A STUDY OF INTRASPECIFIC VARIATION IN *PUSTULARIA CICERCULA* (INCLUDING A SMOOTH FORM TREATED EARLIER AS *P. MARGARITA*)

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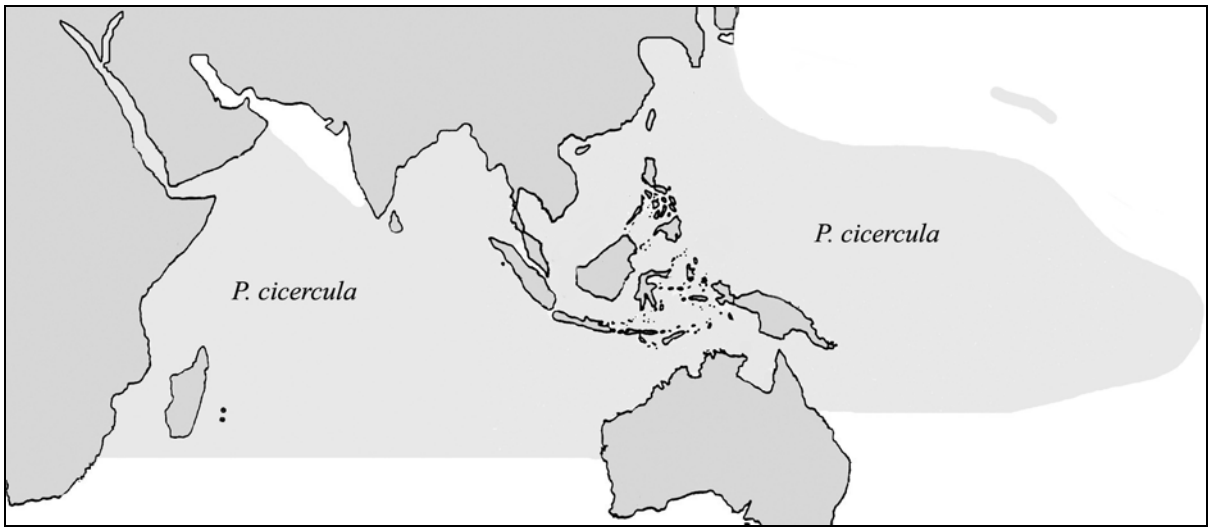
Abstract: In this work intraspecific variation in *Pustularia cicercula* (Linnaeus, 1758) is studied. The conchological material examined includes shells of a smooth form of the species treated in the past as *Pustularia margarita* (Dillwyn, 1817). That allows checking again the taxonomic identity of different populations of the species widely distributed in the Indo-Pacific region. This study is based on 298 shells of the species.
In this study a substantial difference in shell characteristics is found between the western and eastern groups of populations of *P. cicercula*. The western group of population inhabits the Indian Ocean and the western and central parts of the Pacific Ocean. The eastern group of populations inhabits an area of French Polynesia.
A group of populations from the Hawaiian Islands is already described as subspecies *P. cicercula takahashii* Moretzsohn, 2007. The shell characteristics of this group are not discussed in detail in the current study due to absence of large batches of shells from the Hawaiian Islands. A spot-check of a small batch representing that area indicates that it can be treated as an intermediate zone between the two groups mentioned above but this opinion should be checked again in the future and based on study of large batches of shells.
A conclusion is drawn that the difference in statistical shell characteristics between the western and eastern groups is of a subspecific level. The eastern group of populations of *P. cicercula* is described as a new subspecies in a separate work published in Triton 19.
Key words: Mollusca, Gastropoda, Cypraeidae, *Pustularia cicercula,* intraspecific variation, taxonomy.

Introduction

Pustularia cicercula (Linnaeus, 1758) is widely distributed in the Indo-Pacific region (Fig. 1).



1. A distribution range of *P. cicercula* including the smooth form

According to its original description this species supposed to be an easy-to-separate one; the dorsal granules are indicated as the main diagnostic character of this taxon:
"C. testa utrinque rostrata, adspersa punctis elevatis"—shell rostrated at both ends and granulated—Figs. 2-5.

