A Statistical Study of *Cypraea tigris* in the Central Pacific

BY

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(2 Text figures)

INTRODUCTION

THERE HAS BEEN much interest in *Cypraea tigris* Linnaeus, 1758, by both collectors and malacologists because of its large size and its color. In Hawaii, the eastern Pacific limit of its geographical range, *C. tigris* attains a size unequaled anywhere else. This larger size, the wider and straighter aperture, larger and stronger teeth, deeper and broader fossula, and the near absence of a marginal callus were the characteristics used by CATE (1961) to separate the Hawaiian form as a distinct subspecies, *Cypraea tigris schilderiana*. KAY (1961) through shell measurements on *C. tigris* was able to distinguish 3 groups based on size: the large Hawaiian subspecies, a population intermediate in size at Johnston Atoll and a smaller form that occurs throughout the south Pacific. Unfortunately, only 14 specimens were available to KAY (*op. cit.*) from Johnston Atoll, and the 3 size groups were not differentiated statistically. FOIN (1972), using the mean shell lengths of *C. tigris* from Hawaii and localities to the south and west, showed that the gradient in shell size is related to the degree of isolation of a given archipelago.

KAY (1961) suggested that the variation in size exhibited by Hawaiian *Cypraea tigris* may be due to lower surface water temperatures (Bergmann's Rule) or to differences in habitats available to the species in Hawaii. In the Hawaiian Islands, *C. tigris* occurs in relatively deep water, often on a dead coral or basalt substratum (CATE, 1961; KAY, 1961). The high Hawaiian Islands have reefs that differ considerably from those of atolls; in the latter localities *C. tigris* occurs in shallow water areas that also harbor a diverse benthic biota. The inverse relationship of larger shell size to lower surface water temperatures is not clear. KAY (*op. cit.*) noted that 2 *C. tigris* available for study, collected in the Northern Hawaiian chain at Midway Island and Kure Atoll (where the lowest Hawaiian surface water temperatures occur), were small in size and closely resembled the normal south Pacific form. WILSON & SUMMERS (1966), however, have attributed size clines in *C. friendi* off western Australia to corresponding temperature gradients, and SCHILDER (1961) similarly ascribed size clines in *C. arabica* to surface water temperatures.

The validity of the Hawaiian subspecies has been questioned. CATE (1965: 58) and SCHILDER & SCHILDER (1971: 154) recognized the subspecies but BURGESS (1970) and TAYLOR & WALLS (1975) did not; however, no reasons were given for not accepting the subspecies. DONOHUE (1965, 1971, 1977) confined his taxonomic work on *Cypraea* to the species level, thus avoiding trinomials of *C. tigris*. The lack of quantitative information on morphological characters of *C. tigris* makes any assessment of a subspecies tenuous at best. Most of the previous work has been qualitative and hence is subjective. KAY's (1961) findings have shown some interesting gradients in shell size, and FOIN (1972) through regression analysis has presented evidence suggesting that this gradient in size represents a cline. In the present paper I wish to examine this size gradient with adequate sample sizes and appropriate statistical procedures, which may help to determine objectively if the Hawaiian form of *Cypraea tigris* warrants the status of a subspecies.

MATERIALS AND METHODS

All measurements on shells were made with vernier calipers to the nearest 0.1 millimeter. The characters measured included the shell length, width, and height. To be comparable with KAY's (1961) and FOIN's (1972) findings, the present data were considered statistically in 3 geographical groups, *i. e.*, the Hawaiian Islands with 106 specimens, Johnston Atoll with a sample of 70 specimens I collected in 1970, and measurements made on 75 *Cypraea tigris* from other parts of the tropical Pacific (western region – New Guinea, Borneo, Philippines, Palau, and the Great Barrier Reef with 42 specimens as well as the central region – Marshall Islands, Tuamotus, Carolines, Guam, Tonga, and Fiji with 33 specimens). Shells used in these measurements were from the Burke Museum, Seattle, Washington, and 3 private Honolulu collections. All measurement data were analyzed, using least squares linear regression, analysis of variance, and Newman-Keuls multiple range tests.

