Limnology in the tropics: Next steps?

A B Santoso* and R L Toruan
Research Centre for Limnology, Indonesian Institute of Science (LIPI), Cibinong Science Centre, Bogor, 16911

*Corresponding author
Email: ari@limnologi.lipi.go.id

Abstract. Limnology in the tropics provides a new paradigm for inland water science, which has traditionally focused on temperate regions. Numerous studies have shown that tropical inland waters are fundamentally different from temperate systems. Warm conditions, combined with higher solar radiation and higher precipitation rates, have important consequences for biogeochemical processes in tropical waters. In addition, rapid population and economic growth has resulted in high levels of anthropogenic pressures on these systems. Such pressures have resulted in a reduction in the adequate supply of water of acceptable quality in many tropical countries and provide challenges to limnologists in terms of societal concerns and climate change impacts. Using a bibliometric approach to assessing limnological studies in the tropics, we examined how tropical limnology has barely touched the fundamental complexity that tropical inland waters have. Over 12,000 references were found and indexed by Scopus as being within the category of “limnology”. Only 335 of these were grouped under tropical studies. However, similar to those studied globally, studies from the tropics focused mainly on “lake”, “river”, “phytoplankton”, “carbon”, “oxygen”, “fish” and “nutrient”. While areas of research tended to reflect how limnologists perceive the impacts of climate change and eutrophication on lentic and lotic systems, the ecosystem services provided by inland waters and their resilience to disturbance were found to require further study.

1. Introduction
Historically, one of the earliest limnological studies in the tropics was undertaken by the German Sunda Limnological Expedition. The expedition was led by Ruttner in 1928 - 1929 [1], just six years after the foundation of the Internationale Vereinigung für Limnologie (later known as the Societas Internationalis Limnologiae (SIL)) [2]. Based on a strong belief that the tropics and their environmental conditions are the primordial of life [3], the Sunda Expedition headed to the Sunda Islands (Java, Sumatra, and Bali of Indonesia) and spent 10 months collecting plants, animals and water samples [2]. The expedition aimed to explore terrestrial and surface water systems in this previously unexplored part the globe [1]. Not only describing 1100 new species, this expedition also provided hydrographic, physical, and chemical data for 15 lakes that could be correlated with their flora and fauna [4].

The seminal findings of the Sunda expedition are pre-dated by the discovery of the first example of a tropical thermocline (in Lake Malawi), which was described in 1900 [5]. By the 1960s, better explanations of the physico-chemical and biological interactions of tropical lakes began to emerge [e.g.
6, 7, 8], although temperate regions, i.e. Europe and North America, still remained the main focus of limnological investigations at that time [9]. More recently, however, a relatively new paradigm from the tropics has been developed that complements our existing knowledge of inland waters [10] and enhances our understanding of the role of inland waters on the processes and functions of the global biosphere.

It has been demonstrated that inland waters are very important in regulating most global biogeochemical cycles, e.g. [11] and that the paradigm of limnological study is no longer within a microcosm boundary, as postulated by Forbes in 1887 [12]. Limnology has evolved into a comprehensive, interdisciplinary science and frequently adopts an ecosystem perspective approach to address fundamental questions or applied problems [13].

In this paper, we review paradigms and achievements in limnology, especially in tropical regions. As economic development in tropical countries is among the fastest in the world, the ecology of inland waters in these areas should be of great concern to limnologists. For example, as tropical waters are not notably warmer than those in temperate zones, they do not get cold during any part of the year [9]. So, their response to climate change should be of interest to most limnologists. Using a bibliometric approach, we have analysed trends in limnological research, in general, and compared them to those that have been evolving in the tropics. We highlight some of the paradigms of tropical limnology that could address the emerging problems.

2. Global Trends in Limnology and Tropical Limnology

We determined global trends in limnological research by analysing the frequency with which certain words were used in the 12, 181 publications (i.e. journal articles and books) that had been extracted from the Scopus database under the category of “limnology” on 3rd July 2019. Using a text mining technique written under the R statistical package [14], we identified key words used by the authors. These were then visualised as a word cloud, which enabled us to identify the main topics. For better visualisation purposes, we included only key words that have a minimum frequency of appearance of 50. The development of a particular research topic could also be mapped over time using this technique, because we were able to count the frequency of use on an annual basis.

