Chapter

Climate Change and Monitoring of Temperate Lakes

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Abstract

Provided the predicted 2°C temperature increase during this century, lake ecology will go through dramatic changes, and this must be addressed in fish management in purpose of exploitation as well as in species preservation. In temperate lakes with fish communities dominated by cold-water and cool water fish, temperature increase will affect the species dominance. Extended growth season will benefit recruitment of less cool adapted species, total fish density may increase and growth will decrease of some species. Lakes dominated by salmonid fish may become dominated by cyprinids and percids. Primary production will increase due to extended growth season and increased precipitation. This can reduce the oxygen level in the deep layer of lakes when the organic matter decomposes, whereas the upper layer is too warm for cold-water species. In addition, increased density of small plankton feeding fish will reduce the algae feeding zooplankton. Lakes should be monitored by means of modern and sophisticated methods, monitoring lakes from satellites and in situ loggers, and pelagic fish may be counted by echosounding. To counteract increasing density of plankton feeding fish, fish biomass removal is a possible measure, though the effect is limited in time.

Keywords: pelagic zone, plankton, plankton feeders, predation, echo sounding, electronic loggers, remote sensing

1. Introduction

Research on biological resources of any kind may be divided in two categories: research on economical important species to attain optimal exploitation strategy and research to reveal ecological roles of species, commonly in a conservation perspective. The first point is obviously linked to the second, whereas the second point's connection to economy may be unclear and absent, at least apparently. Aquatic organisms of economic importance are mostly found in marine environments [1], while the economical value of freshwater fisheries in most cases is small [2], due to small water bodies and consequently small amounts of potential yield, though there are exceptions, like in the big lakes in North America [3]. It is also still important for hunting and gathering people in some parts of the world [4]. Freshwater bodies are nevertheless important to human society for many purposes, for drinking water, irrigation, and bathing and as landscape elements [5]. The water quality is therefore important in several perspectives, and guidelines for monitoring are recommended by the European Commission [6], among others.

Water quality monitoring is concerned about water chemistry, physics, and biology. Certain elements are more important and are easy to monitor regularly, like phosphorus, nitrogen, acidity, clarity (Secchi depth, color, and turbidity), algae, and chlorophyll [6]. Optical instruments to analyze algae and chlorophyll concentrations are available, and a great benefit with the electronic measure devices is the possibility to install loggers for continuing monitoring [7]. Some biological elements are more laborious and expensive, like algae taxonomy, macro vegetation, zooplankton taxonomy, and fish abundance and ecology.

Lake ecology is affected by natural elements like local geology, climate, lake size, and bathygraphy [8], and a predicted climate change with a temperature increase of 2°C [9] during this century will provide serious consequences. In addition, human activity by the lake and in its catchment, even on remote places, affects the water quality. The organisms comprising a community may be more or less exclusive or rare, and some may be vulnerable or even threatened [10]. Ideally, there should be conducted genetic surveys on every species, but it would probably be a vast of resources. Nevertheless, species or populations that are considered as somehow vulnerable or unique should be analyzed by means of microsatellites or single-nucleotide polymorphism to describe the at-present state as a reference for future surveys [11–15]. Tissue samples should be preserved to be available for future analysis methods. The references are also useful for monitoring effective population size [13–15] and potential changes of allele frequencies, by random or as effects of natural selection.

