Management of Lake Durowskie

2016

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1. Introduction

Wągrowiec is a town in north-western Poland. In the middle of Wagrowiec the Lake Durowskie is located. Lake Durowskie is a very popular attraction for tourists and locals. In the surroundings of the lake there are many possibilities for outdoor activities, particularly swimming or boating in the lake, which is very encouraging for many people. However, until 1999 recreational use of the lake was limited due to the blue-green algae blooms and poor water quality caused by long-term, direct wastewater discharge.

In 2009, the town of Wagrowiec therefore implemented three restoration measures to reduce the appearance of the so called cyanobacteria. The options comprised the installation of aerators for oxygenation of the bottom layer of Lake Durowskie. This was the precondition for the second measure, namely the application of ferrous sulphate to bind accumulated phosphorous which is a cause for algae bloom and thirdly a method of biomanipulation by introducing more predator fish. Due to these approaches an improvement of the water quality could be observed until 2015. The methods used for restoration have yielded positive results so far and contributed to an improvement of water quality. A healthy lake ecosystem is governed by the higher developed creatures in the lake and regulates itself. It is thus underlying a top-down control and provides clean water for free, which can be used by humans for recreational purposes. In case of Lake Durowskie, the continuous human pressures caused an imbalance in the system which was then governed by blue-green algae, the so called cyanobacteria. This state of the lake is called hypertrophic, regulated by a bottom-up control.

Factors that determine the extent of cyanobacteria blooms are very complex. The occurrence of cyanobacterial blooms is very burdensome for the environment and the economy. The most significant hazard related to mass expansion of cyanobacteria are toxins, which they produce. These toxins significantly disturb aquatic ecosystems, limiting and displacing species inhabiting the sediments of water reservoirs. They can also threaten health and life of humans and domestic animals. Furthermore the excessive growth of cyanobacteria deteriorates the light conditions in the deeper layers of the lake, thereby further degrading the functioning and self-regulating ability of the lake.

Whereas the pollution of such a lake ecosystem can happen in a short period of time due to several pressures caused by human activities such as tourism, agriculture or sewage input, the natural process of recovery can take several decades even if pressures are removed (Verdonschot et al., 2012).

This is comparable with a human heart attack. It happens within a few seconds but it takes weeks or months for the person to recover entirely. During this time the person needs assistance by doctors and family members and should not be exposed to any stress. Analogously, it was necessary to support the lake in its recovery process by applying the mentioned restoration measures. The aim of the restoration measures is to prevent algae blooms in the short-term and to ultimately support the lake to recover to a top-down self-regulating system and thereby minimizing the risk of beach closure as indicated in Figure 1.

