Earth-Science Reviews 173 (2017) 259–265

Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

Global loss of aquatic vegetation in lakes

Yunlin Zhang[a,*], Erik Jeppesen[b,c], Xiaohan Liu[a], Boqiang Qin[a,*], Kun Shi[a], Yongqiang Zhou[a,d], Sidinei Magela Thomaz[e], Jianmin Deng[a]

[a] Taihu Laboratory for Lake Ecosystem Research, State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, PR China

[b] Department of Bioscience and Arctic Research Centre, Aarhus University, Vejlsøvej 25, DK-8600 Silkeborg, Denmark

[c] Sino-Danish Centre for Education and Research, Beijing 100049, PR China

[d] University of Chinese Academy of Sciences, Beijing 100049, PR China

[e] Universidade Estadual de Maringá – Nupélia, Av. Colombo 5790, Maringá, PR 87020-900, Brazil

ARTICLE INFO

Keywords:
Aquatic vegetation
Remote sensing
Accelerating loss
Eutrophication
Percent rate of change

ABSTRACT

Quantitative global assessments of aquatic vegetation dynamics in lakes are lacking despite reports of the losses of submerged aquatic vegetation. We conducted a comprehensive global assessment of aquatic vegetation at 155 study sites. We also included ≥ 2 yr of information on the absolute or relative area of aquatic vegetation from the literature. We calculated the difference between initial and final observed aquatic vegetation area (or cover) to represent the overall trends over time. We classified the study sites of aquatic vegetation into the categories "increasing", "decreasing" or "no change" using a threshold of 10%. Aquatic vegetation area (or cover) decreased in 101 study sites, particularly in China (35 study sites), increased in 43 study sites, and showed no marked changes in 11 study sites. Our results revealed an accelerating decrease rate (vegetation loss in terms of area or cover) over time: 13.5 ± 16.9%/yr (1900–1980), 21.8 ± 28.9%/yr (1980–2000) and 33.6 ± 59.8%/yr (after 2000). Moreover, the area (or cover) increase rate in lakes where aquatic vegetation showed recovery decreased from 23.5 ± 29.9%/yr (1980–2000) to 16.8 ± 13.2%/yr (after 2000). We conclude that aquatic vegetation loss is accelerating, especially that of submerged aquatic vegetation and particularly in lakes with an area larger than 50 km^2. The predominance of decreasing vegetation found in our study is likely caused by multiple stressors such as eutrophication, algal blooms, land reclamation, aquaculture cultivation and global climate changes.

1. Introduction

Lakes provide a variety of important ecological services and are affected by multiple human activities as well as global climate change. Due to the important ecological and socioeconomic services provided by aquatic vegetation, including increasing water clarity, stabilizing sediments and further decreasing the rate of nutrient cycling, improving water quality, and providing food and habitats for many aquatic animals (Jeppesen et al., 1998; Horppila and Nurminen, 2003; Orth et al., 2006; Carr et al., 2010), numerous studies conducted over the past five decades have focused on monitoring the changes in the aquatic vegetation of lake ecosystems and identifying the mechanisms driving its distribution, abundance and dynamics (Sand-Jensen et al., 2000; Körner, 2002; Liira et al., 2010; Kolada, 2014; Liu et al., 2015; Phillips et al., 2016). These studies collectively suggest that the loss of aquatic vegetation is a global phenomenon caused by intensified human activities such as land reclamation, aquaculture, and eutrophication as well as global climate change and its resultant increase in temperature and CO_2 and greater UV-B exposure (Sand-Jensen et al., 2000; Körner, 2002; Phillips et al., 2016; Short et al., 2016). Similarly, a global loss of seagrass has been observed in the marine ecosystems (Orth and Moore, 1983; Lotze and Jackson, 2006; Waycott et al., 2009).

The loss of submerged aquatic vegetation, especially in shallow lakes, may trigger a shift from a clear macrophyte-dominated state to a turbid phytoplankton-dominated state (Scheffer et al., 1993). A reduction in the biomass and biodiversity of aquatic vegetation also results in habitat degradation, which negatively affects a variety of aquatic animals and leads to a reduction in ecosystem service functions (Jeppesen et al., 1998). However, some human impacts (*e.g.*, eutrophication) may enhance the cover and biomass of aquatic vegetation that harvests light at or above the water surface (*e.g.*, free-floating species), which may also negatively affect ecosystem services and biodiversity when cover is too high (Villamagna and Murphy, 2010). Moreover, moderate to high nutrient concentrations may lead to

* Corresponding authors at: Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, 73 East Beijing Road, Nanjing 210008, PR China.
E-mail addresses: ylzhang@niglas.ac.cn (Y. Zhang), qinbq@niglas.ac.cn (B. Qin).

http://dx.doi.org/10.1016/j.earscirev.2017.08.013
Received 27 May 2017; Received in revised form 19 August 2017; Accepted 20 August 2017
Available online 08 September 2017
0012-8252/

