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Review on *Polypodium Hydriforme* Infestation of Sturgeon Eggs and Its Implications in Species Conservation

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Abstract. *Polypodium hydriforme* is the only known parasite adapted to intra-cellular parasitism of sturgeon oocytes, thus affecting the delicate life balance of these endangered species. Aquatic ecosystems are often shaped by intricate interactions between various organisms, each playing a distinct role in the overall health and sustainability of the environment, parasites on the other hand pose no beneficial roles and are a threat especially for fragile or declining species. Sturgeons, which are endangered and ecologically important fish species, serve as hosts for this parasite during their crucial reproductive phase. The presence of *Polypodium hydriforme* in sturgeon eggs has prompted investigations into its effects on both the host's reproductive success and the broader aquatic ecosystem. Stating the intricacies of this parasitic interaction is essential not only for unravelling its evolutive adaptations but also for ensuring the conservation of sturgeon populations and the preservation of aquatic biodiversity as a whole.

1 Introduction

Polypodium hydriforme is an enigmatic parasite that was thought until recently to belong to the phylum Cnidaria, however, recent molecular taxonomic data reveals its place closer to myxozoans [1], as *P. hydriforme* and Myxozoa form a clade called Endocnidozoa [2]. Discovered in 1871 within the eggs of sterlet (*Acipenser ruthenus*) from the Volga river in Russia, one of the most important aspects of *P. hydriforme* is the fact that, to date, the parasite has been found in many species of the family *Acipenseridae* [3]. Among the infected are: *Acipenser baerii, Acipenser brevirostrum, Acipenser fulvescens Acipenser gueldenstaedtii, Acipenser medirostris Acipenser nudiventris, Acipenser ruthenus, Acipenser schrenckii Acipenser stellatus, Acipenser transmontanus* and *Huso huso* [4].

The life cycle of *P. hydriforme* is particularly interesting, during its initial parasitic phases, the organism's earliest developmental stages consist of of an dual-nucleus cells within the immature ova [5]. All developmental processes, from embryo to postembryo stages occur within the fish ova, enduring for multiple years. The planula and stolon exhibit an inverted

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arrangement of germ layer. Each parasitic stage is encompassed by a considerably polyploid single-cell trophamnion, analogous to the second polar body.

The compelling association between *P. hydriforme* and sturgeon eggs has spurred investigations into the far-reaching consequences of this parasitic interaction. Beyond its impact on the reproductive success of the host sturgeon, the presence of *P. hydriforme* has the potential to reverberate throughout the broader aquatic ecosystem [6].

The particular preferences of *P. hydriforme* for sturgeon eggs has piqued scientific curiosity, not only to uncover the evolutionary intricacies that have enabled the parasite's adaptation but also to chart a course towards safeguarding sturgeon populations and the entirety of aquatic biodiversity. In this study, we delve into the multifaceted between *Polypodium hydriforme* and sturgeon eggs, exploring its potential implications for both the host species and the ecosystem they inhabit.

2 *Polypodium hydriforme* characteristics and impact on sturgeon reproduction

P. hydriforme stands as a unique exemplar among sturgeon parasites, having undergone intricate adaptations towards intracellular parasitism therefore being regarded as an evolutionarily ancient parasite of sturgeons. The substantial portion of its lifecycle is characterized by endoparasitic residence within the oocytes of Acipenserids. Pioneering inquiries were conducted by Lipin (1911) [7], which delved into the parasite's life cycle unveiling the inversion of germ layers within the parasitic stolon, a phenomenon construed as an evolutionary adaptation to parasitism, and later examined in detail by Raikova (1990) [8]. Infected eggs are twice the size of normal eggs, whitish to ash gray in color, and contained within them parasitic stolons of 1.0–2.5 cm long [9] (Figure 1). Notably, *P. hydriforme* bears profound economic implications due to its impact on the most prized yield of acipenserids – the illustrious black caviar.

The parasite is still consistently posing a significant concern within the caviar industry due to its role as an intracellular parasite of fish eggs, directly affecting production and with no known treatment [10]. The prevalence rates of this parasite have been observed to reach alarming levels, sometimes even reaching 100%, particularly in species like *A. gueldenstaedtii* and *Acipenser ruthenus* [11].

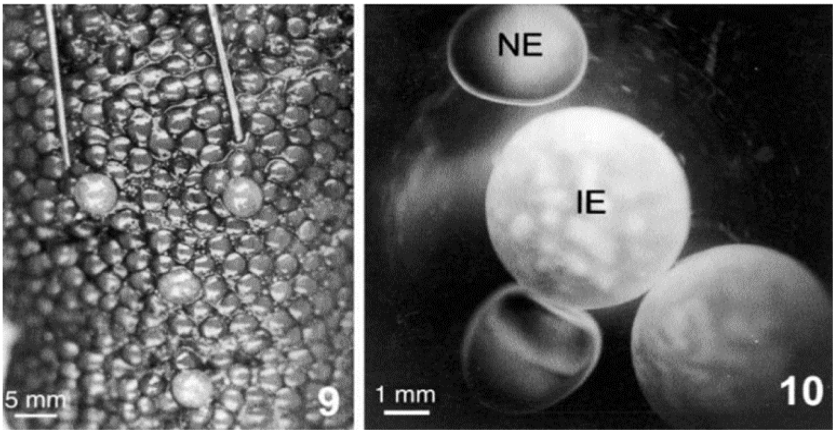

Fig. 1. General view of ovaria of *Acipenser ruthenus* with four larger eggs, infected by *Polypodium hydriforme* (left); infected sterlet eggs (IE) with everted stolon inside each of them and two normal eggs (NE) before spawning (right). Image reproduced with permission from Raikova et al., 1994 [12].