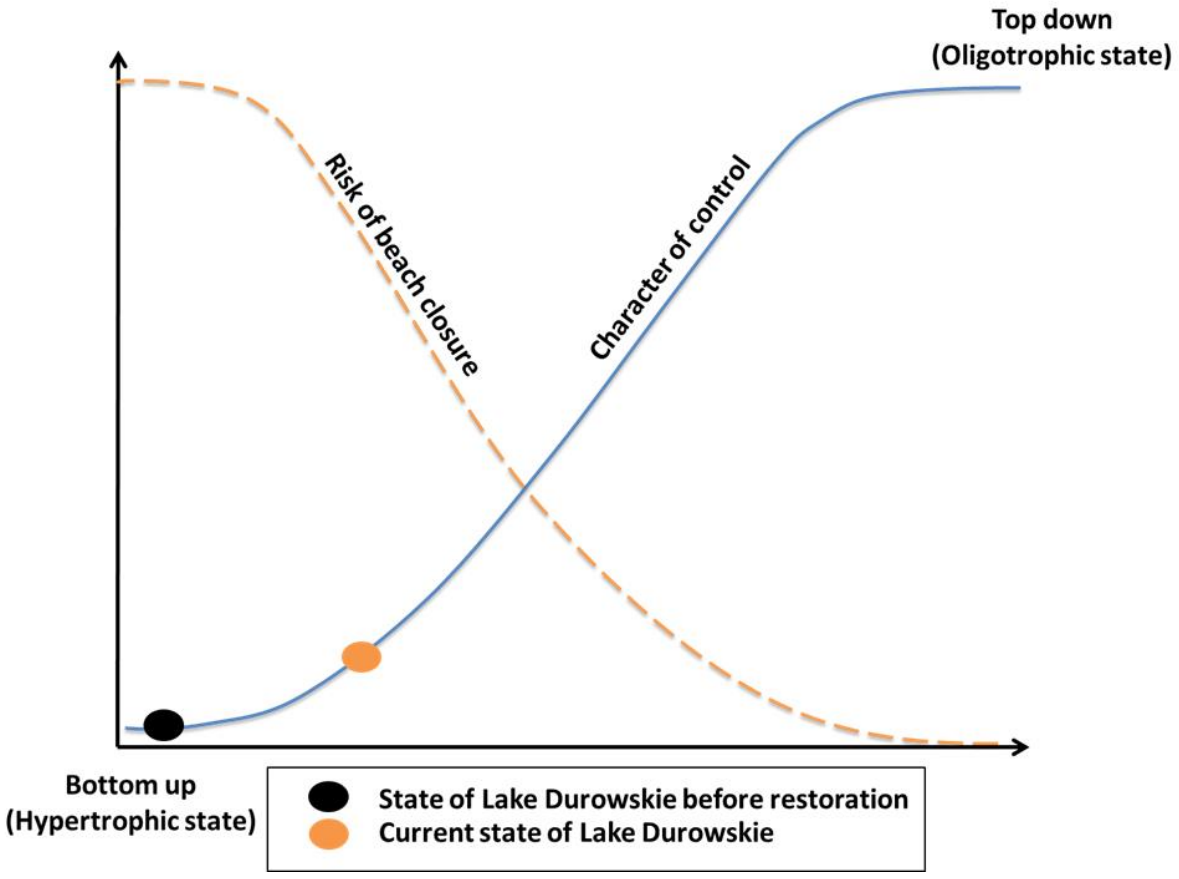

Figure 1 Bottom up and Top down control regarding the risk of beach closure of Lake Durowskie

As is depicted in Figure 1 Lake Durowskie is in transition and on its way to an oligotrophic, self-sustaining state. The risk of beach closure has already been decreased by management.

The people or groups who benefit from the lake and are hence interested in a good water quality are called stakeholders. However, conflicts are possible since every group has a different interest in the lake, e.g. a tourist with a motorboat is causing noise which has a negative impact on the swimmers.

The overall aim of the study is to evaluate the current ecological state of Lake Durowskie by analyzing the main indicators, i.e. the macrophytes, macroinvertebrates, algae, physio-chemical parameters and state of erosion. In the course of the analysis different action scenarios were developed and evaluated according to different criteria to enable the responsible authority to make an informed decision on how to proceed. This included the evaluation of management options in order to identify the options that would in best case be able to meet everyone's needs.

2. Material and Methods

2.1 Study area

The study was conducted in the area of Lake Durowskie (Wagrowiec) from 27.06.2016 to 01.07.2016. Lake Durowskie is a relatively shallow lake (max. depth 14.6 m, average depth 7.9 m) and arose from glacial flow. The surface comes to 143.7 ha and its total volume to 11,322,900 m^3 (Table 1). It is the second last lake of a chain of five lakes and is therefore dependent on the inflow of Lake Kobyleckie.

Table 1 Morphometry of Lake Durowskie including a map of the town of Wagrowiec

Morphometry	
Surface	143,7 ha
Volume	11,322,900 m³
Maximum depth	14,6 m
Average depth	7,9 m
Main tributary	Struga Gołaniecka
Surface of the entire sampling area	236,1 km²
Surface of the direct catchment area	1,581 ha
Share of agriculture area	58,26 %
Share of forest	33,52 %

2.2 Methods

To get an overview of the state of Lake Durowskie following indicators were considered and summarized: state of erosion, macrophytes, macroinvertebrates, algae and physico-chemical parameters.

The level of erosion of the lake and its surrounding was assessed by searching for eroded places by kayak and afoot. Therefore already known places were visited to check if any improvement or degradation is visible but it was also watched for new eroded spots.

The descriptions of the methods used for the remaining indicators can be found in the respective reports. Additionally, all reports of the previous years served as data basis.

