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〈Original article〉

New Records of Five Unarmored Genera of the Family Gymnodiniaceae (Dinophyceae) in Korean Waters

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Abstract – An investigation focusing on the unrecorded and taxonomically undescribed indigenous has been done since 2006. Samples were collected from various sites in the coastal and offshore waters of Korea as well as around Jeju Island. Since 2008, 16 unrecorded species belonging to the family Gymnodiniaceae have been found. The species were as follows: *Amphidinium thermaeum* (2015), *Cochlodinium convolutum* (2015), *C. strangulatum* (2015), *Gymnodinium abbreviatum* (valid name: *G. gracile*), *G. arenicola* (2015), *G. gracile* (2015), *G. dorsalisulcum* (2015), *G. microreticulatum* (2014), *G. micrum* (2016) (valid name: *Karlodinium micrum*), *G. pyrenoidosum* (2016), *G. simplex* (2015), *G. veneficum* (2016) (valid name: *Karlodinium veneficum*), *Gyrodinium aureum* (2015), *G. fusiforme* (2015), *G. dominans* (2014), and *Nusuttodinium latum* (2016) (valid name: *Amphidinium latum*). (The numbers in parentheses refer to the year that the species was found). These species were newly recorded in Korean waters in this study.

Key words : *Amphidinium*, *Cochlodinium*, Gymnodiniaceae, *Gymnodinium*, *Gyrodinium*, *Nusuttodinium*

INTRODUCTION

Dinoflagellates are one of the major groups in the phytoplankton community and they are divided into armored and unarmored species (Dodge 1982). Although many ecological studies have been conducted, many dinoflagellate taxa are still yet to be recorded in Korean waters. The unarmored dinoflagellates, especially, which mostly belong to the family Gymnodiniaceae, are very difficult to identify with merely a light microscope; so, many species in this family have been treated as unidentified by ecological researchers.

Recently, red tides have been occurring frequently on the southern coast of the Korean peninsula. The causative organisms of the red tides include many unarmored dinoflagellates such as *Cochlodinium* spp. (Lim *et al*. 2015). In addition, the water temperature around Jeju Island has been increasing due to climate change caused by global warming and the diversity of the species in the area is changing as well due to the introduction of alien species (Jeong *et al*. 2012). We observed many tropical/subtropical planktonic species from the coastal waters of Korea and from offshore Jeju Island (Kim *et al*. 2013). Some benthic unarmored dinoflagellates from the tidal zone were reported by Shah *et al*. (2013). To date, a total of 133 species in the family Gymnodiniaceae from Korean waters have been reported by previous studies (Han and Yoo 1983; Lee and Yoo 1991; Shim 1994; Cho *et al*. 2008; Kang *et al*. 2013; Shah *et al*. 2013; Lee and Kim 2015; Shin 2016). Lee and Kim (2015) listed 65 species and Shin (2016) described 70 species in this family from Korean waters. However, in-depth information on the taxonomy, distribution, diversity, and molecular phylogeny of unarmored dinoflagellates from Korean waters should be collected. Thus, the aim of this study was

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to find unrecorded and new species of dinoflagellates from Korean waters as part of a project called "Survey and Excavation of Korean Indigenous Species" of the National Institute of Biological Resources (NIBR). In this study, we describe sixteen unarmored dinoflagellates belonging to five genera (i.e. *Amphidinium*, *Cochlodinium*, *Gymnodinium*, *Gyrodinium* and *Nusuttodinium*) as newly recorded species to Korean waters.

MATERIALS AND METHODS

Samples were collected at the coastal stations mentioned in Shah *et al*. (2013) and Lee *et al*. (2014) around Jeju Island and the East China Sea between 2006 and 2016. The plankton samples were obtained using a 20-μm-mesh plankton net and then fixed with formaldehyde (final concentration of about 1%) or glutaraldehyde (final concentration of about 1%). The planktonic dinoflagellates were identified by a light microscope (Axioplan; Carl Zeiss, Oberkochen, Germany). To make the slide specimens for one species, the dinoflagellate samples were washed with distilled water and then the method described by Kim *et al*. (2013) was followed. To allow for more detailed observations, the dinoflagellate cells were isolated with a micropipette, placed on a cover slip, air-dried and then coated with gold for observation under a field emission scanning electron microscope (JSM-6700F; JEOL, Tokyo, Japan).

To identify each species, several monographs reported from different oceans, such as the Indian Ocean (Taylor 1976), Japan's adjacent sea (Yamaji 1984), the British and Atlantic Ocean (Dodge 1982), the Kuroshio Current (Fujioka 1990), Korean waters (Shim 1994), and Gulf of Mexico (Okolodkov 2014) were used. A dinoflagellate classification for the new combinations of the family Gymnodiniaceae was cited from AlgaeBase (http://www.algaebase.org) (Guiry and Guiry 2017).

RESULTS AND DISCUSSION

A total of 133 species of 23 genera (i.e. *Akashiwo*, *Amphidinium*, *Ankistrodinium*, *Balechina*, *Barrufeta*, *Ceratoperidinium*, *Cochlodinium*, *Cucumeridinium*, *Gymnodinium*, *Gyrodiniellum*, *Gyrodinium*, *Karlodinium*, *Karenia*, *Lebouridinium*, *Levanderina*, *Margalefidinium*, *Nusuttodinium*, *Paragymnodinium*, *Polykrikos*, *Testudodinium*, *Togula*, *Prosoaulax*, *Spatulodinium*) belonging to the family Brachidiniaceae, Ceratoperidiniaceae, Gymnodiniaceae, Suessiaceae and Noctilucaceae from Korean waters were identified (Table 1) and classified as below. Among them, 16 species are described in this paper as newly recorded and re-described species in the Korean waters and are marked with asterisks (*) and sharps (#), respectively. The abbreviations, which are based on the species database of AlgaeBase (Guiry and Guiry 2017), are as follows: 'C' indicates a currently accepted name, 'S' a synonym, 'P' a preliminary AlgaeBase entry, and 'U' a name of an uncertain taxonomic status.