From a global perspective, “lake” was the main key word that appeared under the category of limnological research (figure 1). This infers that lakes have been the main object, or locus, of global limnological studies, completely dominating over studies on “river”, “reservoir”, “pond” and “estuary”. “Phytoplankton”, “ecosystem”, “sediment” and “carbon” were also identified as important areas of research, while “oxygen”, “zooplankton”, “fish”, “nitrogen”, “phosphorus”, “community” and “modelling” have been of lesser importance. Almost every year, research on lakes has been published (figure 2), with an average of 50 to 100 publications on lakes per year having been indexed by Scopus. Remarkably, since 2007, research publications on lakes have increased to more than 150 per year. Although initiated in the early 1990’s, research into carbon did not increase rapidly until after 2005. Modelling, compared to other techniques for solving limnological problems, seems to be prominent (figure 1). This technique has been used by limnologists since 2008, building on earlier research that provided a better understanding of rates of change in the mid 90’s (figure 2).

By applying a filtering technique, we were able to extract publications that dealt with tropical issues, only. There were 335 publications in total dealing with those issues. Again, “lake” was the main focus of tropical limnology research (figure 3), with “reservoir” also being ranked very high. Similar to the situation for global limnology, “phytoplankton”, “ecosystem”, “carbon”, “oxygen”, “zooplankton”, “fish”, “nitrogen” and “community” were also the main focus of research in the tropics. Surprisingly, research on lake sediments has rarely been undertaken in this part of the world.
Figure 1. Word cloud of key words used in the published papers indexed by Scopus under the category of limnology. Words that appeared most frequently are shown more prominently.
Through this analysis, we can see that topics studied in the tropics are within the mainstream of global paradigms in limnology. The most high-ranking key words (figures 1 & 3) are aligned with the top-6 research paradigms in limnology, i.e. carbon biogeochemistry, food webs, landscape limnology, nutrient budgets, community size structure and climate change [15]. Thus, the current situation strengthens the global perspective of limnology as well as our understanding of the role of inland water ecosystems in the biosphere. However, further inland water inventories that include their related processes across geographical boundary are indeed still relevant.

Although we may have already had knowledge of the important role of inland waters in the biosphere, limnologists have now been able to convince the international community on the important role of inland waters in regulating the global carbon cycle [16], although many estimates have also included impoundments, rivers and wetlands as well as lakes [17, 18, 19]. Comparing the limnology of tropical vs. temperate systems, in our opinion, has little value. Instead, predictive limnology should be at the forefront of increasing our understanding of the discrete nature of inland waters in serving society, as well as science. Limnology should transform its traditional conceptual perspective into more modern approach that attempts to solve the world’s problems. As emphasised by [20], inland aquatic systems are of huge global importance and limnology should take its rightful place in the global scientific arena. Evidence gathering on what could happen to our inland waters in the face of global warming and increasing anthropogenic pressures should be the main goal of modern limnology.
Figure 3. Word cloud of key words used in the published papers indexed by Scopus under the category of tropical limnology. Words that appeared most frequently are shown more prominently.

3. Facts and Challenges in the Tropics

The tropics have emerged as a critical region of the world with a unique set of development challenges and opportunities. There, the economy is growing at least 20% faster than any other part of the world [21]. The tropics are also home to about 40% of world’s population, and this is predicted to reach 50% by 2050. With such rapid population growth and economic development, energy demands in the tropics are also very high. To solve this problem, hydropower dams have been built and more are to be constructed or planned [22]. These have impacts on freshwater systems.

Currently, almost half of the population in the tropics is considered to be in areas that are vulnerable to water stress, even though just over half of the world’s renewable water resources are located there. Water pollution and sanitation problems are major concerns in many tropical countries. Many South East Asian Rivers are known to be the most polluted in the world [21]. As population and economic growth increase rapidly [23], pressures on renewable water resource are becoming more intense. So, these resources, including their natural environment, need to sustain rapid development in areas in which, on the other hand, governance of natural resources management is still far from perfect. Despite significant investment in infrastructure, poverty, low educational outcome, and poor sanitation and health standard, remain prevalent in many tropical countries. Land degradation, deforestation and poor agricultural practices also indicate how complex the social-ecological interactions in the tropics are. Nearly one-third of all land, including freshwater ecosystems, in the tropics has experienced degradation over the last three decades. High rates of poverty and limited human and institutional capacity are the main challenges that most tropical nations have to face. Further, urbanisation in the tropics has increased more rapidly than the global average, having
increased from 31% of the population in 1980 to 45% in 2010 [21]. This suggests that urban areas will be growing rapidly in the future, as well.

