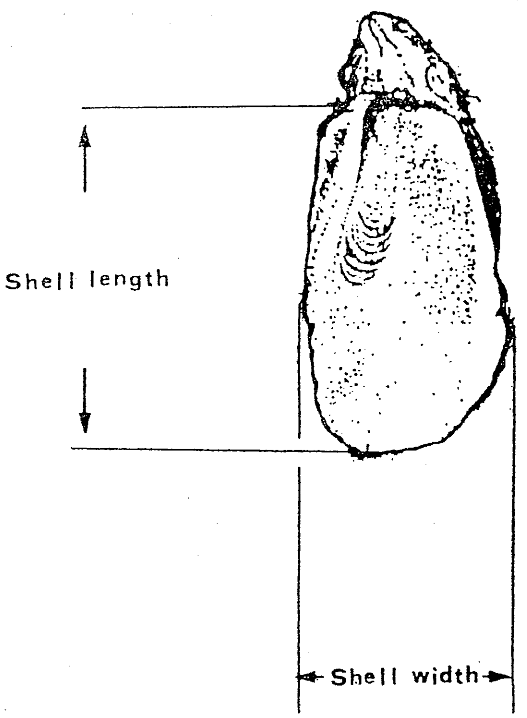

Fig. 2. Model shell of an oyster and related measurements used in this study.

Confidence intervals for median and "prime" (top 5%) parameters were calculated using a "bootstrapping" procedure described by Diaconis and Efron (1983). One thousand bootstrap samples—each equal to the original sample size—were randomly chosen with replacements from the original data set. Median and prime for each of these artificial samples was calculated; confidence intervals were then determined according to the distribution of values calculated from the resampled bootstrap samples.

Correlation and regression coefficients for shell length, width, and meat weight were calculated and compared among the collection sites.

RESULTS

Meat weight

The median weight of Penghu oysters was 9.0 g, significantly higher (5% level) than the other sites where median weights ranged between 3.8 g (Shunsun) and 6.1 g (Dongshi) (Table 1). When using individual weights of the largest 5% of each population as an index ("prime" weight), the prime weight of Penghu oysters reached 20.0 g, whereas those of all other populations were between 9.6 g and 13.3 g (Table 1). The difference between Penghu oysters and oysters from the other seven sites is significantly different at the 5% level. No significant difference in prime weight was found among the seven collection sites located along the west coast of Taiwan (Table 1).

Weight distribution was not normal at all sites; therefore, a square root transformation of meat weight was used for comparison, since the standardized residue of pooled data was not significantly different from normal ($p=0.123$). Penghu specimens were significantly

Table 1
Size parameters of oyster populations at the various sites. Sites along the west coast of Taiwan are arranged by latitude from north to south. "Prime"=size reached by the top 5% of each population. See Materials and Methods section for calculations of confidence intervals (*c. i.*)

Meat weight

Site	*n*	Mean (g)	Median	95% *c. i.*	Prime	95% *c. i.*
Penghu	313	9.6	9.0	7.9-9.6	20.0	18.5-22.6
Shunsun	210	4.5	3.8	3.4-4.2	9.6	8.3-10.3
Lukang	210	5.5	4.9	4.1-5.6	13.3	11.3-14.2
Dongshi	205	6.3	6.1	5.8-6.6	10.8	10.1-11.4
Budai	210	5.3	4.4	3.7-5.8	12.4	10.3-14.5
Tainan	358	5.8	5.8	5.5-6.1	9.7	9.1-10.2
Yunan	106	6.6	6.0	5.2-7.1	12.1	10.3-17.0
Dapongwan	210	5.1	5.0	4.1-5.7	10.5	9.5-11.6

Shell length

Site	*n*	Mean (mm)	Median	95% *c. i.*	Prime	95% *c. i.*
Penghu	313	55	55	54-57	72	70-78
Shunsun	210	34	34	32-36	47	45-49
Lukang	210	36	37	35-39	51	50-54
Dongshi	205	42	43	42-44	58	53-62
Budai	210	36	39	36-41	55	52-58
Tainan	358	43	43	42-44	58	56-59
Yunan	106	38	38	34-39	52	45-55
Dapongwan	210	35	36	35-37	49	47-50

