New Records of Haptophyte Species from the Northeastern Mediterranean Sea for Algal Flora of Turkey

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Abstract

Chrysochromulina alifera, Chrysochromulina lancealata, Chrysochromulina parkeae, Haptolina cf. ericina, Umbellosphaera irregularis, Umbellosphaera tenuis, Umbilicosphaera foliosa, Syracosphaera molischii, Rhodosphera clavigera var stylifera and Opihasterformus were recorded for the first time along the Turkish coasts. Non-calcified haptophyte species Chrysochromulina alifera, C. lancealata, C. parkeae and H. cf. ericina were observed in live samples since formaldehyde damages cells. Among them only C. alifera could be observed with SEM. Either SEM pictures or light microscope images of other species were presented. Although previously reported along Turkish coasts Syracosphaera pulchra was a coccolithophore species most frequently observed after Emiliania huxleyi in the study area. Scyphosphaera apsteinii, Calciosolenia brasilensis and Coronosphaera mediterranea, which were also reported previously along Turkish Seas, were among the rare species encountered in the sampling region.

Introduction

Haptophytes are primarily unicellular, phototrophic and mostly marine microalgae possessing a unique organelle called haptonema, extending between the two flagella. This phylum is classified mainly based on the morphology of calcified or noncalcified scales. While coccolithophores have mineralized inorganic scales at some stage in their life cycle (Billard & Inouye, 2004; Winter & Siesser, 1994), Haptophyte families such as Chrysochromulinaeae have organic scales during their all life cycle (Edvardsen et al., 2011). While there are few studies related to species composition of calcifying haptophytes along Turkish coasts (Aktan, Luglie, Aykulu & Sechi, 2003; Balkis, 2004; Polat & Piner, 2002; Eker-Develi, 2004), there is not even a study dealing with noncalcifying haptophytes in Turkish seas. This phylum of phytoplankton was sometimes disregarded in check lists of phytoplankton groups along Turkish Seas probably due to small size of its species (Polat, 2002; Taş & Okuş, 2006; Taş 2013; Aktan, Balkis and Balkis, 2014). Haptophyte species identified along Turkish coasts are mainly based on light microscope observations. These species are consisted of Anacanthocha acanthos, Calciosolenia brasilensis, C. murrayi, Syracosphaera pulchra, Emiliania huxleyi, Scyphosphaera apsteinii, Coronosphaera mediterranea, Discosphaera tubifera, Rhodolithes claviger and Coccolithus pelagius (Polat & Piner, 2002; Aktan et al. 2003; Koray 2001; Balkis, 2004; Eker-Develi, 2004; Baytut, & Gönülol 2016). There are a few more species identified with light microscope in Eker-Develi (2004) and Polat & Piner (2002) but they should be verified by electron microscope images.

Extant coccolithophores are widespread around the oceans from tropical to polar regions (Chang and Northcote, 2016; Winter and Siesser, 1994). While most other phytoplankton groups prefer high nutrient regions, coccolithophore diversity is highest in warm, low productivity “blue water” regions (Winter & Siesser, 1994). However, under certain conditions coccolithophores such as Emiliania huxleyi (Lohmann) Hay & Mohler bloom in cool and high nutrient waters as in Norwegian Fjords (Berge, 1962). E. huxleyi blooms were also observed along Turkish coastal region of the Black Sea and in the Dardanelles previously (Türkoğlu, 2008; Eker, Georgieva, Senichkina & Kideys, 1999).

In the present study our aim was to investigate nanoplanktic haptophytes having both organic and inorganic scales in the northeastern Mediterranean Sea where there are not any specific study about this group of phytoplankton community. Majority of the studies related to haptophytes are on the western...

