



## Two new generic names for dinophytes harbouring a diatom as an endosymbiont, *Blixaea* and *Unruhdinium* (Kryptoperidiniaceae, Peridinales)

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Kryptoperidiniaceae are a small group of dinophytes hosting a tertiary endosymbiont derived from a diatom (Tomas *et al.* 1973, Horiguchi & Pienaar 1994). Those so called ‘dinotoms’ (Imanian *et al.* 2011) include *Dinothrix*, *Durinskia*, *Galeidinium*, *Kryptoperidinium* (= *Phyllocladum*) and some species currently assigned to “*Peridiniopsis*” and “*Peridinium*” (Tamura *et al.* 2005, Horiguchi & Takano 2006, Hansen *et al.* 2007, Zhang *et al.* 2011). Besides ‘possessing a diatom endosymbiont’ as a highly derived trait, the monophyly of Kryptoperidiniaceae is also supported by a unique type of eyespot that has possibly derived from the original chloroplast (Moestrup & Daugbjerg 2007). In molecular trees, Kryptoperidiniaceae constitute a well supported monophyletic group (Kretschmann *et al.* unpubl.), but it is not finally resolved at present, whether they are embedded in the Thoracosphaeraceae or constitute their sister group (Gottschling & McLean 2013). Regarding habitat preference, molecular trees further indicate at least two independent marine→freshwater transitions in the Kryptoperidiniaceae during the late Paleogene at the latest (Žerdoner Čalasan *et al.* unpubl.).

As currently treated, “*Peridiniopsis*” and “*Peridinium*” are highly polyphyletic assemblages, and a major effort during the past years was put into the disentanglement of the present taxonomic confusion and inconsistency (Carty 2008, Calado 2011, Craveiro *et al.* 2011, 2016, Kretschmann *et al.* 2015, to mention only a few studies). A rigorous classification of peridiniacean dinophytes is still pending but in several publications (Tillmann *et al.* 2012, 2014, Gottschling & McLean 2013, Gottschling & Söhner 2013, Gottschling *et al.* 2017, Gu *et al.* 2013), we aimed at an improved knowledge about phylogenetic systematics of dinophytes by concatenating ribosomal RNA sequences. As a result, some species currently assigned to “*Peridiniopsis*” and “*Peridinium*” (Horiguchi & Takano 2006, Liu *et al.* 2008, Takano *et al.* 2008, Zhang *et al.* 2011, 2014, Yamada *et al.* 2015, You *et al.* 2015) clearly belong to Kryptoperidiniaceae, but not to the taxa, under which they were initially described. Based on molecular and morphological data they represent two distinct evolutionary lineages that are described here as new, namely *Blixaea*, gen. nov., and *Unruhdinium*, gen. nov. New combinations are provided for those species names only, of which morphological and molecular data are available for critical examination.

The specificity of the diatom endosymbiont for their host is not rigorously worked out at present. Some dinophyte species appear to harbour genetically different endosymbionts (Yamada *et al.* in press, Žerdoner Čalasan *et al.* unpubl.), while other species maintain endosymbionts with very similar DNA sequences (e.g., *Unruhdinium* cf. *kevei*, comb. nov., and *Unruhdinium* *jiulongense*, comb. nov.: Takano *et al.* 2008, You *et al.* 2015). Nevertheless, Kryptoperidiniaceae are highly selective towards specific groups of diatoms and do not recruit them arbitrarily: The endosymbiont of marine *Blixaea* *quinquecornis*, comb. nov., for example, is part of a well resolved group within *Chaetoceros*—probably the largest taxon of marine centric diatoms (Horiguchi & Takano 2006)—, and endosymbionts of freshwater *Unruhdinium*, gen. nov., cluster within freshwater *Cyclotella*, but neither within other freshwater species of *Nitzschia* as in the case of *Durinskia*, *Galeidinium* and *Kryptoperidinium*.

### Taxonomic activity

***Blixaea*** Gottschling, gen. nov.—Type: *Blixaea* *quinquecornis* (T.H.Abé) Gottschling, comb. nov.

Description:—Thecate, phototrophic, free-living, primarily marine dinophytes harbouring a *Chaetoceros*-like diatom as endosymbiont, which is separated from the host by a single unit membrane. Kofoidian plate formula: 3', 2a, 7'', 5c, 5''', 2''''', apical pore complex present. Plate surface smooth through granulate, hypotheca with (three through five) predominantly

four distinct spines of varying length. Chloroplasts numerous and belonging to the endosymbiotic alga; eyespot surrounded by three membranes.

Etymology:—The name honours Blix Bargeld (\*1959), who is singer, musician and founder of the Berlin music group Einstürzende Neubauten. The generic name *Blixaea* is sufficiently distinct from malvacean *Bixa* (Linné 1753), because of both the differential auditory phonetics and the diverging taxonomic assignments, that ICN Art. 53 does not apply.