2. Lakes as ecological indicators

Freshwater of lakes, rivers, and groundwater is important for all terrestrial life. There is scarcity of water in parts of the world [16], whereas in the temperate zone, it is usually available, though scarcity may occur in periods of the year. Water bodies are important sources of drinking water, and the quality is monitored for chemical and biological elements. Especially toxicants and pathogens are important, as they are mostly invisible by the eye. Other changes may be visual, like increased abundance of algae, planktonic, or on the bottom substrate or in fish nets. This may indicate eutrophication and could be serious. It indicates high levels of phosphorus, commonly the minimum factor in freshwater [8], though nitrogen also influences the primary production in lakes [17]. Increased phosphorus concentration may be added along lake shores or in the tributaries. Sources can be traced, and this could be a broken sewage pipe and runoff from a droppings pit or from fertilized fields resulting in an acutely polluted tributary. Algae bloom is a problem in hypertrophic lakes, and one characteristic trait is the cyanobacteria, among which, some may produce toxicants when occurring in high density [18, 19]. This has led to death of pasture cattle after drinking the water [20]. Even if such extremes are avoided, high algae production gain more biomass than the grazing chain from zooplankton to fish which may be consumed and decompose, and algae biomass is handled by the detritus chain in deepwater layer where oxygen deficit may occur [8]. Oxygen concentration at different depths is an important factor and is easy to measure with modern equipment. Oxygenated water precipitates iron (III) phosphorus and enriches the sediments, whereas oxygen deficit reduces the iron, and iron (II) phosphorus is soluble and is brought back into the water column during the spring mixing [8]. Phosphorus and chlorophyll a are therefore normally included in lake monitoring programs, and the chlorophyll a concentration is a good indicator of a lake's "health" condition [21]. Oxygen is very serious and may in worst case become

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chronic, and the lake sediments must be covered or replaced with other kinds of substrate, gravels and sand with low phosphorus content [22].

The lake characteristics and the fish community are mutually dependent of each other, but the fish community also depends on accessibility for freshwater species. Freshwater organisms immigrated after the glaciations, and the migrations were hampered or stopped by the topography. Mountains and waterfalls make up effective obstacles to fish distribution, and the distribution of species was determined by the time of immigration and the time of land uplift that created the obstacles. The distance from the glacial refuges and the topography decided the possibility for the entrance. Some fish communities therefore have few species, unaffected of the lake environment. This is clearly demonstrated in Norway, where the river systems in the western part of the country, that is, west of the mountain range, almost exclusively harbor fish of anadromous origin, which means no cyprinids, percids, or pike (*Esox lucius*) [23]. Cyprinid species normally dominate in eutrophic lakes, when present [24–26], and if not, a lake can be eutrophic but with a simpler community. It makes a difference whether the dominating pelagic fish species are cyprinids, coregonids, or Arctic charr (*Salvelinus alpinus*) [27]. They can all feed on zoo-plankton, but with different efficiency, due to different body size, population density and not least, different density of the gillrakers that filter food items from the water. The dense gill rakers of most of the cyprinids filter small zooplankton species that slip through the gill rakers of coregonids, not to mention those of Arctic charr and brown trout (*Salmo trutta*) [28]. This again affects the zooplankton grazing capacity, as the most important herbivorous species are large and more catchable than the smaller species, and algae blooms become more probable [29, 30].

Lakes may serve perfectly as indicators of environmental health condition of its surroundings and its catchment, and lakes are easily observable. Watercolor, clarity, and vegetation development can alarm the public in a lake's vicinity if dramatic changes occur. Bathing, fishing, or just observations from the shore may give a clue.

3. Forming of lakes and their ecosystems

The occurrence of a lake demands a substrate tight enough to hold water, some kind of damming, natural or manmade (eventually built by beavers), and a water supply that exceeds evaporation. Tectonic processes, land uplift, landslides, volcanoes, and quaternary processes can create holes capable of holding water when filled [8]. On the Northern Hemisphere, the glaciers, until 10,000–12,000 years ago, caused land excavations that became lakes and moraines that could dam the water.