Systematics of the family Gymnodiniaceae from the Korean waters

Class Dinophyceae Fritsch in West et Fritsch
- Order Gymnodiniales Apstein
  - Family Brachidiniaceae Sournia
    - Genus *Karlodinium* Larsen
      - *Karlodinium veneficum* (Ballantine) Larsen C
        - = **Gymnodinium micrum* (Leadbeater et Dodge) Loeblich III S
        - = **Gymnodinium veneficum* Ballantine S
    - Genus *Karenia* Hansen et Moestrup
      - *Karenia brevis* (Davis) Hansen et Moestrup C
        - = *Gymnodinium breve* Davis S
  - Family Ceratoperidiniaeceae Loeblich III
    - Genus *Ceratoperidinium* Margalef ex Loeblich III
      - *Ceratoperidinium falcatum* (Kofoid et Swezy) Reñé et Salas C
        - = *Gyrodinium falcatum* Kofoid et Swezy S
  - Family Gymnodiniaceae Lankester
    - Genus *Akashiwo* Hansen et Moestrup
      - *Akashiwo sanguinea* (Hirasaka) Hansen et Moestrup C
        - = *Gymnodinium splendens* Lebour S
    - Genus *Amphidinium* Claperède et Lachmann
      - *Amphidinium acutissimum* Schiller C
      - *Amphidinium carterae* Hulburt C
      - *Amphidinium corpulentum* Kofoid et Swezy C

Table 1. Checklist of the family Gymnodiniaceae in Korean waters (newly recorded and re-described species are marked with asterisks (*) and sharps (#) in this study, and 'n' indicates a species newly recorded in Korean waters by other researches and 'f' a species recorded only in floristic lists (Lee and Kim 2015), and 'syn' a synonym, respectively)

Species name	Han and Yoo (1983)	Lee and Yoo (1991)	Shim (1994)	Cho *et al*. (2008)	Kang *et al*. (2010, 2014)	Shah *et al*. (2013)	Lee and Kim (2015)	Shin (2016)	Present Study
Karlodinium veneficum = syn. **Gymnodinium micrum*									●
Karlodinium veneficum = syn. **Gymnodinium veneficum*									●
Karenia brevis = syn. *Gymnodinium breve*[n]								●	
Ceratoperidinium falcatum = syn. *Gyrodinium falcatum*[f]							●		
Akashiwo sanguinea = syn. *Gymnodinium splendens*	●		●	●			●	●	
Amphidinium acutissimum[f]							●		
Amphidinium carterae						●	●		
Amphidinium corpulentum[f]							●		
Amphidinium crassum			●				●		
Amphidinium flexum[f]							●		
Amphidinium fusiforme[f]							●		
Amphidinium gibbosum						●	●		
Amphidinium globosum[f]							●		
Amphidinium herdmanii						●	●		
Amphidinium incoloratum						●	●		
Amphidinium inflatum[f]							●		
Amphidinium kesslitzii[f]							●		
Amphidinium longum	●		●				●		
Amphidinium massartii						●	●		
Amphidinium mootonorum						●	●		
Amphidinium operculatum						●	●		
Amphidinium ovum[f]							●		
Amphidinium scissum						●	●		
Amphidinium stenii						●	●		
Amphidinium stigmatum[f]							●		
**Amphidinium thermaeum*									●
Amphidinium trulla						●	●		
Ankistrodinium semilunatum = syn. *Amphidinium semilunatum*[n]								●	
Balechina pachydermata = syn. *Gymnodinium dogielii*[n]								●	
Barrufeta resplendens = syn. *Gyrodinium resplendens*[n]								●	
Cochlodinium archimedes[n]								●	
Cochlodinium brandtii[n]								●	
Cochlodinium conspiratum[n]								●	
**Cochlodinium convolutum*									●
Cochlodinium faurei[n]								●	
Cochlodinium helicoides							●	●	
Cochlodinium pulchellum[n]								●	
Cochlodinium pupa[n]								●	
Cochlodinium radiatum[n]								●	
Cochlodinium schuettii[n]								●	
**Cochlodinium strangulatum*									●
Cochlodinium virescens[n]								●	
Cucumeridinium lira = syn. *Gymnodinium lira*[n]								●	
Gymnodinium arcuatum[f]							●		

Table 1. Continued

Species name	Han and Yoo (1983)	Lee and Yoo (1991)	Shim (1994)	Cho *et al*. (2008)	Kang *et al*. (2010, 2014)	Shah *et al*. (2013)	Lee and Kim (2015)	Shin (2016)	Present Study
**Gymnodinium arenicola*									●
Gymnodinium auratum[n]								●	
Gymnodinium aureolum = syn. *Gyrodinium aureolum*							●	●	
Gymnodinium aureum[n]								●	
Gymnodinium austriacum = syn. *Gymnodinium tridenatum*[n]								●	
Gymnodinium biconicum[f]							●		
Gymnodinium bogoriense[n]								●	
Gymnodinium catenatum				●			●	●	
Gymnodinium cinctum[n]								●	
Gymnodinium coeruleum[n]								●	
Gymnodinium contractum[n]								●	
Gymnodinium diploconus[n]								●	
Gymnodinium doma[n]								●	
**Gymnodinium dorsalisulcum*									●
Gymnodinium filum[f]							●		
Gymnodinium flavum[n]								●	
Gymnodinium fuscum[f]							●		
Gymnodinium fusus[n]								●	
Gymnodinium gelbum							●		
Gymnodinium glaucum			●				●		
[#]*Gymnodonium gracile* = syn. [#]*Gymnodinium abbreviatum*			●				●		●, ●
Gymnodonium gracile = syn. *Gymnodinium lohmanni*								●	
Gymnodinium grammaticum[f]							●		
Gymnodinium heterostriatum[f]							●		
Gymnodinium impudicum[n]				●					
Gymnodinium lacustre[n]								●	
Gymnodinium lantzschii[f]							●		
Gymnodinium lineatum[n]								●	
**Gymnodinium microreticulatum*									●
Gymnodinium minor[n]								●	
Gymnodinium mirabile[n]								●	
Gymnodinium multistriatum[n]								●	
Gymnodinium ostenfeldii[n]								●	
Gymnodinium palustre = syn. *Gymnodinium carinatum*[n]								●	
Gymnodinium pulchrum[f]							●		
Gymnodinium pygmaeum[f]							●		
**Gymnodinium pyrenoidosum*									●
Gymnodinium ravenescens[n]								●	
Gymnodinium semidivisum[f]							●		
[#]*Gymnodinium simplex*							●		●
Gymnodinium situla							●	●	
Gymnodinium smaydae[n]					●				
Gymnodinium sphaericum[n]								●	
Gymnodinium sulcatum[n]								●	
Gymnodinium translucens[n]								●	
Gymnodinium uberrimum = syn. *Gymnodinium rotundatum*[n]								●	
Gymnodinium variabile[f]							●		