RESULTS

Length frequencies of *Cypraea tigris* were plotted; these data seem to fall into 3 groups on the basis of size and locality of collection (see Figure 1). The Hawaiian Islands harbor the largest shells, Johnston Atoll has *C. tigris* of intermediate size (Group 2) and shells from other Pacific Islands are the smallest and make up the third group. These findings agree with those of Kay (1961) and Foin (1972).

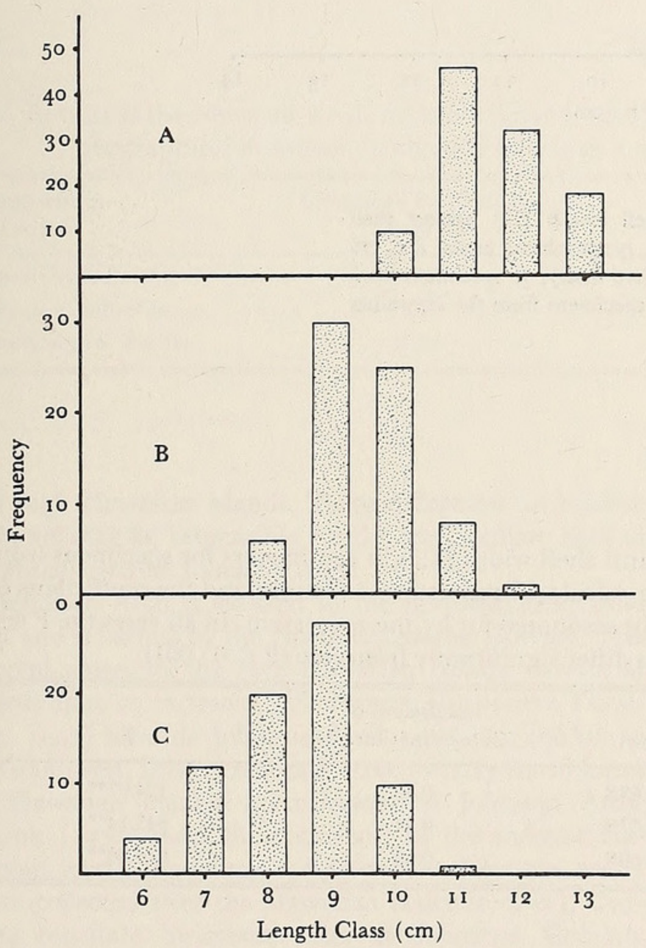

Figure 1

Size frequency plot of the length of *Cypraea tigris* from three geographical areas. The lengths of 106 Hawaiian Island specimens are shown in A, 70 Johnston Atoll specimens in B, and 75 specimens from islands in the Pacific south of Johnston Atoll in C

The relationship of the shell length to breadth from the 3 geographical areas was explored to determine if the slopes of a fitted regression of shell length (X) to shell width (Y_w) differed. Table 1 presents a summary of these regressions, and the lines are plotted in Figure 2. The slopes of the plotted lines are very similar and all differ significantly from zero ($P < 0.001$). The slopes do not differ significantly, implying that the shape of adult shell (the length to width relationship) is similar for specimens from the 3 geographical localities. The same result was obtained for a regression analysis of shell length (X) to shell height (Y_h).

Of the 3 morphological characters measured in this study only the shell length shows appreciable differences that may be related to the collection locality. The results of an analysis of variance of shell lengths from 3 treatments (*i. e.*, geographical areas) is given in Table 2. The mean length of shells from each area differed significantly ($P < 0.001$). To delineate further the statistically significant differences in shell lengths in the analysis of variance, a Newman-Keuls multiple range test (Zar, 1974) was employed. This test compares the mean shell length from one geographical location against another. The results of this test are given in Table 3 and the mean lengths of shells from each locality are significantly different ($P < 0.005$).

DISCUSSION

The results suggest that there are 3 distinct groups of *Cypraea tigris* in the central Pacific based on size. If size alone may be used as a criterion for subspecies differentiation, then the Hawaiian form warrants this separation. The shells from Johnston Atoll are puzzling in that they have all the characters of the Hawaiian form but are intermediate in size. Are they more closely related to the Hawaiian or the south Pacific forms or do they represent yet another subspecies?