Besides, shells of *P. cicercula* are small, elliptical, with attenuated extremities, with a convex to humped dorsum, a depressed spire, a rather flat base, and distinct teeth expanding onto the base from the narrow aperture.

All these shell characters, except the dorsal granules, can also be found in shells of *Pustularia margarita* (Dillwyn, 1817)—Figs. 6-9—which traditionally was considered a valid species.

2-5 *Pustularia cicercula*, 16.5 mm, Phuket, Thailand

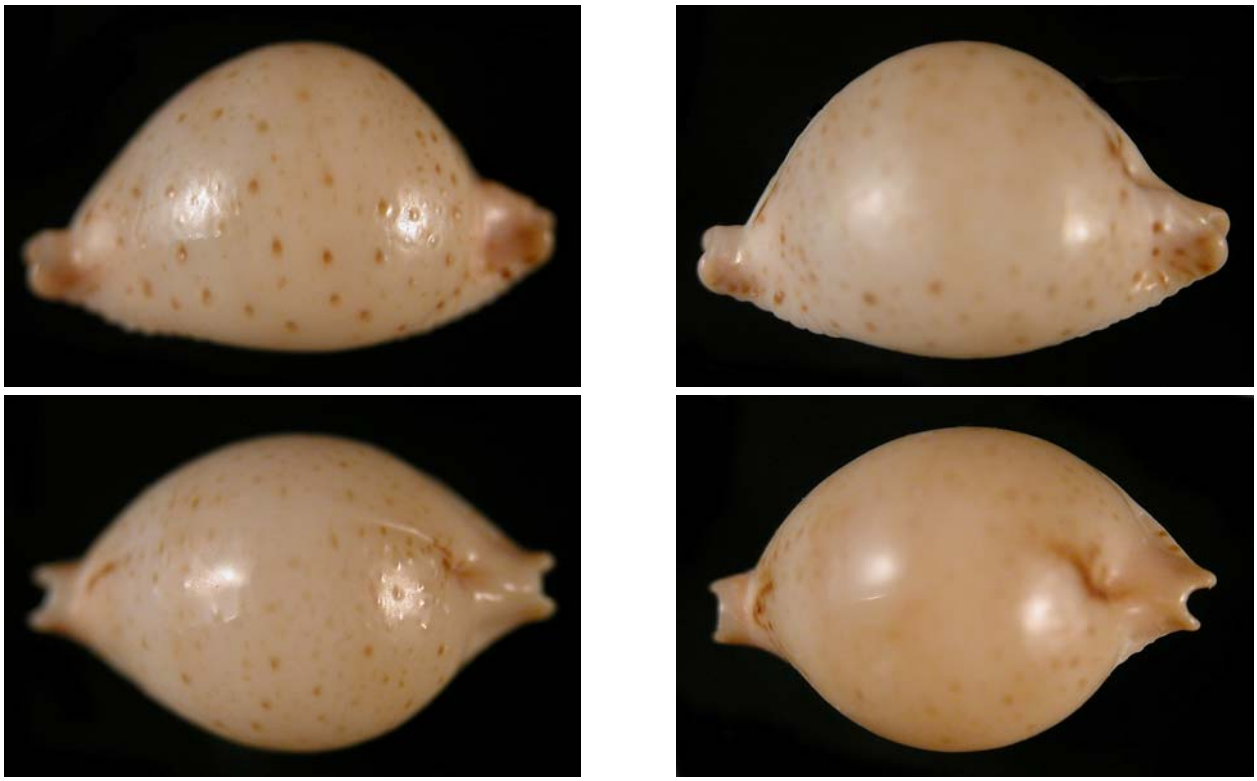
6-9. *Pustularia margarita* (Dillwyn, 1817), 18 mm, the Philippines

Intraspecific variation in *P. cicercula* and *P. margarita* was discussed in Heiman (2005) where an idea stated in Schilder & Schilder (1971) was accepted: *P. cicercula* is a monotypic species and *Pustularia margarita* consists of two subspecies: *P. margarita margarita* and *P. margarita tricornis* (Jousseaume, 1874). That approach was only partly confirmed by a statistical study and the conclusion was drawn that both species are monotypic although the taxonomic identity of their different populations needs further study. Such a study was delayed for some time due to absence of a sufficient conchological material.