Table 1. Continued

Species name	Han and Yoo (1983)	Lee and Yoo (1991)	Shim (1994)	Cho *et al*. (2008)	Kang *et al*. (2010, 2014)	Shah *et al*. (2013)	Lee and Kim (2015)	Shin (2016)	Present Study
Gymnodinium venator						●	●		
Gymnodinium viride[n]								●	
Gymnodinium viridescens						●	●		
Gymnodinium wulffii						●	●		
Gyrodiniellum shiwhaense[n]							●		
Gyrodinium acutum[n]								●	
**Gyrodinium aureum*									●
Gyrodinium biconicum[n]								●	
Gyrodinium capsulatum[n]								●	
Gyrodinium corallinum[n]								●	
Gyrodinium crassum							●	●	
Gyrodinium cuneatum[n]								●	
[#]*Gyrodinium dominans*							●		●
Gyrodinium dorsum[n]								●	
Gyrodinium flavidum[n]								●	
Gyrodinium fulvum[n]								●	
[#]*Gyrodinium fusiforme*							●	●	●
Gyrodinium helveticum = syn. *Gymnodinium helvericum*[n]								●	
Gyrodinium lachryma[f]							●		
Gyrodinium maculatum[n]								●	
Gyrodinium ovoideum[n]								●	
Gyrodinium pellucidum							●	●	
Gyrodinium pepo[n]								●	
Gyrodinium prunus[n]								●	
Gyrodinium spirale			●				●	●	
Gyrodinium truncus[n]								●	
Gyrodinium virgatum[n]								●	
Lebouridinium glaucum = syn. *Gyrodinium glaucum*[f]							●		
Levanderina fissa = syn. *Gymnodinium instriatum*						●		●	
Levanderina fissa = syn. *Gyrodinium fissum*[f]							●		
Margalefidinium catenatum = syn. *Cochlodinium catenatum*[f]							●		
Margalefidinium fulvescens = syn. *Cochlodinium fulvescens*[n]								●	
Margalefidinium polykrikoides = syn. *Cochlodinium polykrikoides*							●		
Nusuttodinium aeruginosum[f]							●		
**Nusuttodinium latum*									●
Paragymnodinium shiwhaense[n]					●		●		
Polykrikos hartmannii							●	●	
Polykrikos kofoidii		●	●				●	●	
Polykrikos lebourae						●	●		
Polykrikos schwartzii		●					●	●	
Testudodinium corrugatum						●	●		
Togula britanniica						●	●		
Togula jolla						●	●		
Prosoaulax lacustris = syn. *Amphidinium lacustre*[n]								●	
Spatulodinium pseudonoctiluca = syn. *Gymnodinium lebouriae*[n]								●	
No. of species	2	2	7	3	2	18	65	70	16

Amphidinium crassum Lohmann C
Amphidinium flexum Herdman C
Amphidinium fusiforme Martin P
Amphidinium gibbosum (Maranda et Shimizu) Jørgensen et Murray C
Amphidinium globosum Schröder C
Amphidinium herdmanii Kofoid et Swezy C
Amphidinium incoloratum Campbell C
Amphidinium inflatum Kofoid C
Amphidinium kesslitzii Schiller C
Amphidinium longum Lohmann C
Amphidinium massartii Biecheler C
Amphidinium mootonorum Murray et Patterson C
Amphidinium operculatum Claparède et Lachmann C
Amphidinium ovum Herdman C
Amphidinium scissum Kofoid et Swezy C
Amphidinium stenii Lemmermann C
Amphidinium stigmatum Schiller C
**Amphidinium thermaeum* Dolapsakis et Economou U
Amphidinium trulla Murray, Rhodes et Jørgensen C

Genus *Ankistrodinium* Hoppenrath, Murray, Sparmann et Leander
Ankistrodinium semilunatum (Herdman) Hoppenrath C
= *Amphidinium semilunatum* Herdman S

Genus *Balechina* Loeblich Jr. et Loeblich III
Balechina pachydermata (Kofoid et Swezy) Loeblich Jr. et Loeblich III C
= *Gymnodinium dogielii* Kofoid et Swezy S

Genus *Barrufera* Sampedro et Fraga
Barrufeta resplendens (Hulbert) Gu, Luo et Mertens C
= *Gyrodinium resplendens* Hulbert S

Genus *Cochlodinium* Schütt
Cochlodinium archimedes (Pouchet) Lemmermann C
Cochlodinium brandtii Wulff C
Cochlodinium conspiratum Kofoid et Swezy C
**Cochlodinium convolutum* Kofoid et Swezy C
Cochlodinium faurei Kofoid et Swezy C
Cochlodinium helicoides Lebour C
Cochlodinium pulchellum Lebour C
Cochlodinium pupa Lebour C
Cochlodinium radiatum Kofoid et Swezy C
Cochlodinium schuettii Kofoid et Swezy C
**Cochlodinium strangulatum* (Schütt) Schütt C
Cochlodinium virescens Kofoid et Swezy C

Genus *Cucumeridinium* Gómez, López-Garcia, Takayama et Moreira
Cucumeridinium lira (Kofoid et Swezy) Gómez, López-Garcia, Takayama et Moreira C
= *Gymnodinium lira* Kofoid et Swezy S

Genus *Gymnodinium* Stein
Gymnodinium arcuatum Kofoid C
**Gymnodinium arenicola* Dragesco C
Gymnodinium auratum Kofoid et Swezy C
Gymnodinium aureolum (Hulburt) Hansen C
= *Gyrodinium aureolum* Hulburt S
Gymnodinium aureum Kofoid et Swezy C
Gymnodinium austriacum Schiller C
= *Gymnodinium tridenatum* Schiller S
Gymnodinium biconicum Schiller C
Gymnodinium bogoriense Klebs C
Gymnodinium catenatum Graham C
Gymnodinium cinctum Kofoid et Swezy C
Gymnodinium coeruleum Antipova C
Gymnodinium contractum Kofoid et Swezy C
Gymnodinium diploconus Schütt C
Gymnodinium doma Kofoid et Swezy C
**Gymnodinium dorsalisulcum* (Hulbert, McLaughlin et Zahl) Murray, Salas et Hallegraeff C
Gymnodinium filum Lebour C
Gymnodinium flavum Kofoid et Swezy C
Gymnodinium fuscum (Ehrenberg) Stein C
Gymnodinium fusus Schütt C
Gymnodinium gelbum Kofoid C
Gymnodinium glaucum Schiller C
[#]*Gymnodinium gracile* Bergh C
= [#]*Gymnodinium abbreviatum* Kofoid et Swezy S
= *Gymnodinium lohmanni* Paulsen S
Gymnodinium grammaticum (Pouchet) Kofoid et Swezy C
Gymnodinium heterostriatum Kofoid et Swezy C
Gymnodinium impudicum (Fraga et Bravo) Gert Hansen et Moestrup C
Gymnodinium lacustre Schiller C
Gymnodinium lantzschii Utermöhl C

