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A Study on Thecate Dinoflagellates in the Neritic Ecosystems of Korea

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Abstract - Dinoflagellates were investigated from the coastal waters of Korea. The total 100 thecate dinoflagellates taxa, comprising of 93 species five varieties and two forms were identified, which were attributed to four orders nine families, 13 genera in Korean coastal waters. 22 species, two varieties and two forms were new to Korean waters. *Ceratium arcticum, C. longirostrum, C. praelongum, C. tripos* var. *ponticum, Gonyaulax jollifei, G. pavillardii, Protoperidinium cassum cassum, P. conicum* f. *asamushi, P. depressum* var. *parallelum, P. elegans* f. *granulatum, P. globifera, P. incognitum, P. majus, P. mite, P. obtusum, P. pallidum daedalum, P. parvum, P. perplexum, P. pyriforme pyriforme, P. pyrum, P. sphaeroides, P. subsphericum, P. valgus, P. venustum, Diplopsalopsis orbicularis, Gotoius abei* were new record species for Korea.

Key words : dinoflagellate, new record species for Korea

INTRODUCTION

Recent outbreaks of red tides have increasingly been large scale and widespread with long periods and densities. The dinoflagellate as a group of significant red tide organism was classified by Schiller (1933, 1937) in his comprehensive volumes on the Dinoflagellata, including all known marine and freshwater dinoflagellates. Subsequently, other taxonomic works of significance have been published in Japan (Abe 1936, 1967, 1981), England (Dodge 1981, 1985), and most prolifically for the South Atlantic and Antarctic by Balech (1976, 1980).

In the following years, electron microscopy has revealed internal and external structures not previously observed or suspected for the Dinophyceae. Abe (1967) and Balech (1959) were among the first to stress sulcal plate tabulations for generic differentiation. Since then several new genera and species have been transferred or named on this basis. Although sulcal plate distinction is necessary for a complete description, many ask the question, of whether it is so specific and without variation that it necessitate a position as a separating character? For example, the sulcus is probably where ingestion takes place, with pseudopodia or extended pusule, through a pore or dispensable plate.

As a rule, morphological criteria are sufficient to classify the dinoflagellate species. From examinations of thousands of specimens, conservative versus variable morphological characters are known for dinoflagellates. In armoured dinoflagellates, the plate patterns provide useful characters for species determination (Taylor 1993).

The first known description of the dinoflagellate in the seas surrounding Korea was made by Yamada (1933). He reported the distribution of the temperate plankton in the western part of the Korean Strait. He reported *Ceratium* sp. for the first time in Korea. After that Park (1956a, b) reported the seasonal changes of phytoplankton in the Korean Strait, as well as the quantity and composition of

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plankton in summer in the southern sea of Korea.

Yoo (1960, 1962) studying the phytoplankton species composition as a part of his study on the food of bivalve mollusks in Suyong (Soo-Young) bay, recorded for the first time in Korea, *Dinophysis* sp. and *Prorocentrum* sp.

Afterward, various aspects on phytoplankton in the coastal waters of Korea have been studied. Park and Kim (1967) reported *Gymnodinium* sp. and *Noctiluca* during their study on the red tide caused in Jinhae bay. Choe (1967, 1969) have comprehensively reported a quantitative and qualitative phytoplankton study incompassing three areas of Korean coastal waters. In this study Choe (1967) reported *Pyrophacus* sp. for the first time in Korea. Some studies on the phytoplankton communities of the Kum River estuary have been described by Kim and Cho (1970), and they reported *Glenodinium foliaceum*.

Microscopical taxonomic studies on the dinoflagellates were carried out by Shim *et al.* (1981) and Han (1981) for the first time in Korea. Shim *et al.* (1981) recorded two families, 3 genera, and 32 species as new records for the Korean coastal waters. At the same time, Han (1981) reported *Prorocentrum minimum, P. triestinum, Oxyphysis oxytoxoides, Gymnodinium pseudonoctiluca, Dissodinium pseudolunula, Peridinium minisculum* and *P. marielebouriae* as new records for the Korean waters.