Polypodium infection takes on heightened significance within Russia, Iran, the European Union, and USA, which are the major global producers of caviar [13]. Free-living specimens of *P. hydriforme* (Figure 2) exhibit biradial symmetry, typically, these specimens possess a sac-shaped body with a set of either 12 or 24 tentacles. The tentacles are organized into two symmetrical lateral groups positioned on the sides of the body.

The tentacles themselves can be categorized into two distinct types: sensory tentacles and supporting (walking) tentacles. Sensory tentacles, which are slenderer in nature, are located at the base of the mouth cone [14]. They form a pair stacked above each other on the oral side of the organism. On the aboral side, there are two pairs of walking tentacles, which are comparatively thicker in structure and play a role in providing support and mobility.

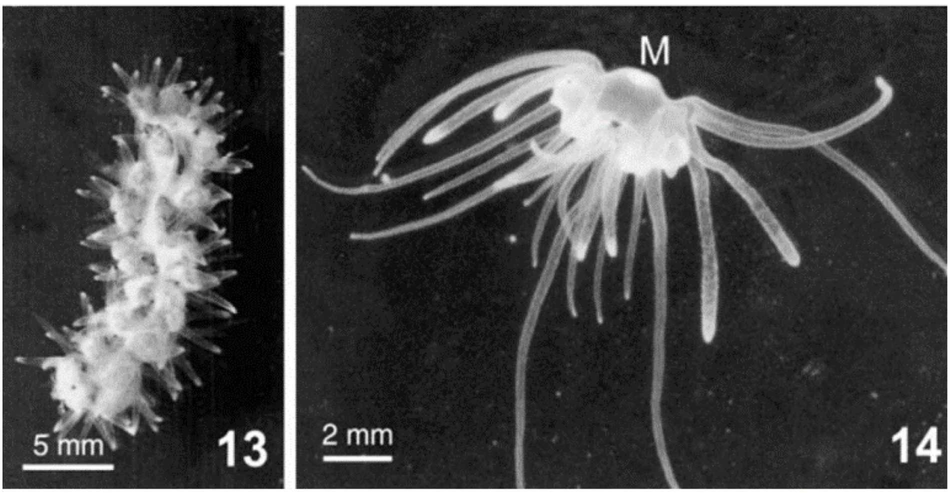

Fig. 2. Stolon with external tentacles hatched from an infected sterlet egg (left) and solitary free-living Polypodium in fresh water (right). M – mouth. Image reproduced with permission from Raikova et al., 1994 [12].

Interestingly, efforts aimed at infecting sterlets measuring 15–17 cm in length with cultured free-living *P. hydriforme*, with or without the inclusion of male and/or female gonads, yielded unsuccessful outcomes [12]. Notably, the *P. hydriforme* individuals displayed an inability to affix themselves to any region of the fish's body, nor were they ingested by the fish. When *P. hydriforme* was intentionally deposited onto sterlets, sporadic instances were observed wherein attachment occurred to the fins through their tentacles, albeit for a duration not exceeding 10 minutes. Furthermore, *P. hydriforme* specimens devoid of gonads exhibited no discernible response to pre-larvae of the sturgeon [12].

These observations serve to lend support to the proposition that the infection of acipenserids potentially transpires during their early life stages, characterized by more delicate skin that renders them susceptible to the impact of *P. hydriforme's* nematocysts. However, the precise reaction of gametophore-carrying *P. hydriforme* specimens to pre-larvae of fish remains an avenue yet to be explored through rigorous experimental inquiry.

3 Conclusions

The intricate interplay between *P. hydriforme* and sturgeon eggs remains a captivating realm of parasitic dynamics and potential ecological ramifications. This parasitic species stands as a distinctive exemplar, having intricately adapted to intracellular parasitism within the oocytes of acipenseriformes.

The cumulative evidence gleaned from these observations resonates with the conjecture that the window of vulnerability for acipenserids to *P. hydriforme* infection may be concentrated during their early life stages. This hypothesis posits that the innate delicacy of the skin during this phase renders them particularly susceptible to the potent nematocysts of *P. hydriforme*. Still, the intricacies of the interaction between gametophore-carrying *P. hydriforme* specimens and pre-larvae of the sturgeon remain an intriguing avenue that beckons further empirical exploration. In light of the intricate and nuanced dynamics elucidated by these findings, the association between *P. hydriforme* and sturgeon eggs emerges as a captivating subject for ongoing scientific inquiry. As our understanding of this interplay deepens, it offers a potential key to unlocking the enigmatic intricacies of host-parasite relationships and their broader ecological implications within the intricate tapestry of aquatic ecosystems.

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