Shell width

Site	*n*	Mean (mm)	Median	95% *c. i.*	Prime	95% *c. i.*
Penghu	206	30	30	29-31	42	40-45
Shunsun	210	22	22	21-23	32	30-33
Lukang	210	26	27	25-29	39	36-40
Dongshi	205	24	24	23-24	33	30-34
Budai	210	22	24	22-25	35	33-37
Tainan	358	24	25	24-25	32	30-33
Yunan	106	29	28	26-29	46	40-50
Dapongwan	210	23	24	22-25	33	31-34

heavier than those from the other collection sites, and comparisons among the seven remaining sites also indicated significant differences (Table 2). For example, specimens collected from Shunsun, Budai, Dapongwan, and Lukang were lighter than those from Tainan, Dongshi, and Yunan.

Table 2
Paired comparisons of square-root transformations of meat weight among sites. (Fisher's PLSD method used; *=significant at 95% level, ns=not significant)

Site	Penghu	Yunan	Dongshi	Tainan	Lukang	Dapongwan	Budai
Penghu							
Yunan	*						
Dongshi	*	ns					
Tainan	*	ns	ns				
Lukang	*	*	*	*			
Dapongwan	*	*	*	*	ns		
Budai	*	*	*	*	ns	ns	
Shunsun	*	*	*	*	*	ns	ns

Shell length and width

Penghu oysters reached a maximum shell length of 93 mm, whereas at all other sites the longest lengths were between 52 and 73 mm. Differences in shell lengths among sites were significant according to a nonparametric statistic based on ranking (Kruskal-Wallis test, corrected $H=538.6$, $p<0.01$, $n=1{,}822$). Differences in shell widths among the various sites were also significant (Kruskal-Wallis test, corrected $H=180.1$, $p<0.01$, $n=1{,}715$) (Table 1). Median and prime lengths were significantly longer

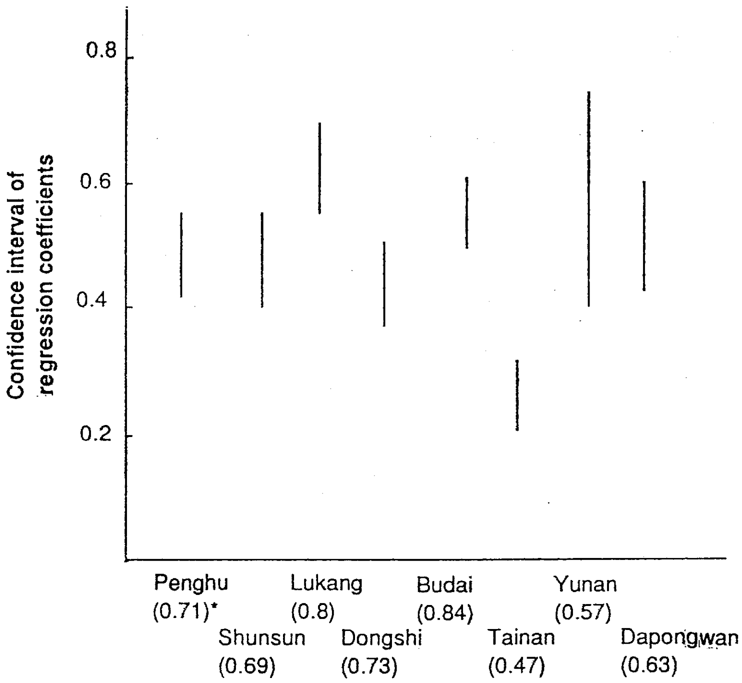

Fig. 3. Confidence intervals (95%) of regression coefficients of the relationship between shell length and shell width in populations from the various sites. Numbers in parentheses under each name are correlation coefficients between shell length and shell width. Sample sizes at each site, see Table 1 shell width.

Table 3
Relationships of the ratio between shell width and shell length versus shell length for *Crassostrea gigas* at 8 sites. **=significant at 1% level; *=significant at 5% level; ns=not significant)

Site	Intercept	Slope	Significant level of slope	Site	Intercept	Slope	Significant level of slope
Penghu	0.631	−0.001	ns	Budai	0.694	−0.002	*
Shunsun	0.798	−0.004	**	Tainan	0.905	−0.008	**
Lukang	0.932	−0.005	**	Yunan	0.984	−0.006	**
Dongshi	0.690	−0.003	**	Dapongwan	0.812	−0.005	**

for Penghu populations when compared with those of the other seven sites; those seven sites also differed among one another.