Material and Methods

Sea water samples were taken with a plastic bucket from the Erdemli coast (36°01′19″N, 34°31′23″E) in the north-eastern Mediterranean Sea during 2015-2016 (Figure 1). Live samples were investigated under microscope directly. In addition, 300 mL seawater was filtered through 1.3 mm diameter and 0.2 µm pore size polycarbonate filters after fixing with borax buffered formaldehyde to have a final concentration of 1.5% and examined with a Zeiss Supra55 field emission scanning electron microscope after coating with platinum using the Quorum Q150R Sputter Coater instrument. For investigation of Chrysochromulina alifera Parke & Manton culture, which was isolated on 30 July 2015 using diluted F/20 Medium, cells were fixed with 2% osmium tetroxide, dehydrated in a graded ethanol series of 25%, 50%, 75%, 95% and 100% for ca. 10 min, critical point dried and examined under SEM same as platinum using the Quorum Q150R Sputter Coater instrument. For investigation of Chrysochromulina molischii, Ophiaster formosus, Rhabdosphaera clavigera var. stylifera, Coronosphaera mediterranea, Syracosphaera pulchra and Calcosolenia brasilensis were identified during the study period. Former three species were new for the Turkish coasts. Scyphosphaera apsteinii belonging to Zygodisccales order, which was reported in Turkish waters previously, was also among the haptophyte species observed once in the sampling area.

**Phylum** Haptophyta
**Class** Coccolithophyceae
**Subclass** Prymnesiophycidae
**Order** Prymnesiales
**Family** Chrysochromulinae
**Genus** Chrysochromulina Lackey, 1939
**Species** Chrysochromulina parkeae Green & Leadbeater 1972 (Figure 4).

**Description:** Cells are elongate (~20 µm) having two equal flagella ~25 µm in length, haptonema shorter.

**Results**
Calcified and noncalcified haptophyte taxa found in the northeastern Mediterranean Sea during 2015-2016 were listed and discussed in the present investigation. 4 new haptophyte species for the Turkish coasts belonging to Chrysochromulina genus were reported. Extant coccoliths belonging to Umbellosphaera tenuis, U. irregularis and Umbilicosphaera foliosa were found for the first time along Turkish seas. Six species belonging to Syracosphaerales order, Syracosphaera molischii, Ophiaster formosus, Rhabdosphaera clavigera var. stylifera, Coronosphaera mediterranea, Syracosphaera pulchra and Calcosolenia brasilensis were identified during the study period. Former three species were new for the Turkish coasts. Scyphosphaera apsteinii belonging to Zygodisccales order, which was reported in Turkish waters previously, was also among the haptophyte species observed once in the sampling area.

**Phylum** Haptophyta
**Class** Coccolithophyceae
**Subclass** Prymnesiophycidae
**Order** Prymnesiales
**Family** Chrysochromulinae
**Genus** Chrysochromulina Lackey, 1939
**Species** Chrysochromulina alifera Parke & Manton in Parke, Manton & Clarke 1956 (Figures. 2, 3).

**Description:** Cells are saddle-shaped with large lateral curved wings. Cell length 4.5-20 µm with a haptonema 7-16 times the cell length (160 µm), the two flagella are approximately equal and 2.5-4 times the cell length. Two golden-brown chloroplasts. Spine scales cover the cell with a circular to ellipsoid base (Figure 2d). Spines are shorter than the diameter of the scales. Cells were isolated on 30 July 2015. Water temperature and salinity were 27 °C and 39 psu in the sampling area. Species similar to C. alifera were observed under light microscope during the year with highest numbers during spring and summer months.

**Distribution in Turkey:** First record along Turkish seas.

**Species** Chrysochromulina parkeae Green & Leadbeater 1972 (Figure 4).

**Description:** Cells are elongate (~20 µm) having two equal flagella ~25 µm in length, haptonema shorter.
Posess spine scales almost equal to body length at both anterior and posterior sides of the cell. It was observed on 29 April, 11 May and 27 May 2016 samples. Seawater temperature and salinity were 21 °C, 21 °C and 23 °C, 39, 39.2 and 38.9 respectively.

**Distribution in Turkey**: First record along Turkish coasts.

**Species**: *Chrysochromulina lanceolata* Chrétiennot-Dinet, Nezan & Puigserver in Puigserver *et al.*, 2003 (Figure 5a-c)

**Description**: Cells are lancet-shaped having two asymmetric anterior arms and a posterior tail. Cells length is ~28-30 μm having two almost equal flagella ~38 μm. Haptonema is shorter than the flagella, ~22 μm in length and extended forward during resting. Swim both anteriorly and posteriorly. A refringent body is present in the posterior part, towards the tail. A lobate protrusion in the ventral side between the tail and arms is present. They swim both forward and backward direction. One of the arms is truncate at the end. It was observed on 27 May and 24 June 2016. Seawater temperature and salinity were 23 °C and
38.9, 27 °C and 39.5, respectively. *Chrysochromulina cf. lanceolate* was observed on 11 May 2016 (Figure 5d-e). One of the arms was very short. The length of body, haptonema and flagellates were ~35 μm, ~15 μm and ~39 μm respectively. Water temperature and salinity were 21 °C and 39.2.