Johnston Atoll is isolated, lying 720 km southwest of French Frigate Shoals in the Hawaiian Archipelago, over 2 000 km from the Marshall Islands to the west and 1 100 km from Kingman's Reef in the Line Islands to the south. Biological collections have been made over the years at Johnston by Edmondson *et al.* (1925), Fowler & Ball (1925), Wells (1954), Gosline (1955), Brock, Jones & Helfrich (1965), Brock, van Heukelem & Helfrich (1966), Buggeln & Tsuda (1966), Brock

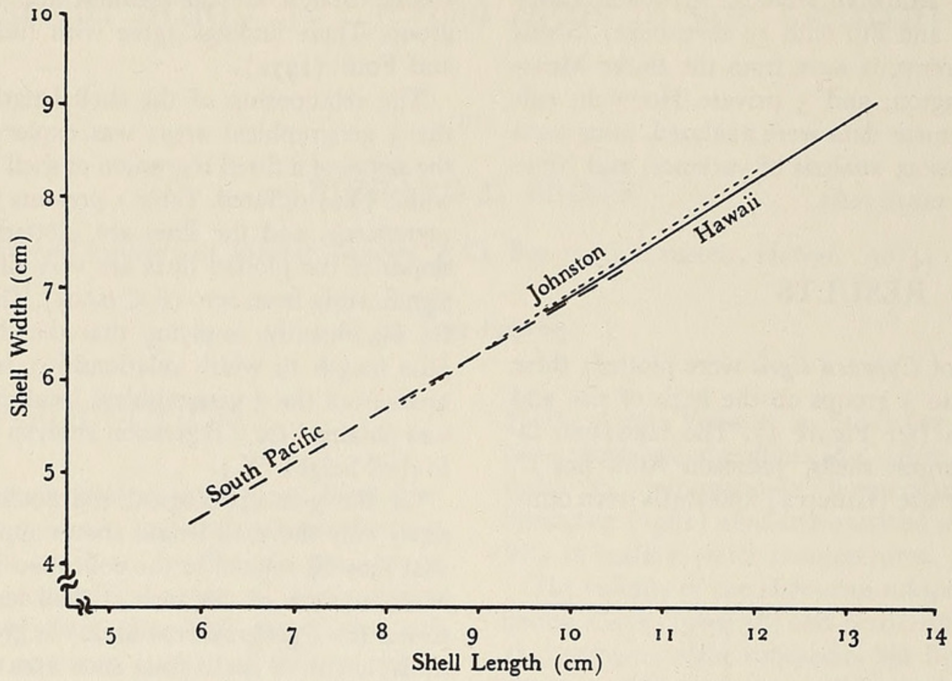

Figure 2

Least squares linear regression of shell length (X) against shell width (Y) for specimens from three geographical areas, *i. e.,* 76 specimens from the South Pacific (dashed lines), 70 specimens from Johnston Atoll (dotted line), and 106 specimens from the Hawaiian Islands (solid line)

Table 1

Results of the linear regression analysis of shell length (X) against shell width (Y_w) in centimeters for specimens from the three localities. Given in the table are sample sizes (N), the calculated regression equations and the coefficients of determination (r^2), a measure of the variation in Y_w (shell width) accounted for by the regression. In all cases the F test indicates that the slopes of the three regression lines differ significantly from zero ($P < 0 \cdot 001$).

Area	N	Fitted Equation	Coefficient of Determination (r^2)	F
Hawaii	106	$Y_w = 0.68 + 0.63X$	0.80	424.07**
Johnston	70	$Y_w = 0.29 + 0.67X$	0.84	345.14**
South Pacific	75	$Y_w = 0.99 + 0.59X$	0.90	674.86**

(1973), Bailey-Brock (1976) and Brock (1979). These studies suggest that the marine fauna is primarily Hawaiian with only a few central Pacific elements being present. However, the dominant corals at Johnston belong to the genus *Acropora.* The genus is virtually absent from around the main Hawaiian Islands, and the *Acropora* at Johnston provide habitats that are similar to atolls to the south and west but that differ greatly from those around

Table 2

Table of the analysis of variance of the lengths of *Cypraea tigris* from 3 areas in the Pacific. The large F value indicates that the mean lengths of shells is significantly different amongst the 3 treatments (geographical localities).