In glaciated areas, when the ice thawed, and a completely barren land appeared, the primary succession started, affected by the local geology, and minerals bound in rocks and stones were released by physical and chemical weathering. Algae, lichens, mosses, and plants started assimilating CO_2 and, according to their needs, phosphorus, nitrogen, and other minerals [8]. Primary production was not hampered by organic bound nutrition and could flourish from the beginning. Grazers appeared and nutrition became in part bound in biota. Lakes got their sediments, slowly but steadily increasing, littoral macro vegetation developed, and animals, crustaceans, insects, mollusks, and others, appeared. Fish were more limited by waterways than most other aquatic organisms, like insects and small invertebrates that can be carried by other organisms or even by wind. In elevated areas, fish were not necessarily a result of the natural process but in many cases brought there by humans [31–33]. This was probably the first significant impact man had on lakes. Stools from sparse populations of Stone Age humans had probably a nonsignificant effect on lake productivity. Introduction of fish, which are mostly second (or higher)-order consumers, adds a predation pressure on organisms of several phyla, classes, and orders, among which, arthropods (especially crustacean and insects), annelids, mollusks, vertebrates, and, among those, other fishes, are important. If one fish species or five or more fish species are present, they structure the community through predation, depending on the species assemblage and the physical and chemical prerequisites of the lake. When the EU Water Directive demands lakes to be restored/maintained in "good status" [34], this is not unambiguous as it depends on the original state, that is, what species, nutrition load, acidity, and content of dissolved particles are and were present.

Monitoring lakes should always be done by comparing the present state with an assumed original state, although a new state is not necessary disastrous. There are many examples of successful introductions of fish species, from a human point of view. What the original state was can to some extent be illuminated by means of sediment analysis, as organisms with scales, like planktonic crustaceans, are preserved [35, 36]. The state should be stable, if not in a mal state, and spring and autumn circulation turning the water column to supply the deep water with oxygen should take place regularly. That will keep the lake sound, so the detritus is treated effectively with oxygen present, and fish dying off under the ice is avoided, as well as bad smell from methane and hydrogen sulfide. Fishing and bathing are of interest for public, and this public use of environmental resources makes people conscious about their state.

4. Monitoring of lake ecology

When monitoring fish communities, observations and measurements are conducted with a certain precision, and most importantly, the methods are described thoroughly enough to be repeated by others. Monitoring the lake ecology, one way or the other, may be regarded as testing a very wide/imprecise hypothesis: Is something changing? A more precise hypothesis can be formulated later, if the monitoring reveals that something in fact is changing. One species may become more abundant, whereas others become sparse, and an explanation can hopefully be found among the factors or variables that were monitored. At present, the temperature is a hot candidate. Others are nutrition load, acidity, new (alien) species, and eventually new parasites [37, 38]. The latter may become very harmful to indigenous species and populations [39].

Important variables may be logged electronically and even be transferred wireless to data archives, and for the large-scale overview, remote sensing by means of satellite images is probably the optimal method [42]. The horizontal overview given by satellite images is superior to the traditional spot sampling. Images taken from planes may surpass the satellite images when it comes to sharpness and details but hardly when it comes to frequency and regularity. Satellite instruments record reflectance of electromagnetic waves of different wavelengths, primarily within the visual specter, blue, green and red color, but also infrared, and longer wave lengths. Reflectance of long waved radiation can be used to calculate temperature and humidity at the earth surface, terrestrial as well as aquatic [43]. Satellite surveillance can easily be done weekly, provided if the sky is not cloudy and the images are available on the Internet, many of them for free. By monitoring surface color, the concentration of chlorophyll a, suspended matter and Secchi depth can be estimated. If worrying values are observed, water samples may be taken to laboratory.

What topics, methods and experimental design should be recommended? During the last two to three decades, efforts are spent to reveal and predict effects of climate change, i.e., increase temperature and changed runoff patterns. Temperature trends alarmed scientists in the 1990s, and lake ecology was predicted to change if