To demonstrate the decision options for the authorities of Wagrowiec three scenarios were developed. Discussions were carried out with professors of Adam Mickiewicz University (UAM), Poznań and Christian-Albrecht University (CAU), Kiel as well as other group members

to integrate knowledge and develop different management approaches. The resulting options were listed in four categories (awareness raising, erosion protection, ecological approaches and technological approaches). Additionally, a suitability analysis was carried out in order to evaluate the applicability of the management options according to the criteria necessity of cooperation, time and effort and the expected efficiency.

The result of this analysis was carried over to a stakeholder analysis, although only the more complex measures, requiring a discussion were considered. This was done in order to evaluate the influence of the respective management options on the different parties.
The interest groups in the case of Lake Durowskie are the inhabitants of Wagrowiec, the fishermen association, tourists, tourist offices and/or administration, private investors, the forestry agency and farmers living upstream. To get to know the stakeholders' interests interviews were conducted by Prof. Beata Messyasz (UAM) over the past years.

3. Results and Discussion

3.1 Integrative review of water quality indicators and management success in 2016

The detailed analysis of the different water quality indicators underlines the lake's stage of development on its way to a top-down controlled system.

Whereas physico- chemical indicators provide a snapshot of the water quality at time of sampling, biological indicators can provide an integrative view of the current state of Lake Durowskie (Kenney, et al., 2009). Phosphorus is one of the most important drivers of cyanobacteria bloom. From the results of total phosphorus (TP) load analysis, a significant improvement in phosphorus immobilization by the applied methods of ferrous sulfate and a reduced nutrient load from upstream waters could be observed. Also other physico chemical indicators improved, which means that the inflow of nutrients from upstream lakes is decreasing. Nevertheless, the overall amount of phosphorus is still high. Please refer to the report of physico- chemical parameters for detailed information.

The fact that the lake is still undergoing a transition phase is illustrated by the results of the diatom index. This diatom index points towards a decreased state at almost all sample

sites. The decreased intensity of some of the management options, such as reducing the applications of ferrous sulphate to bind phosphorus from 3 to 2 applications per year, and using smaller predator fish than intended may be the reason for this result. On the positive side, the diversity of species has increased since the start of restoration (please refer to the algae report for detailed information). This positive development shows that other species than cyanobacteria can increase their influence in the lake ecosystem and that the lake is in transition and building new trophic layers. Furthermore the north-south division apparent in the previous year is no longer prominent.

The recovery of a lake ecosystem which underlies a bottom-up control takes especially long if phosphorus is accumulated in the lake sediments and/ or a disturbed food web postpone the effect of restoration measures (Sondergaard et al. 2001; Sas et al. 1989 as cited in Klapper 2003) as it is also the case for Lake Durowskie. This can be demonstrated by the slower reacting indicators such as the macroinvertebrates which have a very narrow range of environmental requirements and have a relatively long life range: Almost all stations examined showed that according to this indicator the water quality is more or less stable at a moderate state but has increased slightly in some parts of the lake. This is a very usual development for a system in transition and it is essential to monitor its further development, to detect possible warning signals. Such a possible warning signal could be the 30% decrease of *Charetum tomentosae* cover, a water plant very sensitive to a decrease in water quality. Apart from this, an overall positive trend can be derived from the indices concerning macrophytes and the cover of water plants as important physical and chemical filtrators in general has increased by 40%.

Concerning management the main factors discussed in the previous reports seem not to have changed considerably. Some jetties were removed or slightly improved, but the overall pressure seems not to have decreased considerably. This has a negative impact on macrophytes and could be a possible explanation for the decrease of certain species as discussed above. Some minor improvements could be noted at certain heavily eroded places. Unfortunately, the installed structures as indicated in Figure 2 are not sufficient for preventing erosion and even provide a channel for eroded material to enter the lake. In general the erosion prevention measures are rather feeble.

Figure 2 Eroded beach at Lake Durowskie

Additionally, many rubbish-strewn places were found pointing towards a lack of awareness of the local population or tourists (Figure 3).

Figure 3 Litter around Lake Durowskie

3.2 Action Scenarios

In order to facilitate decision making, three scenarios were identified as depicted in Figure 4. In the following the three scenarios will be presented in detail, including the expected responses of Lake Durowskie.