Treatments	Number of Observations (N)	Mean Length (cm)	Standard Deviation
Hawaii	106	11.53	0.83
Johnston	70	9.51	0.78
South Pacific	75	8.43	1.05

Summary of the Analysis of Variance:

Source	Sum of Squares	DF	Mean Square	F
Treatments	447.21	2	223.60	281.89**
Error	196.72	248	0.79	
Total	643.93	250		

Table 3

Results of the Newman-Keuls multiple range test used to analyze the mean length of *Cypraea tigris* shells from 3 geographical locations. In all cases the mean lengths differ significantly from each other ($P < 0 \cdot 005$).

Comparison of Lengths	Calculated Studentized Range (q)	P	q0·005 DF = 248,P	Conclusion
Hawaii vs S. Pacific	32.55	3	4.42	lengths not equal ($P < 0{\cdot}005$)
Hawaii vs Johnston	20.78	2	3.97	lengths not equal ($P < 0{\cdot}005$)
Johnston vs S. Pacific	10.28	2	3.97	lengths not equal ($P < 0{\cdot}005$)

the high Hawaiian islands. These differences in benthic habitats may be responsible for the intermediate sizes of *Cypraea tigris* at Johnston Atoll.

Johnston Atoll is situated in the northeast tradewind belt and is bathed by the North Equatorial Current. This current passes by the high Hawaiian Islands moving at speeds up to 20 cm/second (Sverdrup, Johnson & Fleming, 1942) towards Johnston Atoll 1 300 to 1 400 km to the southwest. This current may serve to carry larval forms of Hawaiian marine invertebrates to Johnston Atoll. Brock (1973) notes the occurrence of the endemic Hawaiian lobster *Panulirus marginatus* at Johnston and I have collected alive the Hawaiian endemic cowry, *Cypraea tessellata* Swainson, 1822 at Johnston. Gosline (1955) has recorded several Hawaiian endemic fish species at Johnston. However, the *C. tigris* population at Johnston is probably not totally dependent on larvae from Hawaii, for on several occasions I have found *C. tigris* pairs brooding eggs at Johnston. This suggests that the population may be self-sustaining.

The only morphological character of *Cypraea tigris* that is readily quantifiable and consistently different in the Hawaiian and Johnston populations is shell size. Other characters used by Cate (1961) in differentiating the Hawaiian subspecies are variable or subjective when one inspects large numbers of specimens. The linear regression analyses indicate that the shape of the adult shell is the same for all populations; hence, the subspecies separation without further experimental evidence must be based only on shell length. Regardless of the statistical evidence, the presence of a population of *C. tigris* intermediate in size at Johnston Atoll suggests that a gradient or cline of size characteristics exists in *C. tigris* from the south Pacific population through Johnston Atoll to the Hawaiian Islands. These findings agree with those of Foin (1972). Schilder (1969) has noted that the size of many cowry species increases towards the periphery of their ranges, producing a cline in size.

The different habitat occupied by the large *Cypraea tigris* of Hawaii and the presence of an intermediate sized form at Johnston Atoll in shallow-water habitats similar to those occupied by the species further south, suggests that this species simply exhibits a gradient in shell size that may be related to differences in environmental conditions. *Cypraea tigris* probably has a phenotypic plasticity that is manifested by morphological (size) variations in response to varying ecological conditions. Thus, as concluded by FOIN (1972), the validity of the Hawaiian subspecies is doubtful and until further experimental work is done, the trinomial should not be used.

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Literature Cited

BAILEY-BROCK, J. H.
1976. Habitats of tubicolous polychaetes from the Hawaiian Islands and Johnston Atoll. Pacif. Sci. 30: 69 - 81

BROCK, RICHARD E.
1973. A new distributional record for *Panulirus marginatus* (Quoy & Gaimard, 1825). Crustaceana 25: 111 - 112
1979. The effects of grazing by parrotfishes (Family Scaridae) on selected shallow Hawaiian marine communities. Ph. D. Dissert., Univ. Wash., Seattle, 176 pp.