Later *Pustularia cicercula takahashii* Morenzsohn 2007 from the Hawaiian Islands is described. In that work *cicercula* and *margarita* are also treated as different species. The latter subspecies is not discussed below in detail due to deficiency of an authentic conchological material from the Hawaiian Islands.

In Heiman (2008a) the present author developed Burgess'(1985) approach and suggested a hypothesis that 'margarita' is a smooth form of *Pustularia cicercula*.
In Heiman & Mienis (2008) the type material of *Cypraea tricornis* Jousseaume, 1874 is studied. The name of this taxon was recycled by the Schilders for a subspecies *P. margarita tricornis* (Jousseaume, 1874) from Polynesia. A conclusion is drawn that the type specimen of *C. tricornis* is a synonym of *P. margarita* and is not relevant to populations of *P. cicercula* from Polynesia.

In Heiman (2008d) distribution of *P. cicercula* and *P. margarita* is compared based on 69 publications and it is shown that the latter is always found within the range of distribution of *P. cicercula*. In Heiman (2008e) shell characters of the latter two species are compared and a conclusion is drawn that conchologically *P. margarita* may be a smooth form of *Pustularia cicercula*. This conclusion is based on the conchological practice showing that shells of *P. cicercula* may be not only distinctly granulated as in Figs. 2-5 or smooth as in Figs. 6-9; they may be partly granulated as in Figs. 10-13. A number of granules may be from one to many and it worth to pay attention on this diagnostic character when intraspecific variation in *P. cicercula* is studied.



10-13. *Pustularia cicercula*, 18-19.5 mm, Lau Lau Beach, North Saipan Island; a form with a reduced number of granules; such shells with practically smooth dorsum are often treated as *P. margarita*

After one accepts that *P. margarita* is a smooth form of *P. cicercula*, a question may arise: what is now the taxonomic identity of different populations of *P. cicercula* after smooth shells, which were earlier treated as *P. margarita*, should be taken into consideration.

Conchological method

In this study a conchological method is the same as in all the previous works by the present author: cowry populations of a species are compared by their statistical shell characteristics. As many as possible shells should be used; 298 shells are considered in this study.

A taxonomic level of different populations of a species depends on their shell characteristics.
If the majority of shells (68% or more) in a population differs from shells of the other populations of the same species by at least one shell character (the shell size, shape, profile, teeth, presence or absence of the dorsal granules and so forth) this fact is a characteristic of a subspecific level.
It is assumed also that populations of a subspecific level must be separated geographically from the other populations of the species.

This approach was suggested in general in early works by E. Mayr (explained, for example, in Mayr (2000)) and the Schilders applied it for Cypraeidae.

Comparing shell characters

Batches of shells belonging to different populations of *P. cicercula* are compared below using the following shell characters:

--the shell length and width;
--the shell profile—convex or humped;
--presence or absence of dorsal granules (if 0 the dorsum is smooth);
--a shape of the columellar teeth-they may be long almost reaching the margins, or they may be short or even absent in the middle of the base.

Other shell characters were also taken into consideration but turned out to be of no help in an attempt to find a difference between the populations compared.
Shell characters of representative batches of shell of different populations of *P. cicercula* are given in Table 1.