Han and Yoo (1983a, b) also carried out taxonomical study on the dinoflagellate in Jinhae bay. The study identified 36 species representing 16 genera. Of them *Dinophysis acuminata, Oxyphysis oxytoxoides, Amphidinium lonum, Diplopsalis pilula, Heterocapsa triquetra, Protoperidinium achromaticum, P. bipes, P. subinerme, Gonyaulax grindleyi, G. triacantha, G. verior, Triadinium orientale*, and *Spatulodinium pseudonotiluca* were new records for Korea. Those researches were carried out with light microscopy. Later using scanning electron microscopy, *Prorocentrum* genus was identified (Lee 1987). Lee (1987) investigated the distribution of dinoflagellate cysts in Masan Bay.

Taxonomical studies on the dinoflagellates in the coastal waters of Korea from 1930 to 1984 were reviewed by Lee and Cho (1985). They classified 5 orders, 19 families, 27 genera, 147 species, 14 varieties and 4 forms were presented. Lee and Yoo (1990) investigated the dynamics and seasonal succession of dinoflagellate community, in this study 4 species were new to Korea. Shim (1994) summarized taxonomic studies on the phytoplankton in the coastal waters of Korea from the early study of 1910's to 1994. In this work, he reviewed the dinoflagellates, classifying five orders 18 families, 26 genera, 115 species and five varieties, two forms.

The authors have already reported the morphological characteristics of the genera *Goniodoma, Dinophysis* and *Prorocentrum* (Shin *et al.* 2004a, b, 2005) from the samples of this study. The present paper includes total species list of the dinoflagellates in Korean coastal waters.

MATERIALS AND METHODS

There were formalin preserved samples from total 17 locations which were shown at the previous studies (Shin *et al.* 2004a, b, 2005), near coastal areas of Korea, from 1990 to 2002. These were net samples of Seoul National University, marine plankton lab. Another material from Jinhae Bay and Masan were Lugol preserved quantitative samples which were given by Coastal Ecosystem Research Lab, KORDI.

1. Light microscope with DIC and with fluorescence

This monograph is the result of the microscopic analysis. Identification of dinoflagellates in water samples is usually best done by using differential interference contrast (DIC), which reveals especially well lighted thecal structures. The microscope was equipped out on a Zeiss Axioskop microscope with a Mc 80 microphotosystem. The observed cell either has chlorophyll or no chlorophyll, a Zeiss epifluorescence system with a number 09 filter. Phytoplankton species were examined microscopically in the living state.

2. Scanning electron microscopy

Electron microscopy gives an apparent three-dimensional image with only one of the surfaces revealed for scanning electron microscopy, fixed materials were used. The materials were filtered gently onto a Nucleopore filter (pore diameter 1 μm), and filters were rinsed with 100 mL of distilled water to remove salt crystals, and then air-dried. For scanning electron microscopy, filters were mounted on aluminum stubs, coated with gold and examined with a JEOL JSM-840A SEM.

RESULTS AND DISCUSSION

Dinoflagellates were investigated from the coastal waters of Korea. In thecate dinoflagellates, the thecal plate pattern has been considered to be important criteria in their classifications. Due to this fact the shape of the theca and the arrangement of the theca were studied.

When every species of the samples were observed, it was obvious that so many varieties of species existed. It is well known that the primitive subgenus *Archaeoperidinium* differs from those of the subgenus *Protoperidinium* by the possession of only two anterior intercalary plates. A species of *Archaeoperidinium, Protoperidinium valgus* was discribed by Abe (1981), but he failed to comment it having two anterior intercalary plates. In actual detailed study for the thecal pattern is necessary. Detailed inspection of epithecal pattern would greatly aid in classifying *Protoperidinium* species.