**Distribution in Turkey:** First record along Turkish coasts.

**Genus Haptolina** Edvardsen & Eikrem, 2011

**Species Haptolina cf. ericina** (Parke & Manton)

Edvardsen & Eikrem in Edvardsen et al. 2011 (Figure 6)

**Basionym** *Chrysochromulina ericina* Parke & Manton

**Description:** Cells ovoid to oblong, 5–10 μm long, haptonema is thinner and longer than the two equal flagella when extended. Flagella are homodynamic. Body is covered with spiny unmineralised scales. It was observed on 6 April 2016 and 18 July 2016. Seawater temperature and salinity were 19 °C and 39.3, 31 °C and 38.6 respectively.

![Figure 4. Live cells of *Chrysochromulina parkeae* (scale bars = 20 μm).](image)

![Figure 5. (a-c) Live cells of *Chrysochromulina lanceolata* from different positions, (d-e) *Chrysochromulina cf. lanceolata* from dorsal and lateral views (scale bars = 20 μm).](image)

![Figure 6. Live cells of *Haptolina cf. ericina* (scale bars = 10 μm).](image)
Distrubition in Turkey: First report along Turkish coasts.

**Phylum** Haptophyta
**Class** Haptophyta incertae sedis
**Order** Haptophyta incertae sedis
**Family** Umbellosphaeraceae
**Genus** Umbellosphaera Paasche in Markali & Paasche 1955
**Species** Umbellosphaera irregularis Paasche in Markali & Paasche 1955 (Figure 7)

**Description:** Size of the protoplast is ~6-10 μm, the diameter of complete coccolithophore is ~10-20 μm. It has an angular view due to the shape of coccoliths.

Coccoliths, having a funnel shaped structure without ridges on the distal part, varied from elliptical to circular with a diameter of 4.5-9 μm at the widest part. Distally concave laths give the cell an irregular appearance. There are about 15-20 radiating elements on coccoliths. It was observed on 11 November 2015 and 15 November 2016 in the samples. Seawater temperature and salinity were 22 °C and 39 on 11 November 2015.

**Phylum** Haptophyta
**Class** Coccolithophyceae
**Subclass** Prymnesiophycidae
**Order** Coccolithales
**Family** Calcidiscaceae
**Genus** Umbilicosphaera Lohmann 1902
**Species** Umbilicosphaera foliosa (Kamptner ex Kleijne) Geisen in Sáez et al. 2003 (Figure 8c)

**Basionym** Cycloplacolithus foliosus Kamptner 1963

**Homotypic Synonym(s)**
Cycloplacolithella foliosa (Kamptner) Haq 1968

**Heterotypic Synonym(s)**
Umbilicosphaera mirabilis Lohmann 1902
Cyclococcolithus mirabilis (Lohmann) Kamptner 1954

**Description:** Coccoliths are circular showing a...
similar distal shield structure with *Calcidiscus*, however the central tube is larger and open. Sutures on distal shield is vigorously kinked. Central area is narrower than in *U. sibogae* coccoliths. Proximal shield is bicyclic, concave and smaller than the distal shield. It was observed on 15 November 2016. A coccolith similar to *C. foliosa* was observed on 15 March 2016 from the distal shield view (Figure 8d). Seawater temperature and salinity were 17 °C and 38.5.

**Distribution in Turkey:** First report along Turkish coasts.

**Phylum** Haptophyta  
**Class** Coccolithophyceae  
**Subclass** Prymnesiophycidae  
**Order** Syracosphaerales  
**Family** Syracosphaeraceae  
**Genus** *Coronosphaera* Gaarder 1977  
**Species** *Coronosphaera mediterranea* type wettsteini (Lohmann) Gaarder and Heimdal 1977 (Figure 8e)  
**Basionym** Zygosphaera wettsteini Kamptner 1937  
**Synonyms:** *Calyptrolithina wettsteini* (Kamptner 1937) Norris 1985  
**Description:** This is the holococcolith type of *C. mediterrana*. Liths are elliptical in shape having a size about ~5 μm. 4-6 irregular pores exists on the distal surface. *Coronosphaera mediterranea* coccoliths were seen on 9 March and 6 April 2016. Seawater temperature and salinity were 16 °C and 38.6, 19 °C and 38.3 respectively.