Table 1

shell characteristics→ area ↓	Lav, mm	W/Lav, %	N of shells having dorsum without granules, %	N of shells with short columel-lar teeth, %	N of shells with humped profile, %
Western Indian Ocean N=31	16	62	19	64	61
Madagascar N=103	-	-	21	-	-
Thailand N=29	18	62	0	21	21
PhilippinesN=33	17	61	30	54	36
Guam N=22	16	59	9	45	77
Pacific Ocean N=29	18	61	3	69	34
French Polynesia N=51	**12**	**57**	**47**	**98**	**96**

Notes (N-number of shells):
1. Shells of the Western Indian Ocean include: 8 from Elat, 12 from Zanzibar, 6 from Mozambique, 3 from Reunion, and 2 from South Africa.
2. For Madagascar we cite a work by Blöcher (1981).
3. 29 shells of Thailand are from Phuket I.
4. 29 shells from the Pacific Ocean include: 7 from North Saipan I. (Mariana Is.), 3 from Guam (not included in another batch received later), 4 from Kwajalein Atoll, 4 from the Hawaiian Islands, 3 from Solomon Is., 1 from Vanuatu, and 7 from New Caledonia.
5. Shells from French Polynesia include 10 from Tuamotu Archipelago and 41 from Tahiti and near-by area.

The data of 195 shells examined in the collections of the Hebrew University of Jerusalem (HUJ), the Tel-Aviv University (TAU), and the present author show that in about 61% of shells from the western Indian Ocean the dorsum is humped; the dorsal granules can be seen in the majority of shells (81%), and the central columellar teeth are short in 64% of shells.
The percentage of smooth shells corresponds with the data in a work by Blöcher (1981).

Shells from Thailand and the western Indian Ocean are similar in length and the relative width but they have mostly convex and granulated dorsum and mostly long columellar teeth.

In populations from the Philippines and other areas of the western Pacific Ocean the shell length and the relative width are similar and there is a small difference in other characters.

Shells from French Polynesia differ from shells of the other populations mentioned above by all given characteristics; the difference is especially substantial regarding the shell length. Besides, most of shells from Polynesia are humped, and have the short teeth in the middle of the columellar lip. The percentage of smooth shells is also higher.

Shell characteristics of *P. cicercula* can be found also in several previous works of students of cowries and these data are compared with our measurements and calculations. The results are given in Table 2.

Table 2
Quantitative shell characteristics of populations of *P. cicercula*

sources	Indian Ocean		Pacific Ocean	
	Lav, mm	(W/L), %	Lav, mm	(W/L), %
Schilder & Schilder (1938)	17, 16	59, 62	**13**	**60**
Schilder & Schilder (1952)	16, 17	59, 62	**13**	**60**
Schilder & Schilder (1966)[2]	16	-	**12**	-
Schilder (1967) W. Australia[2]	16	62	**12**	**61**
Cate (1964)	16.2-19	-	-	-
Cate (1967) Okinawa	-	-	14.5-18.9	-
Cate (1970) Guam	-	-	15.6-20	
Salvat Rives (1975) Fr. Polynesia	-	-	10-16 (**14**), (**11**)	-
Richard & Hunon (1991) Fr. Polynesia	-	-	**8-16**	-
Lorenz (1999)	17-20	-	10-16	-
Okutani (2000) Japan	-	-	<15-20 (17.5)	-
Dharma (2005) Indonesia	10-19	-	-	-
Ikeda, Omi, & Hirota (2007) Japan	-	-	12.3-23 (16)	-
Moretzsohn (2007) Hawaii	17.7 not Hawaii	61	16	59
The current study gives for populations from French Polynesia: the standard deviation for Lav is 1.7 mm, for (W/L)av it is 0.08.			**12**	**56**

Notes:
1. The average data are given in brackets; the data relevant to French Polynesia are given in bold letters.
2. The Schilders examined a total of shells 445 *P. cicercula* and 381 shells of *P. margarita*.
3. Richard & Hunon (1991) examined 75 shells of the species from Tuamotu Archipelago and 15 from Society Is. (Tahiti).

The main information is present in the works by the Schilders because they examined hundreds of shell of *P. cicercula*. So it can be accepted that Lav for the populations of the Indian Ocean is 16-17 mm (16.5 mm). If one accepts the standard deviation for this parameter 2 mm, the range of the shell length for the majority of shells (68%) in the western group of populations can be estimated as Lav ± S or 14.5-18.5 mm. For 95% of shells this range will be 12.5 -20.5 mm
The shell length range for populations of French Polynesia is estimated in this study as follows:

For the majority of shells (68%) it is 10.3-13.7 mm and for 95% of shell it is 8.6-15.4 mm.