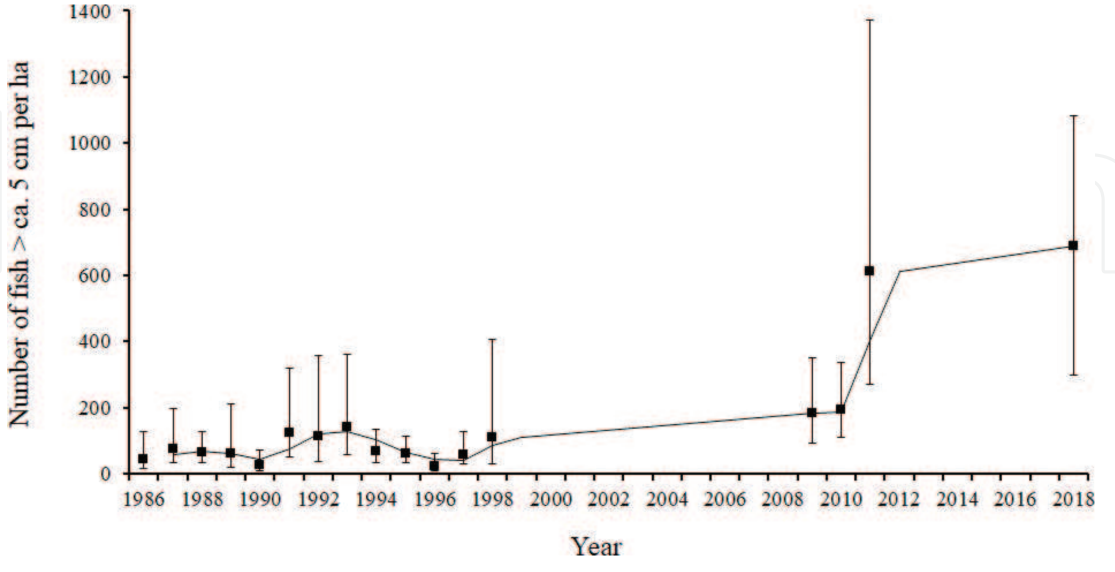

Figure 1.
Density of pelagic fish with body length ≥ approximately 5 cm recorded by means of a SIMRAD EY M echo sounder during 1986–2011 and by means of a SIMRAD EK 15 echo sounder in 2018 in Lake Osensjøen, Southeast Norway. Line shows moving average; vertical lines show 95% confidence intervals. For method description see Linløkken and Sandlund [40].