**Family** Syracosphaeraceae  
**Genus** *Syracosphaera* Lohmann, 1902  
**Species** *Syracosphaera molischii* Schiller 1925 (Figure 9a)  
**Homotypic Synonym**  
*Caneosphaera molischii* (Schiller) Gaarder 1977  
Ziveri,

**Heterotypic Synonym(s)**  
*Syracosphaera corrigis* Okada & McIntyre 1977  
*Syracosphaera elatensis* Winter 1979  
**Description:** According to Young et al. (2003), *Syracosphaera molischii* found in the present study belongs to type 4. Distal flange is smooth and broad with tooth-like protrusions towards the central area. There are irregular concave ridges formed from upward growing laths in the central structure. Coccoliths were observed on 3 February 2016. Seawater temperature and salinity were 16 °C and 38.6.

**Distribution in Turkey:** First report along Turkish coasts.

**Species** *Syracosphaera pulchra* Lohmann 1902 (Figure 9b-c)  
**Description:** Coccolithes are ovoid in shape, having endothecal body caneoliths and circum-flagellar muroliths with bifurcate ending spines. The rim of caneoliths has three flanges, the distal-wall flage is corrugated, mid-wall flange is conspicuous, inner wall-cycle is prominent, the central area is filled by two circles of thin and short concentric radial laths.

Coccoliths are oval and have lengths 5-7 μm. Coccospheres were observed on several occasions on 10 and 22 September 2015, 9 and 25 February 2016, 2, 15 and 22 March 2016, 6 April 2016. Seawater temperature changed from 29 °C to 17 °C, salinity varied from 37.7 to 38.5 in these sampling dates. Holococcolithophore phase, formerly *Calyptrosphaera oblonga* Lohmann, 1902.

**Distribution in Turkey:** Previously reported in the Marmara Sea by Balkıs (2004), Balkıs and Taş (2016) and in the north eastern Mediterranean Sea (Eker-Develi, 2004).

**Family** Syracosphaeraceae  
**Genus** *Ophiaster* Gran, 1912  
**Species** *Ophiaster formosus* Gran, 1912 (Figure 10a)  
**Synonyms:** *Bernardosphaera stellata* Lecal-Schlader 1951  
**Description:** Coccolithes have short and broad string of posterior appendages (osteoliths). *Ophiaster hydroides* has longer and thinner osteoliths. The length of the link coccoliths are about twice the body length. It was observed on 16 December 2015. Seawater temperature and salinity were 18 °C and 39.4.

**Species** *Ophiaster cf. formosus* Gran 1912 (Figure 10b)  
**Description:** Body coccoliths are elliptical muroliths. Outer wall of the rim is high and non-imbricate. Axial structure is not apparent. Laths are overlapped with a few short, separate transversal laths in the central area. A coccolith belonging to this species was observed on 17 February 2016. Seawater temperature and salinity were 13 °C and 38.5. Body caneoliths length is 2.8 μm.

**Distribution in Turkey:** First report along Turkish coasts.

**Order** Syracosphaerales  
**Family** Calciosoleniaceae  
**Genus** *Calciosolenia* Gran 1912  
**Species** *Calciosolenia brasiliensis* (Lohmann) Young in Young et al. 2003 (Fig. 10c)  
**Basionym** *Cylindrotheca brasiliensis* Lohmann 1919  
**Homotypic Synonym(s)**  
*Cylindrotheca brasiliensis* Lohmann 1919  
*Anoplosolenia brasiliensis* (Lohmann) Deflandre 1952  
**Synonyms:** *Calciosolenia grani* Schiller 1925  
*Calciosolenia grani closterium* Schiller 1925  
*Calciosolenia grani cylindrothecaeformis* Schiller 1925  
*Calciosolenia tenuis* Bernard & Lecal (1960)  
*Scapholithus ganoretus* Kamptner (1967)  
*Scapholithus malenus* Kamptner (1967)  
**Description:** Liths are oblique rectangular in shape. There are very regular bars which merge to
form mildly curved axial ridge in the central area. Coccoliths were ~6.4 \( \mu m \) in length which is similar to previously reported values of 5-7 \( \mu m \) in Ziveri, (2004). Liths were observed on 17 February 2016. Seawater temperature and salinity were 13 °C and 38.5.