BROCK, V. E., R. S. JONES & P. HELFRICH
1965. An ecological reconnaissance of Johnston Island and the effects of dredging. First Ann. Reprt. Hawaii Inst. Mar. Biol. Tech. Reprt. 5: 1 - 90

BROCK, V. E., W. VAN HEUKELEM & P. HELFRICH
1966. An ecological reconnaissance of Johnston Island and the effects of dredging. Second Ann. Reprt. Hawaii Inst. Mar. Biol. Tech. Reprt. 11: 1 - 56

BUGGELN, R. G. & R. S. TSUDA
1966. A preliminary marine algal flora from selected habitats on Johnston Atoll. Hawaii Inst. Mar. Biol. Tech. Reprt. 9: 1 - 29

CATE, CRAWFORD NEILL
1961. Description of a new Hawaiian subspecies of *Cypraea tigris* (Linnaeus, 1758) The Veliger 3 (4): 107 - 109; plt. 19 (1 April 1961)
1965. Hawaiian cowries. The Veliger 8 (2): 45 - 61; plts. 4 - 10; 4 maps (1 October 1965)

DONOHUE, JERRY
1965. *Cypraea*: A list of the species. The Veliger 7 (4): 219 - 224 (1 April 1965)
1971. *Cypraea*: A list of the species II. The Veliger 14 (1): 64 - 66 (1 July 1971)
1977. *Cypraea*: A list of the species III. The Veliger 20 (2): 159 - 162; 1 text figure (1 October 1977)

EDMONDSON, C. H., W. K. FISHER, H. L. CLARK, A. L. TREADWELL & J. A. CUSHMAN
1925. Marine zoology of tropical central Pacific. Tanager Exped. Pub. no. 1. B. P. Bishop Mus. Bull. 27: 1 - 148

FOIN, THEODORE C.
1972. Ecological influences on the size of *Cypraea tigris* L., 1758, in the Pacific. Proc. Malacol. Soc. London 40: 211 - 218

FOWLER, H. W. & S. C. BALL
1925. Fishes of Hawaii, Johnston Island and Wake Island. B. P. Bishop Mus. Bull. 26: 1 - 31

GOSLINE, W. A.
1955. The inshore fish fauna of Johnston Island, a central Pacific atoll. Pacif. Sci. 9: 442 - 480

KAY, ELIZABETH ALISON
1961. On *Cypraea tigris schilderiana* Cate. The Veliger 4 (1): 36 - 40; plt. 8; 2 text figs. (1 July 1961)

SCHILDER, FRANZ ALFRED
1961. A statistical study in cowries: the size of *Mauritia arabica* (Linnaeus). The Veliger 4 (1): 15 - 17; 2 text figs. (1 July '61)
1969. Zoogeographical studies on living cowries. The Veliger 11 (4): 367 - 377; 1 map (1 April 1969)

SCHILDER, MARIA & FRANZ ALFRED SCHILDER
1971. A catalogue of living and fossil cowries: Taxonomy and bibliography of Triviacea and Cypraeacea (Gastropoda Prosobranchia). Mem. Inst. Roy. Sci. Belg. (2) 85: 1 - 246 (31 July 1971)

SVERDRUP, HARALD ULRIK, MARTIN WIGGO JOHNSON & RICHARD HOWELL FLEMING
1942. The Oceans, their physics, chemistry, and general biology. Prentice-Hall, New York: 1087 pp.; 265 text figs.

TAYLOR, JOHN & JERRY G. WALLS
1975. Cowries. T. F. H. Publ., Neptune City, N. J. 288 pp.

WELLS, J. W.
1954. Recent corals of the Marshall Islands. U. S. Geol. Surv. Prof. Paper 260-I: 385 - 486

WILSON, BARRY R. & RAY SUMMERS
1966. Variation in the *Zoila friendi* (Gray) species complex (Gastropoda, Cypraeidae) in south-western Australia. Journ. Malacol. Soc. Austral. 1 (9): 3 - 24

ZAR, J. H.
1974. Biostatistical analysis. Prentice-Hall, Inc. Englewood Cliffs, N. J. 620 pp.