Pooling data from all sites, length and width were correlated ($n=1{,}715$, $r=0.68$, $p<0.01$) according to a significant linear relationship: width=0.44 length + 7 mm. When comparing individual sites, significant correlations were also found for each population; correlation coefficients ranged between 0.47 in Tainan to 0.84 in

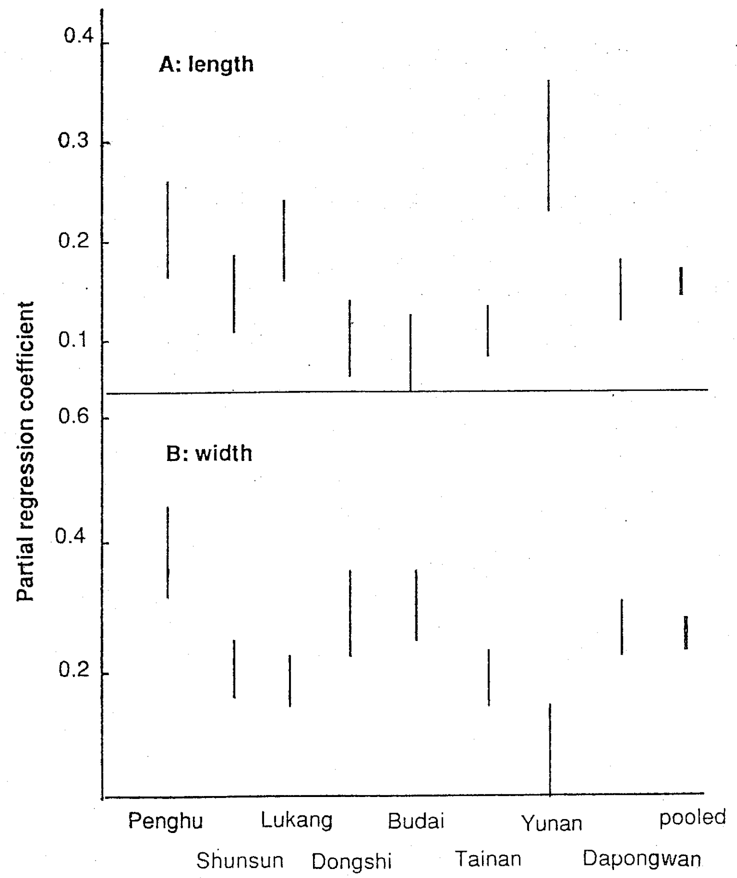

Fig. 4. Confidence intervals (95%) of partial regression coefficients of mean weight versus shell length and shell width of populations from the various sites. Sample size at each site, see Table 1 shell length and shell width, respectively.

Budai (Fig. 3). The slope of the linear relationship, however, was significantly lower for the population in Tainan than for those in the other populations (Fig. 3). In other words, increments for oyster shell width relative to shell length were smaller for oysters in Tainan than oysters in all other areas.

The shell width-shell length ratio changed according to shell length in Shunsun, Tainan, Dapongwan, Dongshi, Lukang, Budai and Yunan; for these sites the slopes reflecting the relationship were significantly different from 0. The trend was toward more slender shell forms increasing shell length at all the above sites. This allometry was not found in Penghu populations (Table 3).

Meat weight vs. shell length and width

The relationship between shell size and meat weight was analyzed using a multiple regression. A significant regression (n=1,715, p<0.01) was obtained from the pooled data:

Meat Weight (g)=−6.2(mm)+0.157 length+0.239 width.

When individual populations weie analyzed separately, significant differences were found in partial regression coefficients (Fig. 4a). For the populations in Tainan, Dongshi, and Budai, the partial regression of meat weight to shell length was significantly lower than those of populations in Penghu, Lukang, and Yunan; the other two sites showed intermediate values. The partial regression coefficients of meat weight on shell width were significantly higher for populations in Penghu, Dapongwan, and Budai than they were for populations in Tainan, Lukang, and Yunan (Fig. 4b).

