Emerging fields in ancient lake research: an evolutionary perspective

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Over the past decades, a number of landmark publications have resulted from evolutionary studies of ancient lake systems and taxa, significantly increasing our knowledge about patterns and processes of evolution in these unique ecosystems. Basic concepts of, for example, sympatric speciation, sexual selection, adaptive radiation, hybridization, and punctuated equilibrium are, at least partly, based on ancient lake studies.

Moreover, ancient lakes, that is, lakes that have continuously existed for hundred thousand or even million years, have long been recognized as centres of biodiversity and endemism and are a major focal point for systematic, ecological and conservation research.

A common problem in ancient lake studies is the lack of knowledge and/or controversy about their limnological history and the unknown origin of respective faunal and floral elements.

Although ancient lakes differ in their origins and characteristics, it is their diversity and endemism that often distinguish them from post-glacial lakes. In fact, these parameters often serve as proxies for the recognition of ancient lakes. Most workers, however, consider longevity to be the only objective criterion for ancient lakes as there is a considerable number of world-wide lakes that are presumably old but lack a high degree of diversity and endemism. On the other hand, there are lakes with incredible biotic diversity that are considered to be relatively young.

Though, studies on ancient lake biota are ongoing for a number of taxa and lakes, no unifying theory on patterns and processes of evolution in ancient lakes exists. Nonetheless, over the past years a number of interesting fields in ancient lake research has emerged:

1) *Biogeographical origin of biotas*
   This topic deals with questions of, for example:
   - From where received ancient lakes their first biota?
   - What are the biogeographical relationships of these lakes?
   - When and how often did outside species invade the basin?
   - Did they diversify within the respective lakes?

2) *Rates of evolutionary change*
   This topic deals with the highly controversial question whether the often high degree of biodiversity observed in ancient lakes is the result of: I) a presumed long-term stability, providing the environment for long-term survival of old lineages due to less pronounced extinction rates, II) rapid changes of the

lake's environment due to major geological, hydrological or climatic changes leading to an initial extinction of taxa with subsequent rapid speciation events, or III) a punctuated equilibrium - a combination of both long-term stability and rapid changes as driving force of macroevolution.

3) *Endemic biodiversity and recognition of species*
   This field deals with modes and spatial scales of endemism in ancient lakes, the recognition/identification of species in general, and how to treat conflicts among morphological, ecological and genetic data.

4) *Modes of speciation*
   Though, the field of speciation in ancient lakes has received considerable attention, there is an ongoing controversy about modes of speciation in ancient lakes. Moreover, there is a considerable bias in ancient lake research towards sympatric speciation and adaptive radiations. Thus, concepts of sympatric vs. allopatric and parapatric speciation or adaptive vs. non-adaptive radiation will stay on the mind of evolutionary biologists for years to come.

5) *Invasion biology*
   This field deals with identifying and tracking alien species invading a lake and assessing their impacts on the endemic biodiversity. At the same time, it also assesses the potential of ancient lake taxa to become invasive.

6) *Conservation biology*
   Focal points of conservation research are an assessment of the importance of endemic ancient lake biota for maintaining biodiversity, and assessment of anthropogenic pressures and a monitoring of endemic biodiversity, particularly in hot spot areas.

All these topics have been subject of major studies attractive significant funding from national and international organisations and resulting in key publications in leading journals. Interestingly, many of these studies were conducted by international research groups within a multidisciplinary framework comprising, for example, molecular biologists, geologists, climatologists and palaeontologists.