Gymnodinium lineatum Kofoid et Swezy C
**Gymnodinium microreticulatum* Bolch, Negri et Hallegraeff C
Gymnodinium minor Lebour C
Gymnodinium mirabile Penard C
Gymnodinium multistriatum Kofoid et Swezy C
Gymnodinium ostenfeldii Schiller C
Gymnodinium palustre Schilling C
=*Gymnodinium carinatum* Schilling S
Gymnodinium pulchrum Schiller C
Gymnodinium pygmaeum Lebour C
**Gymnodinium pyrenoidosum* Horiguchi et Chihara C
Gymnodinium ravenescens Kofoid et Swezy C
Gymnodinium semidivisum Schiller C
#*Gymnodinium simplex* (Lohmann) Kofoid et Swezy C
Gymnodinium situla Kofoid et Swezy C
Gymnodinium smaydae Lee *et al*. C
Gymnodinium sphaericum (Calkins) Kofoid et Swezy C
Gymnodinium sulcatum Kofoid et Swezy C
Gymnodinium translucens Kofoid et Swezy C
Gymnodinium uberrimum (Allman) Kofoid et Swezy C
=*Gymnodinium rotundatum* Klebs S
Gymnodinium variabile Herdman C
Gymnodinium venator Jørgensen et Murray C
Gymnodinium viride Penard C
Gymnodinium viridescens Kofoid C
Gymnodinium wulffii Schiller C

Genus *Gyrodiniellum* Kang, Jeong et Moestrup
Gyrodiniellum shiwhaense Kang, Jeong et Moestrup C

Genus *Gyrodinium* Kofoid et Swezy
Gyrodinium acutum (Shütt) Kofoid et Swezy C
**Gyrodinium aureum* (Conrad) Schiller C
Gyrodinium biconicum Kofoid et Swezy C
Gyrodinium capsulatum Kofoid et Swezy C
Gyrodinium corallinum Kofoid et Swezy C
Gyrodinium crassum (Pouchet) Kofoid et Swezy C
Gyrodinium cuneatum Kofoid et Swezy C
#*Gyrodinium dominans* Hulbert C
Gyrodinium dorsum Kofoid et Swezy C
Gyrodinium flavidum Kofoid et Swezy C
Gyrodinium fulvum Kofoid et Swezy C
#*Gyrodinium fusiforme* Kofoid et Swezy C
Gyrodinium helveticum (Penard) Takano et Horiguchi C
=*Gymnodinium helveticum* Penard S
Gyrodinium lachryma (Meunier) Kofoid et Swezy C
Gyrodinium maculatum Kofoid et Swezy C
Gyrodinium ovoideum Kofoid et Swezy C
Gyrodinium pellucidum (Wulff) Schiller C
Gyrodinium pepo (Shcütt) Kofoid et Swezy C
Gyrodinium prunus (Wulff) Lebour C
Gyrodinium spirale (Bergh) Kofoid et Swezy C
Gyrodinium truncus Kofoid et Swezy C
Gyrodinium virgatum Kofoid et Swezy C

Genus *Lebouridinium* Gómez, Takayama, Moreira et López
Lebouridinium glaucum (Lebour) Gómze, Takayama, Moreira et López-Garcia C
=*Gyrodinium glaucum* (Lebour) Kofoid et Swezy S

Genus *Levanderina* Moestrup, Hakanen, Hansen, Daugbjerg et Ellegaard
Levanderina fissa (Levander) Moestrup, Hakanen, Hansen, Daugbjerg et Ellegaard C
=*Gymnodinium instriatum* (Freudenthal et Lee) Coats S
=*Gyrodinium fissum* (Levander) Kofoid et Swezy S

Genus *Margalefidinium* Gómez, Richlen et Anderson
Margalefidinium catenatum (Okamura) Gómez, Richlen et Anderson C
=*Cochlodinium catenatum* Okamura S
Margalefidinium fulvescens (Iwasaki, Kawami et Matsuoka) Gómez, Richlen et Anderson C
=*Cochlodinium fulvescens* Iwasaki, Kawami et Matsuoka S
Margalefidinium polykrikoides (Margalef) Gómez, Richlen et Anderson C
=*Cochlodinium polykrikoides* Margalef S

Genus *Nusuttodinium* Takano et Horiguchi
Nusuttodinium aeruginosum (Stein) Takano et Horiguchi C
**Nusuttodinium latum* (Lebour) Takano et Horiguchi C
=*Amphidinium latum* Lebour S

Genus *Paragymnodinium* Kang, Jeong, Moestrup et Shin
Paragymnidinium shiwhaense Kang, Jeong, Moestrup et Shin C
Genus *Polykrikos* Bütschli
Polykrikos hartmannii Zimmermann C
Polykrikos kofoidii Chatton C
Polykrikos lebourae Herdman C
Polykrikos schwartzii Bütschli C
Genus *Testudodinoum* Horiguchi, Tamura, Katsumata et Tamaguchi
Testudodinium corrugatum (Larsen et Patterson) Horiguchi, Tamura, Katsumata et Tamaguchi C
Genus *Togula* Jørgensen, Murray et Daugbjerg
Togula britanniica (Herdman) Jørgensen, Murray et Daugbjerg C
Togula jolla Jørgensen, Murray et Daugbjerg C

Order Suessiales Fensome, Taylor, Norris, Sarjeant, Wharton et Williams
Family Suessiaceae Fensome, Taylor, Norris, Sarjeant, Wharton et Williams
Genus *Prosoaulax* Calado et Moestrup
Prosoaulax lacustris (Stein) Calado et Moestrup C
= *Amphidinium lacustre* Stein S

Class Noctilucophyceae Fensome, Taylor, Norris, Sarjeant, Wharton et Williams
Order Noctilucales Haeckel
Family Noctilucaceae Kent
Genus *Spatulodinium* Cachon et Cachon
Spatulodinium pseudonoctiluca (Pouchet) Cachon et Cachon C
= *Gymnodinium lebouriae* Pavillard S

Taxonomic description of unrecorded dinoflagellates

Genus *Amphidinium* Claperède et Lachmann 1859

Holotype species: *Amphidinium operculatum* Claperède et Lachmann 1859.

Description: The unarmored free-living cells have various sizes that range from small to large (<10–100 μm). The cell is globular to fusiform and dorsoventrally compressed. The cingulum is situated near the anterior end of the cell and rotates around the cell more than once. The sulcus extends from the cingulum to the antapex. Some species temporarily developed cysts for reproduction purposes with the exception of resting cysts. Some species contained toxic substances.

***Amphidinium thermaeum* Dolapsakis et Economou 2009 (Fig. 1a)**

Synonym: No synonym.

References: Dolapsakis and Economou 2009, Figs. 1–47.

Specimen examined: Serial No. LJB2015005 / No NIBR no. Photo only.

Description: The cell is oval and dorsoventrally compressed. It has a small, tongue-shaped epicone that extends dorsally from the ventral side of the hypocone apex. The hypocone is asymmetric with a round antapex and convex side. The sulcus that begins near the cell's ventral center extends wide and fades posteriorly but not does not reach the antapex. The nucleus is usually round or oval and located at the hypocone posterior. The chloroplast has a golden-brown color.