DISCUSSION

It is obvious that Penghu oysters are larger than those from the other seven sites in Taiwan, both in terms of individual weight and linear shell measurement (with the exception of shell width in Yunan) (Table 1). Spat used to grow Penghu oysters was imported from Budai and Dongshi; therefore, no genetic differences would be expected between oysters in Penghu and the rest of Taiwan at least in the beginning stages of growth. Thus, environmental factors are more likely to have caused the observed size difference.

Due to the strong winds which start in October in Penghu, grown oysters harvested before the end of September after a growing season which is no longer than those on the west coast of Taiwan; generally, more than one year of growth is required before harvesting. Therefore, age is probably not the cause for the vast difference in size between oysters from Penghu and those from the west coast of Taiwan.

Penghu oysters are hung from floats which provide continuous immersion at a fixed depth. Presumably they can feed continuously and are subject to less environmental fluctuation than oysters in intertidal zones, where immersion times are shorter and environmental factors are more variable. The history of oyster culture in Penghu is shorter (20 years) than that in other parts of Taiwan (about 200 years) (Lin, 1969; Lin and Tang, 1980). Possible effects of environmental degradation would be less severe in a relatively young farming environment (Ito and Imai, 1955). Other differences between the Penghu archipelago and the west coast of Taiwan (e.g., predators) may also have contributed to the observed size differences. However, no environmental factor was pinpoined as being the major cause for these differences in size. Our establishment of the size difference, and the unlikelihood of genetic factors being the main cause for the difference (since Penghu spat comes from Taiwan), are indicative of the notion that oyster production could be increased on the west coast of Taiwan through environmental improvement.

Among populations at the seven collection sites along the west coast of Taiwan, significant differences were also found in size parameters (Table 1). Besides differences in the medians and primes of meat weight, shell length, and shell width, the correlation between shell length and shell width and the slope between the two linear measurements of the shells varied among the sites. These differences may be attributable either to different farming environments or to genetic factors. A more stringent experimental design, e. g., transplantation, is required in order to pinpoint specific environmental factors contributing to the differences. On the other hand, a genetic component may also be important; however, virtually nothing is known about gene flow and genetic variability among the study sites. A genetic study of the populations along the coast and at Penghu based on isozyme electrophoresis is currently being conducted by the authors.

The "prime" size used in this study is better than using the largest size as an index of the maximum size a particular population can reach; the former is less likely to be affected by chance, since the latter is determined by a single individual which may be an anomalous individual. Prime size is also better as an index than median size for several reasons; for example, only large individuals are used in selective breeding for commercial purposes. If certain alleles are related to the large size of individuals in a population, it is the prime size—not median size—which reflects the extent to which these alleles may be contributing to differences.

The allometry of shell form, as indicated by changing ratios between shell length and shell width increasing shell length, was found at all sites except Penghu. This is likely caused by environmental factors, since Penghu spat was imported from the west coast of Taiwan. Whether or not the same factor(s) caused the large size and the lack of shell form allometry in Penghu oysters remains to be investigated. Experiments comparing spat on cultches with isolated spat may indicate whether crowing plays a role in influencing shell form.

Differences between regressions of meat weight on shell measurement among the studied populations indicates that, for the same weight of meat produced, different shell amounts may be secreted. Penghu was the only site where both partial regression coefficients (on length and width) were higher than the pooled data (Fig 4). Thus, for identical amounts of secreted shell, Penghu oysters produce more meat than those at other sites. Shell weight is probably a better parameter for purposes of estimating shell secretion / meat ratio. However, oyster shells are often encrusted with foreign organisms—such as barnacles and tubeworms—which render shell weight estimation impractical.

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臺灣各地區牡蠣體型大小的差異

宋克義　劉莉蓮　陳昭倫　陳章波

由臺灣西海岸及澎湖等八個地區所收集之牡蠣經相關係數、廻歸分析以及中量、主量 (prime) 比較各區牡蠣之肉重、殼長、殼寬後發現各區牡蠣之體型有顯著差異，而以澎湖地區牡蠣爲最大，除了肉重與殼長、殼寬廻歸較大，殼形（殼長殼寬比）亦有差異。

本研究確立了臺灣各地區養殖牡蠣體型大小差異的存在，環境因素可能是主要造成臺灣西海岸和澎湖牡蠣差異之主因；而臺灣西海岸各地區之差異可能受環境及遺傳因素影響。