**Distribution in Turkey:** Previously reported along Turkish coasts by Polat and Piner (2002) and Koray (2001).

**Order** Syracosphaerales  
**Family** Rhabdosphaeraceae  
**Genus** Rhabdosphaera Haeckel, 1894  
**Species** Rhabdosphaera clavigera var. stylifera (Lohmann) Kleijne and Jordan, 1990  
**Basionym:** Rhabdosphaera stylifer Lohmann, 1902  
**Description:** Coccosphere is composed of discoidal exothecal rhabdoliths and helatoform endothecal rhabdoliths. Both exothecal and endothecal rhabdoliths are elliptical in shape, endothecal rhabdoliths have helatoform spines.  
**Dimension:** Coccosphere diameter without processes is ~8-10 \( \mu m \). It was observed on 30 March 2016 and 24 June 2016. Seawater temperature and salinity were 17 °C and 38.7, 27 °C and 39.5 respectively.

**Distribution in Turkey:** First report along Turkish coasts.

**Subclass** Prymnesiophycidae  
**Order** Zygodiscaceae  
**Family** Pontosphaeraceae  
**Genus** Scyphosphaera

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**Figure 9.** Scales of (a) Syracosphaera molischii type 4 (scale bar = 2 \( \mu m \)) and (b) Syracosphaera pulchra (scale bar = 600 nm), (c) a cells seen under light microscope (scale bar = 20 \( \mu m \)).

**Figure 10.** (a) Ophiaster formosus (scale bar = 5 \( \mu m \)), (b) A scale belonging to Ophiaster cf. formosus, (scale bar = 400 nm), (c) Calciosolenia brasiliensis (scale bars = 2 \( \mu m \)).

**Figure 11.** Rhabdosphaera clavigera var stylifera (scale bar = 10 \( \mu m \)).
Species *Scyphosphaera apsteinii* Lohmann 1902 (Figure 12)  
Basionym: *Scyphosphaera* apsteini Lohmann, 1902  
Synonyms Pontosphaera scutellum Kamptner (1952)

**Description:** Species is dimorphic having vase-shaped lopadoliths with a convex outline and flat ovoid cribriliths similar to the ones of *Pontosphaera japonica*. However, body coccoliths of *S. apsteinii* are less regular than of *P. japonica* (Young et al. 2017). There are morphological variabilities in this species (Lohman 1902). **Dimensions:** Coccosphere long axis ~40 μm, discoliths length ~7-10 μm, lopadoliths length ~11-14 μm. Species was observed on 3 February 2016. Seawater temperature and salinity were 16 °C and 38.6.

**Distribution in Turkey:** Previously reported along Turkish coasts by Koray (2001) and Koray et al. (2000).

**Discussion**

A total of ten new haptophyte species were recorded along the Turkish Seas in the present investigation. Their worldwide distribution was shown on Table 1. Although found in the western

![Figure 12. (a) Scyphosphaera apsteinii cell with three lopadoliths and cribriliths seen from inside of a lopadolith (scale bar = 10 μm) (b) a cribrilith observed with SEM (scale bar = 400 nm).](image)