Size: 10–30 μm long, 8–20 μm wide.

Sampling: 3 May 2015. Sinyang beach in Jeju (33°26′06″N, 126°55′23.3″E).

Habitat: Marine and benthic species and found in sand.

Distribution: Europe: Thermaikos Gulf, Greece (Dolapsakis and Economou 2009).

Note: This species was reported as *Amphidinium* sp.1 var. *carterae* for unrecorded indigenous species by NIBR in 2015 and reported as a newly recorded species in Korean waters in the present study.

Genus *Cochlodinium* Schütt 1896

Lectotype species: *Cochlodinium strangulatum* (Schütt) Schütt 1896.

Description: The cells are unarmored and heterotrophic with chained colonies. It possesses informal shapes with circular apical grooves that encircle the apex with the anterior sulcus. The cingulum is deep and has a descending left-spiral that rotates around the cell approximately 1.5–2 times. The sulcus invades the epicone as a wide loop near the apex.

***Cochlodinium convolutum* Kofoid et Swezy 1921 (Fig. 1b)**

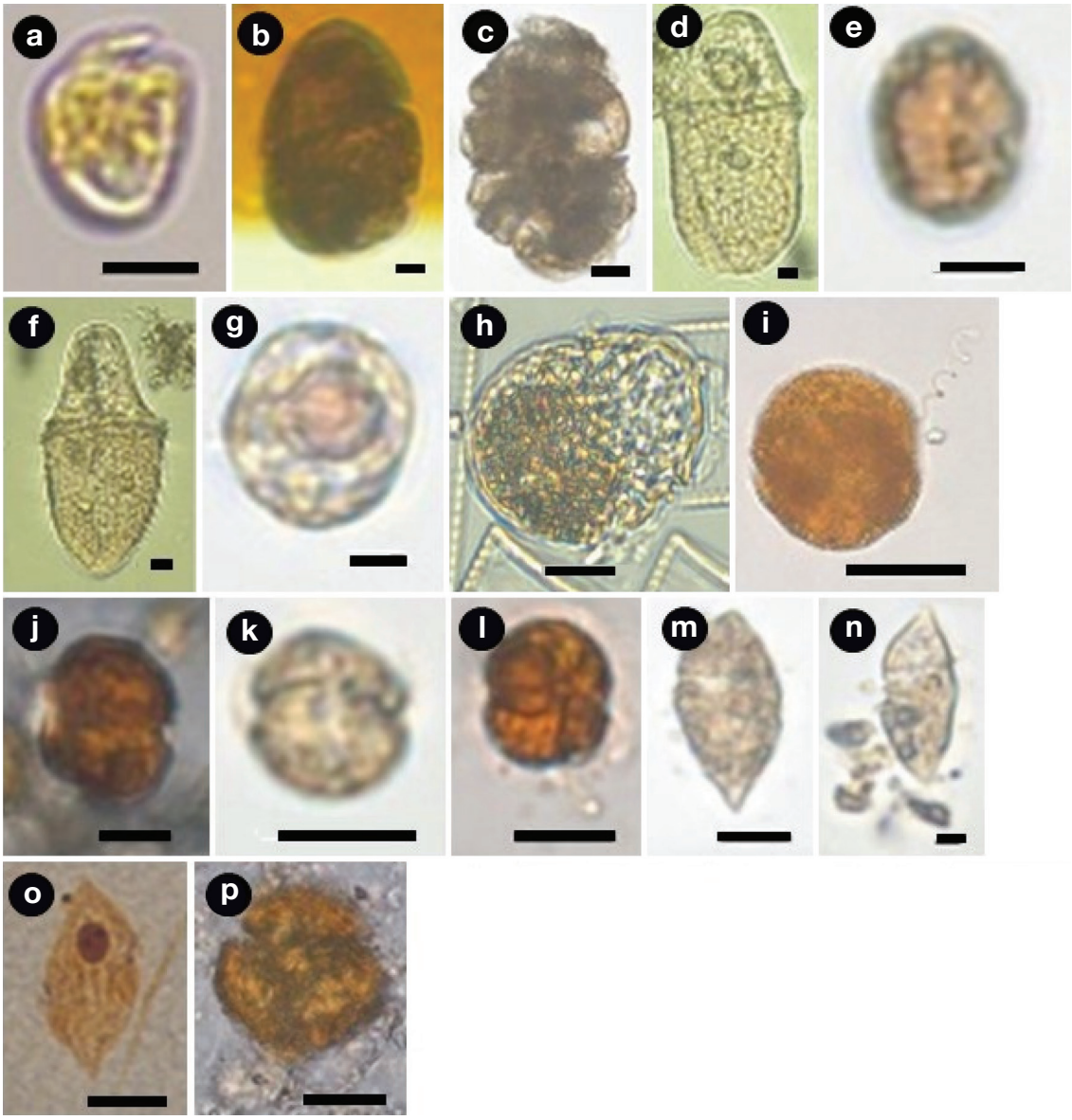

Fig. 1. Light micrographs of the family Gymnodiniaceae, (a) *Amphidinium thermaeum*, (b) *Cochlodinium convolutum*, (c) *Cochlodinium strangulatum*, (d) *Gymnodinium abbreviatum* (valid name: *Gymnodinium gracile*), (e) *Gymnodinium arenicola*, (f) *Gymnodinium gracile*, (g) *Gymnodinium dorsalisulcum*, (h) *Gymnodinium microreticulatum*, (i) *Gymnodinium micrum* (valid name: *Karlodinium micrum*), (j) *Gymnodinium pyrenoidosum*, (k) *Gymnodinium simplex*, (l) *Gymnodinium veneficum* (valid name: *Karlodinium veneficum*), (m) *Gyrodinium aureum*, (n) *Gyrodinium fusiforme*, (o) *Gyrodinium dominans*, (p) *Nusuttodinium latum* (synonym: *Amphidinium latum*). Scale bars, 10 μm.

Synonym: No synonym.

References: Gárate-Lizárraga *et al*. 2011, Fig. 1a–f; Omura *et al*. 2012, p. 84.

Specimen examined: Serial No. LJB2015006 / No NIBR no. Photo only.

Description: The cells are elongated and have a fusiform shape. The epicone is tapered toward the apex, and the hypocone is rounded with two wide lobes. The lobe on the left side is always bigger than the lobe on the right side. The cingulum encircles the cell approximately 1 to 1.5 times.

Size: 55–87 μm long, 34–50 μm wide.

Sampling: 22 Apr. 2015. Tap-dong coast in Jeju Island (33° 32′18″N, 126°33′2.9″E).

Habitat: Marine and planktonic species.