One can see that the expected maximal length of the majority of shell in the Polynesian populations-13.7 mm-is less than the minimal length of the majority of other populations of the species; this is a substantial difference. Only large to giant shells of the Polynesian populations may be of the same size as small and dwarf shells of the other populations of the species. The probability of such an event can be estimated as about 0.026. The difference in the shell length is in this case a good diagnostic characteristic of a subspecific level.

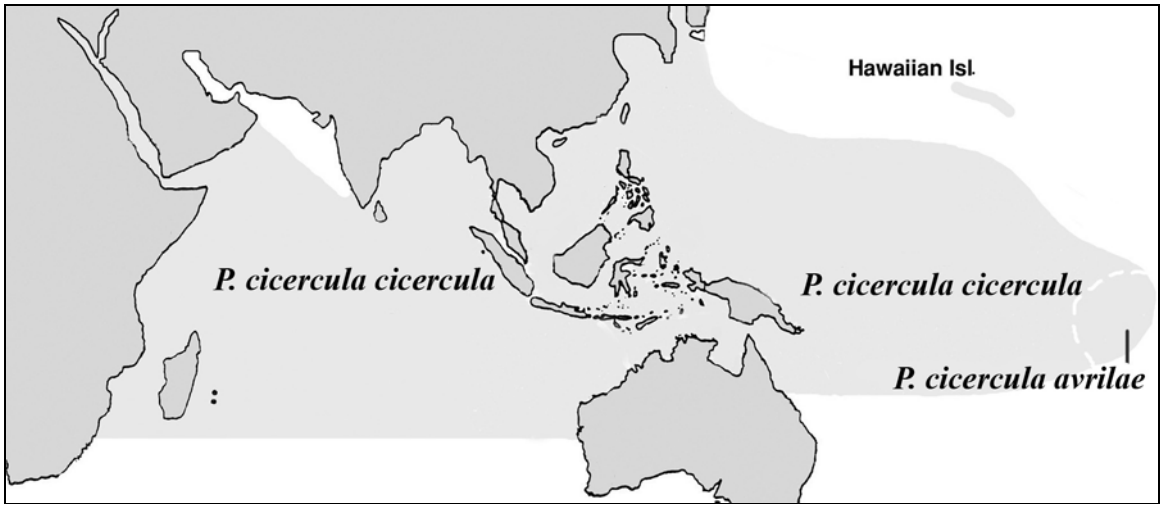
Compatibility of the shell characteristics given in Tables 1-2 with shell information available from other sources is checked and confirmed by using pictures and descriptions given in conchological works listed in section Literature below (not mentioned in Table 2), in Heiman (2008d), and on different web sites of the Internet.

Nomenclatural question

Schilder (1966a) studied cowry shells belonging to the collection of C. Linnaeus preserved in the Cabinet of the Linnean Society of London and mentioned that one of these shells—the neotype (no label)—is *Pustularia bistrinotata* Schilder & Schilder (1937). "The dorsal blotches of the bleached neotype are very pale so that they evidently escaped Linnaeus' observation, and he did not mention them in the description and quoted a figure of *staphylaea* which also has an unspotted dorsum; but Hanley (1855, p. 198) possibly noticed the dorsal spots, as he referred *cicercula* to an illustration of Sowerby (1836) which shows the dorsally spotted *bistrinotata*. Therefore, in future *bistrinotata* should be called *cicercula*, and the granulated unspotted whitish *cicercula* of various authors should be called *lienardi* (Jousseaume, 1874)."

However, this approach was not accepted in the malacological practice and even Schilder & Schilder (1971) did not follow their own suggestion and listed *lienardi* as a synonym of *cicercula*.