**Table 1.** Worldwide distribution of haptophyte species found in the present investigation

<table>
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<th>Black Sea</th>
<th>North Sea</th>
<th>Boreal Sea</th>
<th>Baltic</th>
<th>Adriatic</th>
<th>Arabian Sea</th>
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Mediterranean Sea previously, non-calciﬁng haptophytes *Chrysochromulina alifera*, *C. parkeae*, *C. lanceolata* and *C. cf. ericina* (Puigserver et al., 2003) were found ﬁrst time in the Levantin basin of the Mediterranean Sea and along Turkish coasts. It was striking that the ratio of haptonema length : cell length (16:1) in *C. alifera* (Fig. 3) was twice higher than the value previously reported in the western Mediterranean Sea (Puigserver et al., 2003). According to Parke et al. (1956), this ratio was 2-2.5:1 in the North Atlantic Sea. *Chrysochromulina parkeae* was ﬁrst reported in the Mediterranean Sea during 1971-1972 (Leadbetter, 1974) and it was not recorded in this sea until the present investigation. There are relatively few records in literature about its presence (Table 1). It was diﬃcult to identify non-calciﬁng haptophyte species *C. cf. ericina* since we do not have electron microscope images. *H. hirta* and *C. spinifera* also have spines similar to the ones that we have observed. However, *C. spinifera* has shorter haptonema than ﬂagella (see the long haptonema in our species Fig. 6) and the shape of *C. hirta* is spherical, not oval or heart shaped as our species (Edwardsen et al., 2011). It was also recorded only once in the Mediterranean Sea by Leadbeater (1974). *C. lanceolata* is a new species ﬁrst identiﬁed in the western Mediterranean Sea (Puigserver et al. 2003). It was also reported in the Atlantic Ocean (Seoane, Eikrem, Arluzea & Orive, 2009) before the present study (Table 1). *Umbellosphaera irregularis* was reported in the Mediterranean Sea previously (Kleijen, 1993; Heimdal, 1997) but it is the ﬁrst record in the Turkish coasts. It was previously reported as a tropical species (Winter & Siesser 1994). *Umbellosphaera tenuis* and *Umbilicosphaera foliosa* were also found in the Aegean Sea region of the Mediterranean Sea previously (Dimiza et al., 2008a; Dimiza et al., 2015) but they are the ﬁrst reports for the Turkish coasts. *U. tenuis* was also observed in the southern part of the eastern Mediterranean (Oviedo, Ziveri, Alvarez & Tanhua, 2015). They are reported as tropical and subtropical species in literature (Perch-Nielsen, 1985; Hallegraeff & Jeffrey, 1984). *Syracosphaera molischii* and *Ophiaster formosus* belonging to Syracospherales order are also ﬁrst reports for the Turkish waters. They were reported in the Adriatic Sea previously (Vilicic, Marasovic & Miokovic, 2002). *Ophiaster formosus* is a species very similar to *Ophiaster hydroideus* morphologically in SEM images (Young et al. 2017 ). A scale found in the present investigation probably belong to *O. formosus* and seem to be slightly different shown by Young et al. (2017) (Fig. 10b). Percopo, Siano, Cerino, Sarno & Zingone (2011) found S. molischii type 2 in the western Mediterranean previously. *Rhodosphaera clavigera* var *stylifera* observed in the present study could be same with *Rhodolithecis claviger* reported along Turkish coastal waters (Koray, 2001), unfortunately there is no photograph in the publication for comparison. *Scyphosphaera apsteinii*, *Coronosphera mediterranea*, *Syracosphera pulchra* and *Calcosolenia brasiliensis* found in the present study were reported along Turkish waters and in the Mediterranean Sea previously (Baytay & Gönüül, 2016; Koray, 2001; Koray et al., 2000; Polat & Piner, 2002; Vilicic et al., 2002; Balkis, 2004; Dimiza et al., 2015; Balkis & Taş, 2016). *Syracosphera pulchra* was the most frequent coccolithophore species that we have coincided after *Emiliania huxleyi*. During our sampling it was observed in eight different dates, mostly in spring and autumn. Mediterranean Sea is one of the most nutrient-poor regions of the global ocean (Dugdale & Wilkerson, 1988). Thus, high diversity of coccolithophores is expected. Eastern Mediterranean is even more nutrient-poor than the western part (Krom, Kress, Brenner & Gordon, 1991; Yacobi et al., 1995; Psarra, Tselepides & Ignatiades, 2000). However, eastern Mediterranean coccolithophore studies are limited with the Aegean Sea (Malinverno et al., 2008; Dimiza et al., 2008; Dimiza et al., 2015). According to our literature survey, this is the ﬁrst study related to haptophyte species composition along the coast of southern Turkey.

**Acknowledgement**

This study was supported by TÜBİTAK 115Y767 and BAP 2016-2-TP-2-1912 projects.

**References**


**References**


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