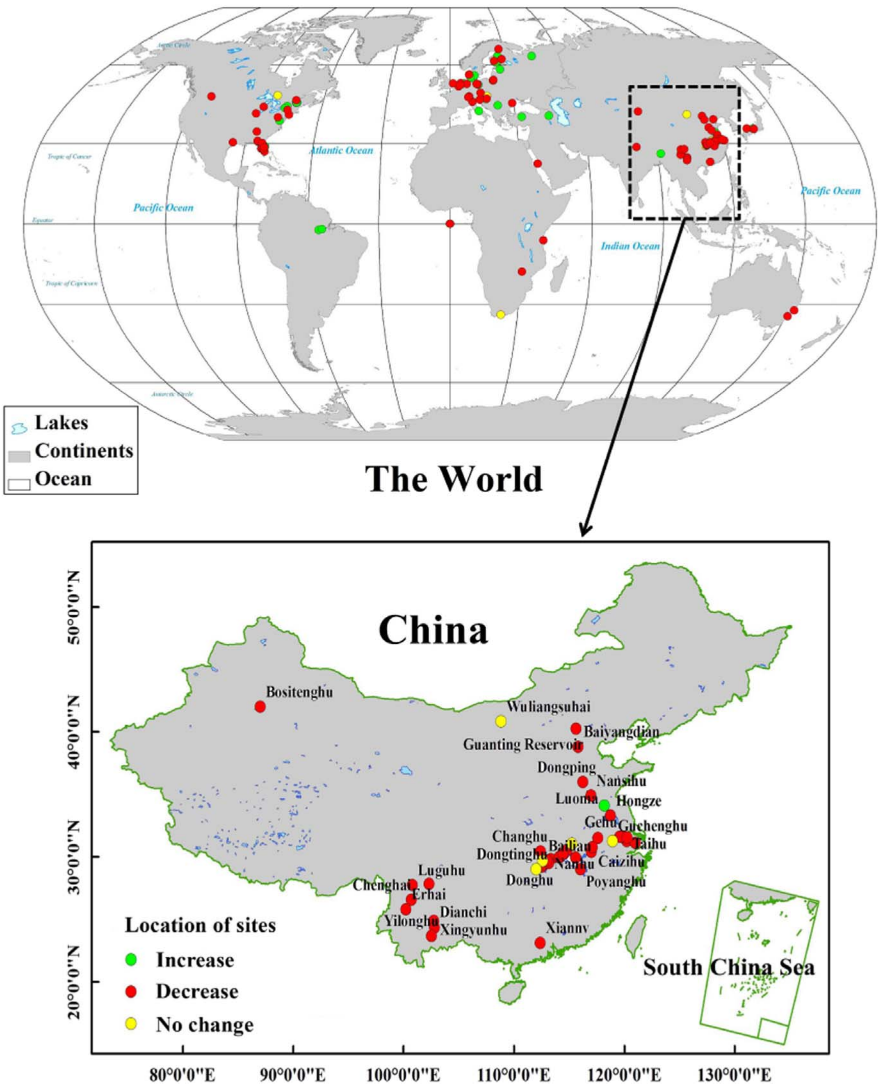

Fig. 1. Spatial distribution of study sites around the world and in China. Green indicates a decrease, red an increase, and yellow no change in aquatic vegetation. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

excessive macrophyte growth, which may hinder boating, commercial fishing and angling.

Previous efforts to assess general trends in the distribution of aquatic vegetation in lakes and its abundance, composition, richness, and diversity have focused on one or a few lakes within a small geographical area (Sand-Jensen et al., 2000; Körner, 2002). Most studies have also been based on limited quantitative data (Schelske et al., 2010; Cheruiyot et al., 2014; Dong et al., 2014; Baastrup-Spohr et al., 2016), yielding ambiguous results. Some studies demonstrate a widespread and abrupt decline (Sand-Jensen et al., 2000; Körner, 2002), while others show a less dramatic decline (Havens et al., 2005; Oťaheľová et al., 2011) or, occasionally, a local increase (Liira et al., 2010; Depew et al., 2011; Baastrup-Spohr et al., 2016). However, no global dataset of the temporal changes in aquatic vegetation cover in freshwater ecosystems exists, which prevents a comprehensive and systematic assessment of the global trends of aquatic vegetation in lakes.

Historical data offer valuable information on the temporal changes in the aquatic vegetation of lakes, although they may be somewhat biased towards lakes with major changes and the time series may be irregular or affected by differences in sampling techniques. Accordingly, we conducted a global literature review following standardized criteria and generated a quantitative dataset from 155 study sites around the world covering the 1900–2015 time period and a range in lake area from < 0.1 km^2 to > 1000 km^2 (Table S1). The objectives of our study were to provide a global assessment of changes in aquatic vegetation area or cover in lakes in recent decades and to assess if the temporal trends are related to regional and lake size differences. Furthermore, we discuss the potential driving mechanisms and highlight approaches that can be used in the recovery of lake aquatic vegetation. Our global analysis fills a gap in current knowledge and serves as a basis for further systematic ecological investigations, monitoring, assessments, management and restoration of aquatic vegetation in lakes around the world.

2. Methods

2.1. Literature review

We searched the Science Citation Index (SCI) Expanded database and generated almost 4000 references about aquatic vegetation. Specifically, we searched the data in the SCI Expanded database, Web of Science (1900–2015) using the topic words (“aquatic vegetation*” or “aquatic plant*” or “macrophyte*” or “submerged plant*” or “submersed plant*” or “floating plant*” or “emergent plant*”) and (“lake*”) and (“loss*” or “change*” or “dynamic*” or “decline*” or “increase*” or “decrease*” or “recovery”). To cover the Spanish and Portuguese speaking world, we also used the words in Portuguese: (*vegetação aquática** or *vegetacao aquatic* or *planta* aquática* or *planta* aquatic** or *macrófita** or *macrofita**) and (*lago** or *lagoa**) and (*perda** or *mudança** or *mudanca** or *dinâmica** or *dinamica** or *declínio** or *declinio** or