Conclusions

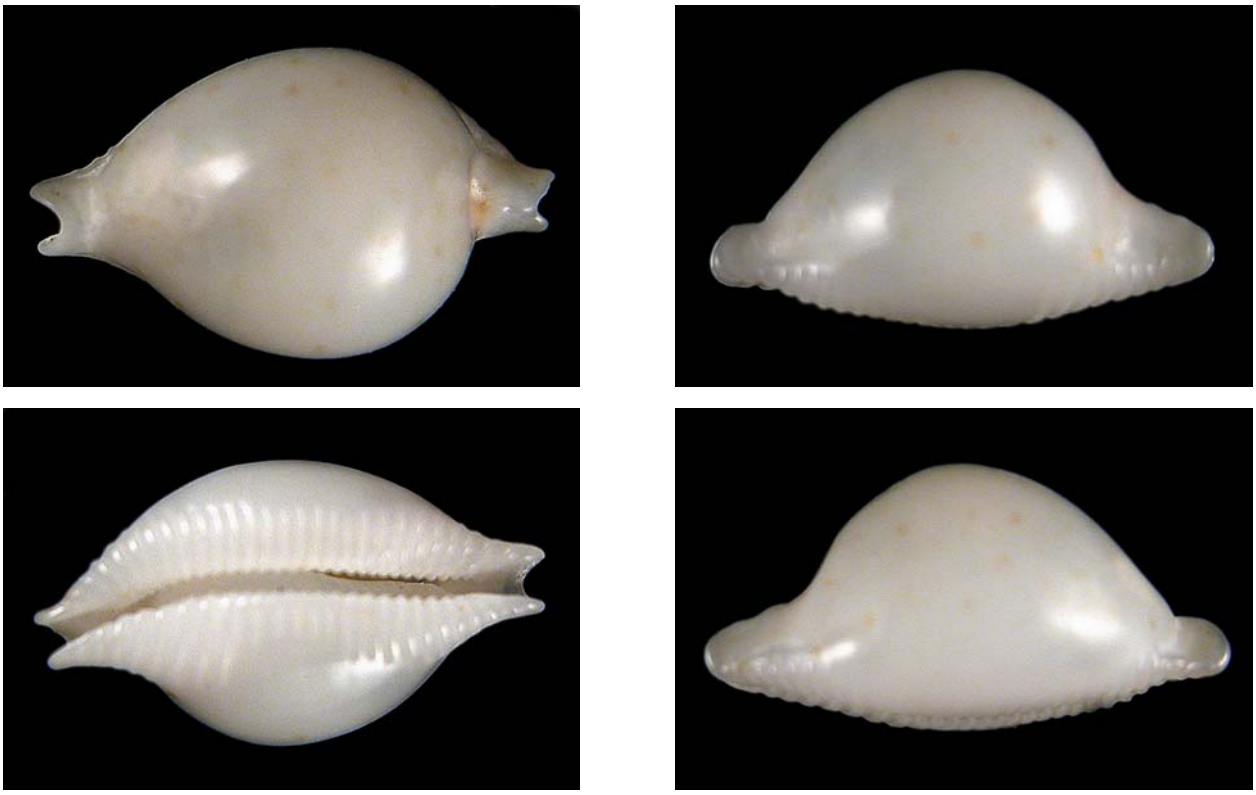


14. New distribution range of *P. cicercula* including the smooth form

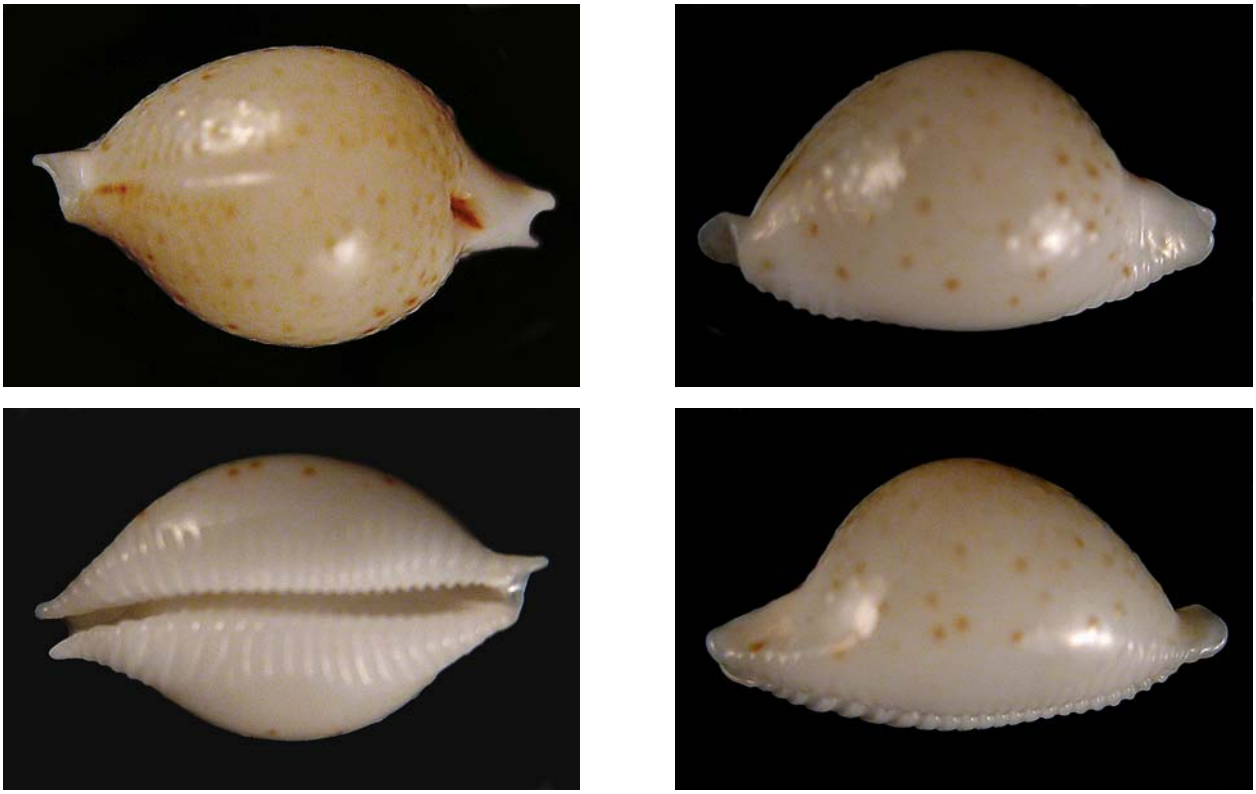
At least three groups of populations of *P. cicercula* can be separated by their statistical shell characteristics as can be seen in Fig. 14:

1. The western group from the Indian Ocean and the Western and Central Pacific Ocean.

2. The eastern group from the French Polynesia. Shells of this group are much smaller and their mostly humped dorsum is almost smooth with only a few granules sometimes present at the extremities and sides. Examples of the shells of this group can be seen in Figs. 15- 26.
Based on the current study this group of populations is described in Triton 19 as a new subspecies: *P. cicercula avrilae*.



15-18. *P. cicercula*, 13.5 mm, French Polynesia, Tuamotu, Fakarava Atoll



19-22. *P. cicercula*, 13.7 mm, French Polynesia, Tuamotu, Takapoto Atoll

23-26. *P. cicercula*, 18.6 and 16.5 mm, the Hawaiian Islands, Maui

3. The third group of populations is already described as a subspecies *P. cicercula takahashii* Moretzsohn, 2007.

My impression based on the original description of *P. cicercula takahashii* and examining a small batch of shells from that area is that populations of the species from the Hawaiian Islands—Figs. 23-26—can be related to the intermediate zone between the two groups mentioned above and have mixed shell characteristics. This is my only preliminary impression; the taxonomic identity of the Hawaiian populations of the species will be studied in the future, when a conchological material needed for such a study will be available.

Figs. 10-13 are an example of shell with mixed characters: almost smooth large shells with several small granules hardly visible.

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