Distribution: Central America: Gulf of California, USA (Gárate-Lizárraga *et al*. 2011).

Note: This species was reported as *Cochlodinium* cf. *convolutum* for unrecorded indigenous species by NIBR in 2015 and reported as a newly recorded species in Korean waters in the present study.

***Cochlodinium strangulatum* (Schütt) Schütt 1896 (Fig. 1c)**

Synonym: Homotypic synonym: *Gymnodinium strangulatum* Schütt, *Cochlodinium miniatum* Kofoid & Swezy; Heterotypic synonym: *Cochlodinium miniatum* Kofoid et Swezy, *Plectodinium miniatum* (Kofoid et Swezy) Taylor.

References: Omura *et al*. 2012, p. 84; Gómez *et al*. 2017, Figs. 1, 2.

Specimen examined: Serial No. LJB2015007 / NIBRDN 0000000003.

Description: This species has large and unarmored cells that do not develop colonies and occasionally live alone and away from a chain. The cells have a form tightened by the cingulum. The cingulum encircles the cell approximately 1.5−1.8 times.

Size: 100−120 μm long, 30−50 μm wide.

Sampling: 25 Mar. 2015. Sewha Coast in Jeju Island (33° 35′5″N, 126°52′60″E).

Habitat: Marine planktonic species.

Distribution: Europe: Mediterranean (Gómez 2003).

Note: This species was reported as *Cochlodinium* cf. *strangulatum* for unrecorded indigenous species by NIBR in 2015 and reported as a newly recorded species in Korean waters in the present study.

Genus *Gymnodinium* Stein 1878

Lectotype species: *Gymnodinium fuscum* (Ehrenberg) Stein 1878

Description: The cells have variable sizes that range from small to large (5−200 μm). The shape of the cell is globular to spindle and dorsoventrally compressed. Some species had long-chained colonies, while others were enclosed in temporary hyaline cysts. The cingulum and sulcus are well-developed. The cingulum is circular or slightly displaced and sometimes arbitrary. The sulcus expands from the cingulum to the antapex, extends to the epicone, and encircles the apex. The chloroplasts are both present and absent (Guiry and Guiry 2017).

***Gymnodinium abbreviatum* Kofoid et Swezy 1921 (Fig. 1d)**

Synonym: No synonym.

References: Dodge 1982, p. 83, Fig. 9a.

Specimen examined: Serial No. LJB2015008 / No NIBR no. Photo only.

Description: The cell body is long and about twice the maximum body circumference with an informal oval shape and round cross section. The epicone is considerably smaller than the hypocone and has a semi-conical shape based on a round apex. The hypocone is long, wide, and round and leads to the antapex. The cingulum is not deeply digested, and the sulcus has a direct route from the apex to the antapex. The nucleus appears largely in the hypocone.

Size: 85−120 μm long, 50−75 μm wide.

Sampling: 23 Apr. 2015. Hamduk coast in Jeju Island (33° 34′30.8″N, 126°41′2.6″E).

Habitat: Marine planktonic species.

Distribution: Atlantic Islands: Canary Islands (Afonso-Carrillo 2014); Europe: Britain (Parke and Dixon 1976).

Note: This species might be currently regarded as a taxonomic synonym of *Gymnodinium gracile* Bergh (Guiry and Guiry 2017). It was reported as *Gymnodinium* cf. *abbreviatum* for unrecorded indigenous species by NIBR in 2015. It was described as *G. gracile* by Shim (1994) in Korean waters and is re-described in the present study.

***Gymnodinium arenicola* Daragesco 1965 (Fig. 1e)**

Synonym: No synonym.

References: Omura *et al*. 2012, p. 84.

Specimen examined: Serial No. LJB2015009 / NIBRDN 0000000004.

Description: This species has small cells. The roof-shaped apical groove extends counterclockwise from the extension of the sulcus. The nucleus is often found in the middle of the cell.

Size: 18−38 μm long, 14−33 μm wide.

Sampling: 25 Mar. 2015. Sewha coast in Jeju Island (33°17′ 1.4″N, 126°49′27.9″E).

Habitat: Marine planktonic species.

Distribution: Europe: British (Parke and Dixon 1976; Thessen *et al*. 2012).

Note: This species was reported as *Gymnodinium arenicolum* for unrecorded indigenous species by NIBR in 2015 and reported as a newly recorded species in Korean waters in the present study.

***Gymnodinium gracile* Bergh 1881 (Fig. 1f)**

Synonym: Heterotypic synonym: *Gymnodinium lohmannii* Paulsen, *Gymnodinium roseum* Lohmann, *Gymnodinium abbreviatum* Kofoid et Swezy.

References: Yamaji 1984, p. 110; Omura *et al*. 2012, p. 85.

Specimen examined: Serial No. LJB2015011 / No NIBR no. Photo only.

Description: The epicone has a cylindrical shape with a protruding end of a cell. The bottom has an oval shape that is much chunkier than the top. The cingulum is wrapped around the middle of the cell, and the sulcus extends from the center of the cell to the lower part of the cell.

Size: 90−130 μm long, 60−65 μm wide.

Sampling: 23 Apr. 2015. Hamduk coast in Jeju Island (33° 34′30.8″N, 126°41′2.6″E).

Habitat: Marine planktonic species.

Distribution: Asia: Russia (Bessudova *et al*. 2014); Atlantic Islands: Canary Islands (Gil-Rodriguez *et al*. 2003, Afonso-Carrillo 2014); Central America: Baja California (Gárate-Lizárrage 2014), Gulf of California (Escobar-Morales and Hernández-Becerril 2015); Europe: Baltic Sea (Hällfors 2004), Black Sea (Gómez and Boicenco 2004), Britain (Parke and Dixon 1976), Helgoland (Hoppenrath 2004), Mediterranean (Gómez 2003); South America: Brazil (Odebrecht 2010).

Note: This species was reported as *Gymnodinium* cf. *gracile* for unrecorded indigenous species by NIBR in 2015. It was described by Shim (1994) in Korean waters and is re-described in the present study.

***Gymnodinium dorsalisulcum* (Hulbert, McLaughlin et Zahl) Murray, Salas et Hallegraeff 2007 (Fig. 1g)**

Synonym: *Katodinium dorsalisulcum* Hulbert, McLaughlin et Zahl.

References: Omura *et al*. 2012, p. 74; Hoppenrath *et al*. 2014, p. 44, Fig. 44a−d.

Specimen examined: Serial No. LJB2015010 / NIBRDN 0000000005.

Description: The cell is long, thin egg-shaped and dorsoventrally flattened. The epicone is longer than the hypocone. The cingulum is wide, deeply cracked and sloping. The narrow sulcus extends onto the epicone and continues to apical groove.