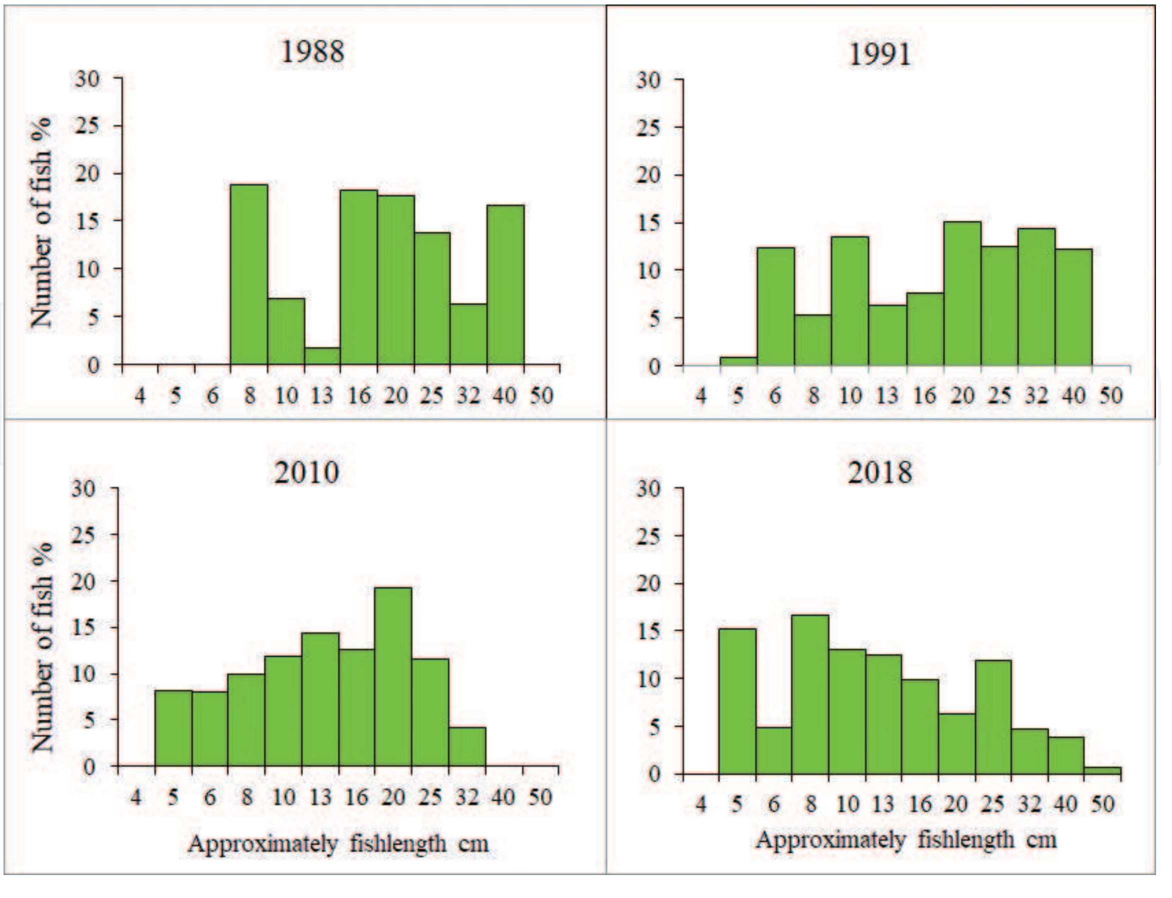

Figure 2.
*Length distribution of pelagic fish in four selected years (of **Figure 1**) based on echo target strength distribution from echo sounding in Lake Osensjøen, transformed to approximate fish lengths by the target strength—Fish length algorithm presented by Lindem and Sandlund [41].*

this tendency continued [44]. Time series of temperature, combined with existing knowledge about temperature effects on fish ecology, affecting recruitment success and growth [45–48], differing between species, will benefit some species and opposite to others. The algae community reflects the lake's nutrition load but is also affected by the grazing zooplankton, which is affected by the zooplankton feeding fish [27]. Coregonids are important plankton feeders in cool and cold-water lakes, whereas cyprinids compete more efficiently as temperature and nutrition load increase and oxygen concentration decreases, and this is the most frequent in shallow lakes [8]. How can this be monitored and what changes can be observed so far?

In the regulated and oligotrophic Lake Osensjøen in Southeast Norway, pelagic fish density, mainly whitefish and vendace, has been monitored by means of echo sounding since the 1980s, and during the first decade of this century, a pronounced density increase was observed, and a study was published in 2015 [40]. Year-class strength of both species was positively correlated with summer temperature, especially for vendace, as whitefish recruitment was also affected by the regulated water level (due to spawning sites at relatively shallow water). The vendace population increased, whereas whitefish in the pelagic zone decreased. A follow-up survey in 2018 confirmed high density of pelagic fish, and there was more than a sixfold increase since the 1980s and 1990s (**Figure 1**), and simultaneously, the proportion of fish >30 cm decreased, and the proportion of fish <20 cm increased (**Figure 2**). This has probably had an effect on the zooplankton community, of which samples are collected, but so far not analyzed. As the density increase was due to increased density of vendace, the growth rate of vendace has decreased [40].

5. Monitoring of lakes using satellites

Eutrophication and temperature increase may be expected to cause cyprinid dominance and amplify the effects of eutrophication through more intensive grazing on zooplankton. Temperature increase also affects recruitment and growth of percids positively [46, 48–50], among which perch and pikeperch are piscivorous and may play an important role in regulation of roach (*Rutilus rutilus*) and other cyprinids [51]. Exploitation with gill net fishing should be performed with great care to retain a sufficient number of large predatory specimens. What sufficient means should be a subject of research, which should otherwise concentrate on the description of species biomass of aquatic biotopes, with special attention on functional groups; who is eating who or what? Can it be stated an optimal balance between biomasses of consumers of first and second/third order, like between omnivorous/benhivorous/planktivorous cyprinids and species of higher trophic levels, like perch, pikeperch (*Sander lucioperca*) and pike and eventually the piscivorous cyprinid, the asp (*Aspius aspius*)? If not, serious measures may become necessary, like removal of fish biomass, which is shown to have a positive effect on zooplankton abundance, though not long lasting [52–54]. Stocking top predators, affecting the zooplanktivorous fish, may also have a positive effect on herbivorous zooplankton abundance [51, 55].