The aim of this work is to refine current ideas on dinoflagellates from the Korean coastal waters. Looking at previous Korean studies, it is a wonder that so much of *Protoperidinium divergence* were observed. These species which were rare in my samples were frequently recorded in several locations. And a species which was abundant, *Protoperidinium venustum*, had no record in previous Korean studies. It suggests that these abundant species were misidentified as *Protoperidinium divergence*. Due to the similarity in their cell shapes, this misidentification is very likely. *Protoperidinium venustum* have a longer apical horn and two longer antapical horns.

During the time when authors observed Yosu coastal waters in 1980, reference such as Dodge (1982) and Abe (1981) were not available for *Protoperidinium obtusum*. The only reference available of this species was Schiller's (1937) description. The unavailability of other references may have been another factor in this misidentification. In Korean coastal waters, *Protoperidinium obtusum* is observed frequently, several workers may have made a similar misunderstanding for this species, perhaps this is why this particular species is new to Korea.

Another problem of Korean coastal waters' records is *Protoperidinium subinerme*, recorded once in Jinhae bay (Han 1981). This species was also frequently observed in Korean coastal waters.

Family Triadiniaceae and Heteroaulaceae are same Family. Though these two names are mere synonyms, a few researchers recorded then to be two diffenent families. Following this mistake, Dodge (1981) attributed the same genus *Heteroaulacus* and *Goniodoma* to be different genus. Due to their lack in experience and specialty. Such mistake could be easily made. Another factor contributing to such mistake is the similarity in the corresponding names. The presence or absence of chloroplasts, coupled with subtle morphological distinctions, has now been widely accepted as a feature of generic significance in the dinoflagellates *Peridinium* and *Protoperidinium* (Balech 1980).

Phylogeny of the dinophysoids from the paper of Hallegraeff and Lucas (1988), they suggested that *Dinophysis* genus evolved from the simplest form, like *Dinophysis parvula*, which has only small girdle list and sulcal list. From *Dinophysis parvula* evolved into three different ways. The first is cell body development and sulcal list and also girdle list development. The second is excessive development of sulcal lists and girdle lists. The third is the fact that the cell body was getting bigger. In *Phalacroma sphaeroideum* absent of sulcal list and girdle lists, this species might have been more primitive form than *Dinophysis parvula*.

As a result, 100 taxa, comprising 93 species five varieties and two forms were identified, which can be attributed to four orders nine families, 13 genera (Appendix). This taxonomic classification is mainly based on Taylor's classification (1987). A detailed information for the genus were followed that of Taylor (1976). Detailed species informations were taken from Abe's (1936, 1967, 1981) and Balech's (1959, 1963, 1976, 1980, 1989) classification. To identify the genus *Protoperidinium*, the shape of the first apical plate and the second anterior intercalary plate were used. From this point of view, genus *Protoperidinium* was classified.

CONCLUSION

From this study 100 dinoflagellate taxa, comprising of 93 species five varieties and two forms were identified, which were attributed to four orders, nine families and 13 genera. Among these 22 species and two varieties two forms are new to Korean coastal waters.

This study dealt only with thecate dinoflagellates, because

of the lack of unarmored dinoflagellates at the fixed samples. It is necessary to study the unarmored group while they are alive.

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Appendix Dinoflagellate species observed in this study (* : New record species for Korea)