Size: 25−40 μm long, 15−28 μm wide.

Sampling: 23 Apr. 2015. Sewha beach in Jeju Island (33°31′ 31.4″N, 126°51′40.3″E).

Habitat: Marine and benthic species, found in the sandy sediments and tropical area.

Distribution: Australia and New Zealand: Australia (Murray *et al*. 2007).

Note: This species was reported as an unrecorded indigenous species by NIBR in 2015 and reported as a newly recorded species in Korean waters in the present study.

***Gymnodinium microreticulatum* Bolch, Negri et Hallegraeff 1999 (Fig. 1h)**

Synonym: No synonym.

References: Bolch *et al*. 1999, Figs. 1−9; Omura *et al*. 2012. p. 74.

Specimen examined: Serial No. LJB2014007 / No NIBR no. Photo only.

Description: The cells are small in size and egg-shaped with two cones. The grooves rotate counterclockwise. The cingulum is descending, well-defined, and deeply excavated. The sulcus on the hypocone is well-defined and broadens slightly toward the antapex.

Size: 25−34 μm long, 15−22 μm wide.

Sampling: 18 Sep. 2014. Coastal waters around Ioe-do Island (33°38′3″N, 126°21′3″E).

Habitat: Marine and planktonic species.

Distribution: Australia and New Zealand: Tasmania (Bolch *et al*. 1999), Queensland (Phillips 2002); Europe: Portugal (Amorim *et al*. 2002); South America: Uruguay (Bolch *et al*. 1999).

Note: This species was reported as an unrecorded indigenous species by NIBR in 2014 and reported as a newly recorded species in Korean waters in the present study.

***Gymnodinium micrum* (Leadbeater et Dodge) Loeblich III 1970 (Fig. 1i)**

Synonym: *Woloszynskia micra* Leadbeater et Dodge 1966.

References: Dodge 1982, p. 89, Fig. 10a.

Specimen examined: Serial No. LJB2016006 / No NIBR

no. Photo only.

Description: The cells are oval and round. The epicone is slightly smaller than the hypocone. The cingulum is deeply engraved and projects from the epicone to the right back side of the hypocone. The sulcus extends a short distance into the epicone and extends under the antapex of the hypocone.

Size: 8–14 μm long, 9–15 μm wide.

Sampling: 28 Apr. 2015. Sungsan coast in Jeju Island (33° 26′27″N, 126°57′12″E).

Habitat: Marine and planktonic species.

Distribution: Europe: Baltic Sea (Hällfors 2004), Britain (Parke and Dixon 1976).

Note: This species might be currently regarded as a taxonomic synonym of *Karlodinium micrum* (Leadbeater et Dodge) Larsen belonging to family Brachidiniaceae (Guiry and Guiry 2017). This species was reported as an unrecorded indigenous species by NIBR in 2016 and reported as a newly recorded species in Korean waters in the present study.

***Gymnodinium pyrenoidosum* Horiguchi et Chihara 1988 (Fig. 1j)**

Synonym: No synonym.

References: Horiguchi and Chihara 1988, Figs. 2–18; Hoppenrath *et al*. 2014, p. 102, Fig. 46.

Specimen examined: Serial No. LJB2016009 / No NIBR no. Photo only.

Description: The cell is oval and dorsoventrally flatten. It has the specific motility of *Gymnodinium* spp. The epicone and hypocone are similar in size. The median cingulum is nearly without displacement, only slightly descending for about a third to half of a cingulum width. The thin and deep sulcus extends to the antapex.

Size: 18–22 μm long, 13–15 μm wide.

Sampling: 19 Apr. 2016. Subjikoji beach in Jeju Island (33° 26′08″N, 126°55′28″E).

Habitat: Marine and benthic species, found in sand.

Distribution: Asia: Japan (Horiguchi and Chihara 1988), Okinawa, Japan (Shah *et al*. 2010).

Note: This species was reported as an unrecorded indigenous species by NIBR in 2016 and reported as a newly recorded species in Korean waters in the present study.

***Gymnodinium simplex* (Lohmann) Kofoid et Swezy (Fig. 1k)**

Synonym: *Protodinium simplex* Lohmann.

References: Dodge 1982, p. 89, Fig. 10e.

Specimen examined: Serial No. LJB2015012 / NIBRDN 0000000006.

Description: The cell is oval and round. The epicone is narrow and shorter than the hypocone. The cingulum is wide and slightly anterior to the center of the cell. The sulcus is shallow, not always discernible, and does not extend onto the epicone. The anterior of the cell is round and the hypocone has rounded sides. The antapex is also rounded, flattened or indented by the sulcus.

Size: 7–9 μm long, 6–7 μm wide.

Sampling: 25 Mar. 2015. Hamduk coast in Jeju Island (33° 34′30″N, 126°41′2.6″E).

Habitat: Marine and planktonic species.

Distribution: Atlantic Islands: Canary Islands (Gil-Rodriguez *et al*. 2003; Afonso-Carrillo 2014); Australia and New Zealand: New Zealand (Haywood *et al*. 2007; Chang *et al*. 2012); Central America: Costa Rica (Jang *et al*. 2015); Europe: Adriatic Sea (Vilicic *et al*. 2002), Baltic Sea (Hällfors 2004), Black Sea (Gómez and Boicenco 2004), British (Parke and Dixon 1976), Croatia (Vilicic *et al*. 2009), English Channel (Jang *et al*. 2015), Italy (Siano *et al*. 2009), Mediterranean (Gómez 2003); North America: Caribbean, Mexico (Merino-Virgilio *et al*. 2013), Mexico (Jang *et al*. 2015); South America: Brazil (Bicudo and Skvortzov 1970; Odebrecht 2010), Canary Islands (Afonso-Carrillo 2014), Pacific Islands: Pacific Ocean (Jang *et al*. 2015)

Note: This species was reported as *Gymnodinium* cf. *lantzschii* for unrecorded indigenous species by NIBR in 2015, which had been misidentified at that time. The specimen was re-identified as *Gymnodinium simplex*. It was recorded by Lee and Kim 2015) in Korean waters and is re-described in the present study.

***Gymnodinium veneficum* Ballantine 1956 (Fig. 1l)**

Synonym: No synonym.

References: Ballantine 1956, p. 467, Figs. 6–17; Dodge 1982, p. 89, Fig. 10c.

Specimen examined: Serial No. LJB2016008 / No NIBR no. Photo only.

Description: The cell is ovoid and not flattened with an

equal epicone and hypocone. The epicone is slightly convex and pointed in the apex. The round and deep sulcus extends onto the epicone and hypocone and decreases in depth towards the apex and antapex. The cingulum is deeply embedded and encircles the cell once.

Size: 9–18 μm long, 7–14 μm wide.