To get an overview, lakes and river systems should be monitored by means of satellite images. These are available from several sources, and many are for free [43]. The resolution of the images varies, and whereas some satellites, like the Sentinel 3 A and B satellites, have rather low resolution with 300 × 300 m pixels in the visual wave specter, the two twin satellites pass every second day, that is, together they collect daily images of every spot of the inhabited world [56]. The Landsat 7 and 8 satellites depict an area every eighth day [43], and the Sentinel 2 A and B satellites do it every fifth day [57]. These pairs of satellites have pixels of 30 × 30 m and

10 × 10 m, respectively, and the images are useful to characterize lakes with 5–10 km^2 surface area. The images consist of different color bands, and these bands, and combinations of them, may be used to develop algorithms for environmental factors like chlorophyll a [43], if combined with in situ measurements. The distribution of colors nevertheless may give a clue of horizontal variation of, for example, chlorophyll.

In the southernmost East Norway, lakes of the Halden river system exhibits pronounced variation of trophic state. A satellite image of August 13, 2018, from Landsat 8, with manipulated pseudo colors showing the relationship between the reflectance of the green (reflected by chlorophyll) and the red (absorbed by chlorophyll) color bands, shows colors from blue to green, yellow, and orange/red (**Figure 3**). In the Lake Bjørklangen and Lake Hemnessjøen, the chlorophyll a concentration has through the years frequently been measured to 10–15 μg/l; in Lake Rødenessjøen it has been measured to 5–10 μg/l [58], whereas in the "blue" Lakes Setten and Rømsjøen [59], the chlorophyll a concentration is <5 μg/l. It must be added that the pixel values are also influenced by turbidity, that is, suspended solids, like in