DIVISION PYRROPHYTA
CLASS DINOPHYCEAE
Order Prorocentrales
Family Prorocentraceae
Genus *Prorocentrum*
Prorocentrum balticum
Prorocentrum compressum
Prorocentrum concavum
Prorocentrum gracile
Prorocentrum lima
Prorocentrum micans
Prorocentrum minimum
Prorocentrum triestinum
Order Dinophysiales
Family Dinophysiaceae
Genus *Dinophysis*
Dinophysis acuminata
Dinophysis caudata
Dinophysis dens
Dinophysis fortii
Dinophysis infundibulus
Dinophysis irregulare
Dinophysis lapidistrigiliformis
Dinophysis mitra
Dinophysis parvula
Dinophysis rapa
Dinophysis rotundata
Genus *Phalacroma*
Phalacroma sphaeroideum
Family Amphisoleniaceae
Genus *Oxyphysis*
Oxyphysis oxytoxoides
Order Gonyaulacales
Family Ceratiaceae
Genus *Ceratium*
* *Ceratium arcticum*
Ceratium breve
Ceratium breve var. *parallelum*
Ceratium candelabrum
Ceratium furca
Ceratium fusus var. *seta*
Ceratium gibberum
Ceratium inflatum
Ceratium lineatum
Ceratium longipes
* *Ceratium longirostrum*
Ceratium macroceros
Ceratium massiliense
Ceratium platycorne
* *Ceratium praelongum*
Ceratium pulchellum
Ceratium ranipes
Ceratium tripos tripos
* *Ceratium tripos* var. *ponticum*
Ceratium tripos var. *alaniticum*
Family Gonyaulacaceae
Genus *Gonyaulax*
Gonyaulax diegensis
Gonyaulax digitale
Gonyaulax grindley
* *Gonyaulax jollifei*
* *Gonyaulax pavillardii*
Gonyaulax polygramma
Gonyaulax spinifera
Gonyaulax verior
Genus *Lingulodinium*
Lingulodinium polyedrum
Family Pyrophaceae
Genus *Pyrophacus*
Pyrophacus horologium
Family Triadiniaceae
Genus *Goniodoma*
Goniodoma orientale
Goniodoma polyedricum
Goniodoma sphaericum
Order Peridiniales
Family Podolampadaceae
Genus *Podolampus*
Podolampus spinifera
Family Protoperidiaceae
Genus *Protoperidinium*
Subgenus *Archaeoperidinium*
Protoperidinium minutum
* *Protoperidinium valgus*
Subgenus *Protoperidinium*
Group orthoperidinium
Section conica
Protoperidinium conicum
* *Protoperidinium conicum* f. *asamushi*
Protoperidinium latissimum
Protoperidinium marielebourae
Protoperidinium mazenaueri
* *Protoperidinium obtusum*
Protoperidinium pentagonum
Protoperidinium punctulatum
Protoperidinium somma
Protoperidinium subinerme
Section oceanica
Protoperidinium claudicans
Protoperidinium depressum
* *Protoperidinium depressum* var. *parallelum*
Protoperidinium elegans
* *Protoperidinium elegans* f. *granulatum*
Protoperidinium murrayi
Protoperidinium oblongum
Protoperidinium oceanicum
* *Protoperidinium venustum*
Group metaperidinium
Section meta (5) globula
* *Protoperidinium majus*
* *Protoperidinium sphaeroides*
* *Protoperidinium globifera*
Section meta (5) unipes
* *Protoperidinium cassum cassum*
Protoperidinium cerasus
* *Protoperidinium incognitum*
* *Protoperidinium perplexum*
Protoperidinium pyriforme
* *Protoperidinium pyriforme pyriforme*
* *Protoperidinium pyrum*
Section meta (5) hexa
Protoperidinium curvipes
Section meta (4)
Protoperidinium brochi
Protoperidinium crassipes
Protoperidinium divergence

Appendix Continued.

*	*Protoperidinium parvum*		*Protoperidinium pellucidum*
	Group paraperidinium		*Protoperidinium spinulosum*
	Section para (4)	*	*Protoperidinium subsphericum*
	Protoperidinium granii		Genus *Diplopsalopsis*
*	*Protoperidinium mite*	*	*Diplopsalopsis orbicularis*
	Protoperidinium pallidum	Genus	*Gotoius*
*	*Protoperidinium pallidum daedalum*	*	*Gotoius abei*