A better understanding of the uniqueness of the tropical climate and the environmental conditions that it creates, and of its biodiversity and sociocultural lives, is crucial for developing plans and strategies that support infrastructure development in the tropics. Such effort is a prerequisite to providing habitable areas that have the natural resource capacity required to feed its dense population and provide energy, while ensuring environmental sustainability. Currently, most tropical nations are less developed than their counterparts in the rest of the world. In particular, investment in research and development is low, as indicated by the lower number of enrolments in tertiary education per capita and the fewer scientific and technical papers that have been published. In the light of this, creating a better understanding of the processes, functions and services of ecosystems appears to be a really challenging task.

4. Next Steps?
We believe that where there are challenges, there are also opportunities. Alongside the mega-scale challenges in the tropics, come big opportunities for the development of innovative science and, with economic improvements, come opportunities for the tropics to improve their scientific capacities. Investment in research and science is important if tropical nations are to undergo rapid economic and population growth with minimal impacts on the environment. This is important, not only for their competitiveness in the global economy, but also in terms of maintaining their future environment. It is now recognised that natural ecosystems provide services that underpin all life on Earth, and that humans are a subset of those ecosystems. So, knowledge of human impacts and ecosystem responses are keys to assessing sustainability. In relation to sustainability in inland water ecosystems, limnology is well placed to provide a better understanding of the processes, structure and functions of such systems. It also has a pivotal role to play in the evidence based management of lakes, rivers, reservoirs, wetlands and other terrestrial aquatic ecosystems. With its inter/multi-disciplinary approach to science, limnology can also integrate scientific evidence and stakeholder engagement to develop methods for the effective management of the aquatic ecosystems (figure 4). Furthermore, through transdisciplinary networks that include scientists, policy makers and managers, the rate of progress towards sustainable management would improve.
Figure 4. Stakeholder interaction in addressing multidimensional problems in inland waters.
Combining traditional wisdom with the experiences of people living and working in the tropics is the key to developing sustainable solutions to the effective management of inland waters. Recognising and acknowledging the way that the local people interact with their aquatic ecosystems is an important aspect of management. The science of limnology would benefit from embracing local knowledge to create a better understanding on aquatic ecosystems. It should also contribute to establishing a detailed understanding of the extent and causes of an environmental problems, as well as developing techniques to solve those problems or to minimise their impact. Hence, more local people need to be exposed to limnology, through formal education and/or the training of students. It is likely that, as in other countries, citizen-based water quality monitoring programs will eventually grow as communities become more aware to their environment.

Effective partnerships across regions, pan-tropical and beyond, and across disciplines may also generate an environment that supports the development of limnology in the tropics. This strategy would also fundamentally advance our limnological knowledge from a global perspective, increasing our overall understanding of the functions and services provided by inland waters to planet Earth.

5. References
[1] Göltendhboth 1996 In: Perspectives of Tropical Limnology (edsSchiemer F & Boland K T), pp. 1-18
[2] Egerton F N 2014 Bull. Ecol. Soc. Am. 133–48
[3] Thienemann A F 1959 EinLebenimDienste der Limnologie
[4] Ruttner F 1963 Fundamentals of limnology
[5] Fullerborn F 1990 Verh. Ges. Erdk. Berl. 28: 332-338.
[6] Eccles D H 1962 Nature 194 1097–1098
[7] Coulter W 1963 Limnol. Oceanogr. 8 463–77
[8] Talling J F 1969 SIL Proceedings, 1922-2010 17 998–1012
[9] Talling J F 2008 Freshw. Rev. 1 119–41
[10] Lewis Jr W M 1987 Annu. Rev. Ecol. Syst. 18 159–84
[11] Engel F, Farrell K J, McCullough I M, et al 2018 Sci. Nat. 105 2512
[12] Elster 1974 Mitt. Int. Ver. Theor. Angew. Limnol. 20:7–30.
[13] Cole J J 2009 In:Encyclopedia of Inland Waters (eds. Likens G E)
[14] R Core Team 2019 Version 3.5.3
[15] Downing J A 2014 Int. Waters 4 215–32
[16] Cole J J, Prairie Y T, Caraco N F, et al J 2007 Ecosystems 10 171–84
[17] Messager M L, Lehner B, Grill G, Nedeva I and Schmitt O 2016 Nat. Commun. 7 1–11
[18] Lehner B and Grill G 2013 Hydrol. Process. 27 2171–86
[19] Lehner B and Döll P 2004 J. Hydrol. 296 1–22
[20] Downing J A 2009 SIL Proceedings, 1922-2010 30 1149–66
[21] State of the Tropics 2014 Report
[22] Zarfl C, Lumsdon A E, Berlekamp J, Tydecks L and Tockner K 2014 Aquat. Sci. 77 161–70
[23] State of the Tropics 2017 Report