PARASITES are typically small organisms that exploit their host both as a food source and as a habitat. Although well-studied as human pathogens and organisms prejudicial to human interests, they have been persistently ignored in microbial aquatic ecology. Increased awareness of the important role of viruses in marine aquatic ecosystems in processes as diverse as species competition, carbon cycling, and gene transfers has recently changed our overall view of aquatic parasites. Recent evidence of the widespread occurrence of small eukaryotic parasites, requiring eukaryotic hosts, has highlighted the existence of another kind of pathogens which potentially has specific ecological roles.

THE (RE)-DISCOVERY OF THE EXISTENCE OF EUKARYOTIC PARASITES AMONG PLANKTON

During the last decade, novel eukaryotic lineages have been discovered within the smallest fraction of marine eukaryotic plankton using culture-independent methods (mainly by the analysis of the genetic diversity of the 18S ribosomal RNA gene). All investigations performed so far have shown the overwhelming occurrences of environmental DNA sequences affiliated to novel eukaryotic lineages that have been grouped under the term of MALV (for Marine ALVeolate). These enigmatic new lineages represent up to 50% of sequences retrieved in all marine environments, from coastal waters to deep hydrothermal vents. They are everywhere.

Today, MALV sequences are believed to belong to Syndiniales, a group of species composed to date exclusively of marine parasites, which have been known for more than a century! Indeed, molecular techniques have clearly revealed the widespread occurrence of such parasites in marine waters. Interestingly, recent studies performed with the smallest planktonic fraction taken from lakes also revealed a high proportion of environmental sequences belonging to putative parasites (mainly chytrids, Cercozoa, Perkinsozoa and Colpodellida). Although different lineages have been retrieved from marine and freshwater ecosystems, these converging observations show the ecological significance of small eukaryotic parasites in aquatic environments.

ECOLOGICAL SIGNIFICANCE OF SYNDINIALES

Described Syndiniales species are all obligate parasites, and infect a wide range of hosts such as dinoflagellates, ciliates, cnidarians, crustaceans (like copepods and crabs), chaetognaths, radiolarians and fish eggs. Indeed, these parasites potentially affect most marine planktonic organisms. In particular, Syndiniales includes the widespread genus Amoebophrya, known to infect a large number of (if not all) dinoflagellate species, including several responsible for toxic ‘red tides’ (Fig. 1). The Amoebophrya vegetative life-cycle takes about 2-3 days and is characterized by alternation between a small, free-living stage (the dinospore) and an endoparasitic growing stage (the trophont) (Fig. 2). The life-cycle starts when a dinospore, a biflagellate cell 2-10 µm in

As global warming takes hold, research shows that a group of eukaryotic marine parasites could have a far-reaching impact on marine ecology.

LAURE GUILLOU
CATHARINA ALVES-DE-SOUZA
RAFFAELE SIANO
HUMBERTO GONZÁLEZ

The ecological significance of small, eukaryotic parasites in marine ecosystems
Although different lineages have been retrieved from marine and freshwater ecosystems, these converging observations show the ecological significance of small eukaryotic parasites in aquatic environments.

**IMPLICATIONS OF SYNDINIALES FOR FOOD WEBS AND CARBON FLOW**

Considering the wide host range of Syndiniales, these parasites could have a key role in marine planktonic food webs and fisheries. However, the ecological impact of such eukaryotic parasites remains to be conceptualized and considered by biogeochemical models. All species known to date are highly virulent, as infection generally voids host cell replication and results irreversibly in death of the host. Estimates based on culture experiments using dinoflagellate hosts suggest that almost half of the host biomass is transformed into dinospores; the rest is rapidly incorporated into the pool of particulate and dissolved organic matter (POM and DOM) and used as substrates by marine bacteria. Syndiniales dinospores can be very abundant within the smallest size fractions of marine eukaryotic plankton. Sometimes they can account for an important proportion (>25%) of nanoplanctonic (2–20 μm) organisms and can constitute a suitable food source for microzooplankton (the heterotrophic protists between 20–200 μm). Like viruses, these parasites reroute a substantial proportion of the carbon inputted in the general food webs, and interfere in the competition between species by preferentially infecting the most actively growing species. This process is called the viral loop (or viral shunt) for viruses. The myco loop describes a similar pathway for chytrids infecting freshwater diatoms. Additionally, eukaryotic parasites are particularly efficient infective agents of large, inedible dinoflagellates, releasing carbon biomass potentially refractory to microbial grazing activity. The myco loop describes a similar pathway for chytrids infecting freshwater diatoms. By homology, Syndiniales produce a 'dino loop' within marine food webs, from microalgae to large metazoans.

**CONCLUSION**

That fact that Syndiniales parasites constitute a very diverse and widely distributed parasitic group suggests that they could play an important role both in host population regulation and microbial communities. This could be particularly relevant at the surface of all oceans, where microbial food webs usually dominate the carbon flux through complex trophic interactions. They may also have a key role in the regulation of invasive species in the context of the recent global warming and coastal migrations. However, more quantitative studies are required to better evaluate the functional role of these parasites and their contribution to carbon flow in marine food webs.

**FURTHER READING**


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Fig. 2 (left): Life cycle of Amoebophrya sp. infecting Neoceratium minimum. Red, nucleus of the host and the parasite; green, cytoplasm of the parasite detected by fluorescent in situ Hybridization; Samples taken from the Mediterranean Sea, collected during the BOUM cruise.

C. Alves-de-Souza

Fig. 3 (bottom): Parasitic loops in marine food webs. A potential role for eukaryotic parasites is highlighted by the dino loop pathway that parallels the viral loop for smaller organisms.

DOM, Dissolved organic matter; POM, particulate organic matter; L. Guillo & C. Alves-de-Souza