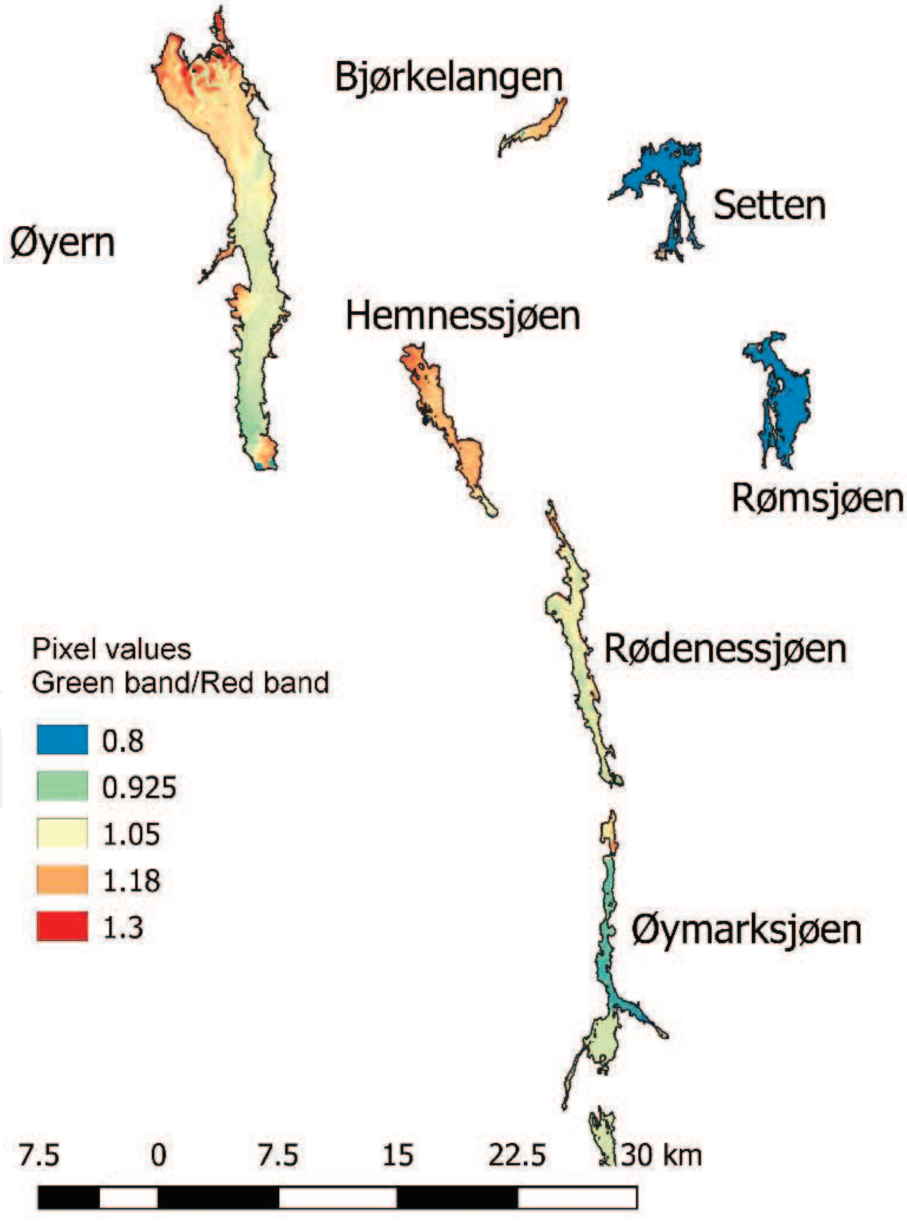

Figure 3.
Seven lakes in southernmost East Norway (Lat/Lon: 59°20′32″–59°56′60″, 11°02′13″–11°48′22″) showing horizontal variation of the ratio (pixel values of the green color band)/(pixel values of the red color band), based on a Landsat 8 satellite image, roughly indicating the distribution of chlorophyll [60].

the inlet of Lake Øyern and in the neighboring Glomma river system, which is not corrected for in this presentation.

In situ sampling, varying in space (horizontal) and time (seasonal), should be combined with satellite image analysis, to estimate reliable algorithms for the relationships between the chlorophyll a concentration, clarity and turbidity, and reflectance values (corrected pixel values) of different color bands of the satellite images. When this is established, satellite images can be used for regularly monitoring, daily in large lakes (>50 km^2) and weekly in smaller lakes, though it will depend on the weather, that is, the cloudiness, which must be minor and surely not cover the lake. This can reveal point sources of pollution, and in situ sampling may be conducted during few days.

Fish monitoring is commonly done by gill net fishing or trawling, laborious and costly, and therefore is not conducted too often. As the pelagic fish stock is of special interest in eutrophication, hydro acoustic equipment is recommendable, and that can be done regularly, like every or every third or fifth year. The time of year and time of day affect the results, due to the spatial distribution of the fish, which must be in the pelagic zone and not too close to the surface to be recorded. An echo sounder counts the single fish, integrates schools to numbers of fish, and estimates density and target strength distribution which can be transformed to fish size distribution. This method can easily record increased density and changed size distribution, which is a probable result of climate change and is possibly the case in the Lake Osensjøen (**Figures 1** and **2**).

6. Conclusion

Lakes play important roles as ecological elements in nature and comprise important resources for human societies. They are also important as indicators of the ecological state of their catchment and are relatively easy to observe and monitor, by in situ sampling, by electronic logging, and by means of remote sensing from satellites. Thorough studies should be conducted to describe the at-present state of lakes, which is now largely taken care of through the EU Water Frame Directive, and it should be linked to monitoring routines by electronic logging devices and to remote sensing by means of satellite images. Algorithms relating reflectance to situ measurements should be worked out on a broad scale.

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Conflict of interest

There is no conflict of interest.

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