*Blixaea*, gen. nov., is currently monotypic, but may include more taxa such as “*Peridinium*” *quinquecorne* var. *trispiniferum* from Mexico (Aké-Castillo & Vázquez 2011). The diagnostic feature of *Blixaea*, gen. nov., is the presence of predominantly four distinctive hypothecal spines (Abé & Saitō 1981), and a *Chaetoceros*-like diatom as endosymbiont (Horiguchi & Pienaar 1991) has not been reported from any other Kryptoperidiniaceae. In molecular phylogenetics, *Blixaea*, gen. nov., is distinct from all Kryptoperidiniaceae, of which DNA sequence data are available (Horiguchi & Takano 2006, Yamada *et al.* in press, Kretschmann *et al.* unpubl.), and it does not show any filamentous or palmelloid growth as *Dinotrix* (Pascher 1927), of which no DNA sequence data are available at present. It further differs from *Peridinium*, under which it was initially described, in both habitat preference (marine *versus* freshwater) and the presence of not more than two (*versus* three) intercalary plates.

*Blixaea quinquecornis* (T.H.Abé) Gottschling, *comb. nov.*, basionym: *Peridinium quinquecorne* T.H.Abé, Science Reports of the Tohoku Imperial University. Series 4, Biology 2: 410, fig. 30. 1927. *Protoperidinium quinquecorne* (T.H.Abé) Balech, Revista del Museo Argentino de Ciencias Naturales Bernardino Rivadavia e Instituto Nacional de Investigación de las Ciencias Naturales / Hidrobiología 4: 59. 1974.—Type: Japan. Honshū, Tōhoku, Mutsu Bay (collection date unknown).

*Peridinium quinquecorne* has been synonymised with *Heterocapsa quadridentata* (Hansen 1995, Okolodkov *et al.* 2016), which would have taxonomic priority over the type species selected here. We hesitate to designate the older but largely unused name as type species as long as the diatom endosymbiont has not been verified based on material investigated under that name.

***Unruhadinium*** Gottschling, *gen. nov.*—Type: *Unruhadinium jiulongense* (H.Gu) Gottschling, *comb. nov.*

Description:—Thecate, phototrophic, free-living, primarily freshwater dinophytes usually harbouring a *Cyclotella*-like diatom as endosymbiont, which is separated from the host by a single unit membrane. Kofoidian plate formula with maximally ten epithecal plates (including 6'') and 5c, 5''', 2''''', apical pore complex present. Plate surface smooth through granulate though never ornamented by a network of minute ridges, hypotheca with a varying number of more or less distinctive spines. Chloroplasts numerous and belonging to the endosymbiotic alga; eyespot surrounded by three membranes.

Etymology:—The name honours Andrew Chudy (\*1957, a.k.a. N.U.Unruh), who is musician, experimental percussionist and instruments inventor. He is best known for his work with the Berlin music group Einstürzende Neubauten, of which he also is a founder.

*Unruhadinium*, gen. nov., currently comprise 5–10 species with the presence of *Cyclotella*-like diatoms as endosymbionts and a reduced number of epithecal plates as diagnostic traits. The general plate formula of the epitheca should be 4' 0a 6'' (Bourrelly 1968, Zhang *et al.* 2011), but *Unruhadinium jiulongense*, *comb. nov.*, and *Unruhadinium minimum*, *comb. nov.*, are described as having 3' 1a 6'' (Zhang *et al.* 2014, You *et al.* 2015). This inconsistency makes it difficult to separate the entirety of *Unruhadinium* from *Peridiniopsis* (under which many of its constituent species were initially described) likewise having 3' 1a 6'' (Calado & Moestrup 2002), although both taxa are only distantly related in molecular phylogenetics (Gottschling *et al.* 2017). Nevertheless, the differing number of cingular plates (6c in *Peridiniopsis* *versus* 5c in *Unruhadinium*, gen. nov.), the presence of longer through shorter spines on the hypotheca in *Unruhadinium*, gen. nov. (absent in *Peridiniopsis borgei*), and the cell surface (never ornamented by a network of ridges in *Unruhadinium*, gen. nov., but in *P. borgei*) may further argue for the uniqueness of *Unruhadinium*, gen. nov.

In molecular phylogenetics, *Unruhadinium*, gen. nov., is distinct from all Kryptoperidiniaceae, of which DNA sequence data are available (Liu *et al.* 2008, Takano *et al.* 2008, Zhang *et al.* 2011, 2014, You *et al.* 2015, Yamada *et al.* in press, Kretschmann *et al.* unpubl.), and it does not show any filamentous or palmelloid growth as *Dinotrix* (Pascher 1927), of which no DNA sequence data are available at present. It is one of the two freshwater lineages identified in the Kryptoperidiniaceae, and it differs from *Durinskia oculata*, which has a regular formula of 4' 2a 6'' in the conformation of the epitheca (Kretschmann *et al.* unpubl.). The endosymbiont's nucleus could not be confirmed yet for *Unruhadinium niei*, *comb. nov.*, in light microscopy (Liu *et al.* 2008), but the numerous chloroplasts are being also part of, and therefore evidence for, the engulfed alga. Its presence also in this species is further corroborated by sequencing of endosymbiont loci (Zhang *et al.* 2014).