Sampling: 19 Jan. 2016. Ojo-ri coast in Jeju Island (33°27′48.6″N, 126°55′14.3″E).

Habitat: Marine and benthic species, found in sand.

Distribution: Atlantic Islands: Canary Islands (Gil-Rodriguez *et al*. 2003); Europe: Britain (Parke and Dixon 1976; Bergholtz *et al*. 2006).

Note: Note: This species might be currently regarded as a taxonomic synonym of *Karlodinium veneficum* (Ballantine) Larsen belonging to the Brachidiniaceae family (Guiry and Guiry 2017). It was reported as *Gymnodinium veneficum* for unrecorded indigenous species by NIBR in 2016 and reported as a newly recorded species in Korean waters in the present study.

Genus *Gyrodinium* Kofoid et Swezy 1921

Holotype species: *Gyrodinium spirale* (Bergh) Kofoid et Swezy.

Description: Small-to-large (<5–<200 μm) unarmored unicellular free-living, predominantly motile flagellates, sometimes enclosed in temporary cysts. Cells globular to fusiform, often dorso-ventrally, rarely laterally compressed, with well-developed cingulum and sulcus, transverse and longitudinal flagella. Cingulum displaced at least 1/5 of total body length (for less cingulum displacement, see *Gymnodinium*) (Guiry and Guiry 2017).

***Gyrodinium aureum* (Conrad) Schiller 1928 (Fig. 1m)**

Synonym: *Spirodinium aureum* Conrad.

References: Omura *et al*. 2012, p. 57.

Specimen examined: Serial No. LJB2015013 / NIBRDN 0000000007.

Description: The epicone and hypocone are conical, and the hypocone is larger than the epicone. The stripes are on the surface, and the apical groove is oval.

Size: 29–57 μm long, 25–31 wide.

Sampling: 25 Mar. 2016. Tap-dong coast in Jeju Island (33°32′18″N, 126°33′2.9″E).

Habitat: Marin and planktonic species.

Distribution: Britain (Parke and Dixon 1976).

Note: This species was reported as *Gyrodinium* cf. *aureum* for unrecorded indigenous species by NIBR in 2015 and reported as a newly recorded species in Korean waters in the present study.

***Gyrodinium fusiforme* Kofoid et Swezy 1921 (Fig. 1n)**

Synonym: Heterotypic synonym: *Spirodinium fusus* Meunier 1910.

References: Dodge 1982, p. 99, Fig. 12a; Shin 2016, pp. 188–189.

Specimen examined: Serial No. LJB2015014 / NIBRDN 0000000008.

Description: This cell has an elongated oval shape and the antapex ends are pointed. The cingulum exists around the body of the cell. The epicone is slightly smaller than the hypocone with a slender cone shape and the hypocone is also slender and conical. The cingulum begins about one third of the length from the apex and descends in a left-handed spiral to about a third of the body length from the antapex. The sulcus is shallow and incompletely described.

Size: 50–125 μm long, 13–26 wide.

Sampling: 25 Mar. 2015. Sewha coast in Jeju Island (33°35′5″N, 126°52′60″E).

Habitat: Marine and planktonic species.

Distribution: Europe: Adriatic Sea (Vilicic *et al*. 2002), Baltic Sea (Hällfors 2004), Britain (Parke and Dixon 1976; Dodge 1982), Croatia (Vilicic *et al*. 2009), Mediterranean (Gómez 2003), Romania (Caraus 2017), Mexico (Merino-Virgilio *et al*. 2013).

Note: This species was reported as *Gyrodinium* cf. *fusiforme* for unrecorded indigenous species by NIBR in 2015. It was described by Shin (2016) in Korean waters and is re-described in the present study.

***Gyrodinium dominans* Hulbert 1957 (Fig. 1o)**

Synonym: No synonym.

References: Hulburt 1957, p. 1, Fig. 63a, b; Omura *et al*. 2012, p. 81.

Specimen examined: Serial No. LJB2014008 / NIBRFL0000130512, NIBRFL0000130513.

Description: The shape of the cell varies but is generally oval or spherical, and it appears almost circular when viewed from the antapex. The epicone is a round and dome-

shaped and wider and shorter than the hypocone. The cingulum spirals four times to the left with a displacement of the end of the total cell length from the antapex. The cell surface has 7−10 vertical lines.

Size: 13−40 μm long, 9−20 wide.

Sampling: 18 Sep. 2014. Coastal waters around Ioe-do Island (33°38′3″N, 126°21′3″E).

Habitat: Marine and planktonic species.

Distribution: Asia: China (Liu 2008), Korea (Lee *et al*. 2014); Europe: Baltic Sea (Hällfors 2004), Denmark (Strom *et al*. 2013).

Note: This species was reported as an unrecorded indigenous species by NIBR in 2014. It was recorded by Lee and Kim (2015) in Korean waters and is re-described in the present study.

Genus *Nusuttodinium* Takano et Horiguchi 2014

Holotype species: *Nusuttodinium latum* (Lebour) Takano et Horiguchi 2014.

Description: This species is an unarmored dinoflagellate with chloroplast derived from the endosymbiotic, periodically acquired and temporarily retained cryptomonads. The vesicular chambers in the nuclear envelope are absent. The apical groove curves around the apex in a counter-clockwise direction (Guiry and Guiry 2017).

***Nusuttodinium latum* Takano et Horiguchi 2014 (Fig. 1p)**

Synonym: *Amphidinium latum* Lebour.

References: Dodge 1982, p. 65, Fig. 6D; Takano *et al*. 2014, p. 762, Fig. 1A−C, p. 764, Fig. 2A, B; Hoppenrath *et al*. 2014, p. 52, Fig. 18A−C.

Specimen examined: Serial No. LJB2016001 / No NIBR no. Photo only.

Description: The shape of the cell is round and square to rectangle from the ventral side and dorsoventrally flattened. The epicone has a conical shape with a pointed apex. The cingulum is wide and exists in the form of completely circular cells. The sulcus is narrow and extends directly to the center of the antapex. The cells have apical grooves around the apex.

Size: 16−25 μm long, 13−26 μm wide.

Sampling: 31 Jul. 2015. Subjikoji beach in Jeju Island (33°26′08″N, 126°55′28″E)

Habitat: Marine and benthic species, found in sand and subtropical.

Distribution: Atlantic Islands: Canary Islands (Gil-Rodriguez *et al*. 2003; Alfonso-Carrillo 2014); Europe: Britain (Parke and Dixon 1976), Mediterranean (Gómez 2003).

Note: This species was reported as *Amphidinium latum* for unrecorded indigenous species by NIBR in 2016. However this was transferred to genus *Nusuttodinium* (Guiry and Guiry 2017) and reported as *Nusuttodinium latum* for newly recorded species in Korean waters in the present study.

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