*Unruhadinium jiulongense* (H.Gu) Gottschling, *comb. nov.*, basionym: *Peridiniopsis jiulongensis* H.Gu in X.You, Z.Luo, Y.Su, L.Gu & H.Gu, Nova Hedwigia 101: 316–318, figs 1–3. 2015.—Type: People's Republic of China. Fujian, Zhangzhou, Jiulongjiang River, Xipi reservoir (December, 2012).

*Unruhdinium kevei* (Grigorszky & Vagas) Gottschling, *comb. nov.*, basionym: *Peridiniopsis kevei* Grigorszky & Vagas in Grigorszky, Vagas, Borics, Klee, Ant.Schmidt & Borbély, *Acta Botanica Hungaria* 43: 168–172, figs 2–21. 2001.—Type: Hungary. Jász-Nagykun-Szolnok, Mezőtúr, Peresi Holt-Körös (collection date unknown).

*Unruhdinium minimum* (Qi Zhang, G.X.Liu & Z.Y.Hu) Gottschling, *comb. nov.*, basionym: *Peridiniopsis minima* Qi Zhang, G.X.Liu & Z.Y.Hu, *Algological Studies* 145/146: 122, figs 1–3. 2014.—Type: People’s Republic of China. Fujian, Zhangzhou, Jiulongjiang River (August, 2011).

*Unruhdinium niei* (G.X.Liu & Z.Y.Hu) Gottschling, *comb. nov.*, basionym: *Peridiniopsis niei*, G.X.Liu & Z.Y.Hu, *Nova Hedwigia* 87: 490–496, figs 3–6. 2008.—Type: People’s Republic of China. Hubei, Wuhan, East Lake (Donghu) (March 18, 2004).

*Unruhdinium penardii* (Lemmerm.) Gottschling, *comb. nov.*, basionym: *Glenodinium penardii* Lemmerm., *Hedwigia* 39 Beiblatt: 117. 1900. *Peridiniopsis penardii* (Lemmerm.) Bourr., *Protistologica* 4: 9. 1968.—Type: Swiss Confederation. Geneva, Lake Geneva (collection date unknown). Note: Lemmermann (1910) used the same epithet for a new species of *Peridinium* and included the name *Glenodinium penardii* in his taxonomic header. Thus, it remains unclear whether Lemmermann (1910) considered it as distinct from the present species (then, it was not validly published because of ICN Art. 52.1.), or a combination of it (then, the indicated ‘spec. nov.’ is confusing). Anyhow, the combination of Lindemann (1925) back to *Glenodinium* is not validly published.

*Unruhdinium penardii* var. *robustum* (Qi Zhang, G.X.Liu & Z.Y.Hu) Gottschling, *comb. nov.*, basionym: *Peridiniopsis penardii* var. *robusta* Qi Zhang, G.X.Liu & Z.Y.Hu, *European Journal of Protistology* 47: 151, figs 2–3, 4C. 2011.—Type: People’s Republic of China. Yunnan, Manwan, Luodi River (Apr, 2008).

There is some connection between the productivity of the Berlin music group Einstürzende Neubauten and the promotion of issues in natural science (‘Newtons Gravitätlichkeit’, ‘Total eclipse of the sun’), biology (‘DNS Wasserturm’) and also botany (‘Blume’, ‘In the garden’, ‘Sag’ mir, ‘wo die Blumen sind’). However, our present choice for new generic names in the dinophytes may stimulate a discussion about the contemporariness and usefulness of Recommendation 20A (h) in the *International Code of Nomenclature for algae, fungi, and plants* not to ‘dedicate genera to persons quite unconnected with botany, mycology, phycology, or natural science in general.’ Historically, the recommendation goes back to the *Vienna Rules* at the beginning of the 20<sup>th</sup> century when (phanerogam) botanists may have considered themselves rather at the end of the biodiversity assessment in terms of taxa at the generic level. We are aware today, however, that myriads of lineages remain to be named, particularly in the microbial world of algae and fungi, arguing against an unnecessary limitation and for a more liberal and open-minded application of *The Code* in this respect. This would be in tradition of, for example, Linné (1753), who dedicated many of his plant names to mythological figures, and has been recently readopted with naming the fern *Gaga* dedicated to one of the contemporary heroes (Li *et al.* 2012). The approach has also found broad application in zoology and thus, our proposal comes as a small but perceivable step forward towards the harmonisation (if not even unification) of *The Codes*, being an important motivational drive for the work on such ambiregnal protists as the dinophytes.

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