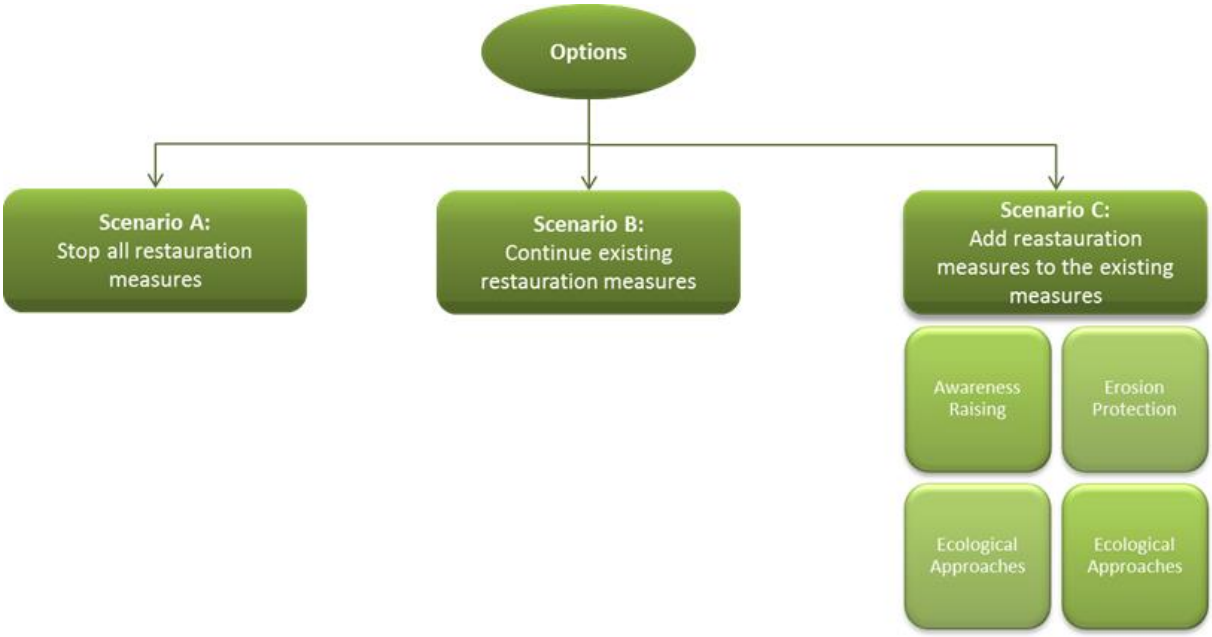

Figure 4 Action scenarios including Scenario A (Stop of all restauration measures), B (Stagnation) and C (Additional/ improved restauration measures)

3.2.1 Scenario A - Stop of all restoration measures

Scenario A describes a situation where all restauration measures are discontinued. At first glance this seems an attractive option, as the water quality in Lake Durowskie is currently suitable for swimming. When taking a closer look at the results of the water quality indicator analysis, most of the physico-chemical indicators point towards an improvement of the lake's state. On the contrary, the diatom index indicates that this is still an instable state. The fact that cyanobacteria were found in the samples taken, points out that a discontinuation of restauration measures would, with a very high probability, lead to a new bloom of cyanobacteria.

The example of Lake Swarzędzkie not far from Wagrowiec, where restoration measures were discontinued hastily, shows that the recovery of a heavily polluted lake takes time. Contamination by sewage degraded the water quality in Lake Swarzędzkie until 1991,

when a water treatment plant was built. Just as it was the case for Lake Durowskie the negative results of exceeding exposure to pollutants resulted in blooms of cyanobacteria. Therefore, recreational use was prevented. Since September 2011 Lake Swarzędzkie had thus to be supported by comparable restoration methods as Lake Durowskie (phosphorus inactivation, aeration of the bottom layer of the lake with one aerator and biomanipulation). However, in 2014, the new authority of Swarzędz decided to stop the restoration measures, except for the operation of the aerator. This decision was based on a rather one-sided tourism strategy, relying solely on the existing aquapark as available recreation option. This caused an immediate change of phosphorus concentration and water oxygenation. Already in late summer 2015, a reoccurrence of cyanobacteria bloom could be observed. In 2016 this negative development accelerated, and the first algae bloom was noticed in early spring. Figure 5 shows the development of phosphorus concentrations (as a cause of the algae bloom) in April 2014 (the last year of restoration) and 2016 (two years after). This is further supported by (Figure 6) depicting the chlorophyll-a concentration, as an indicator of the increasing algae bloom.

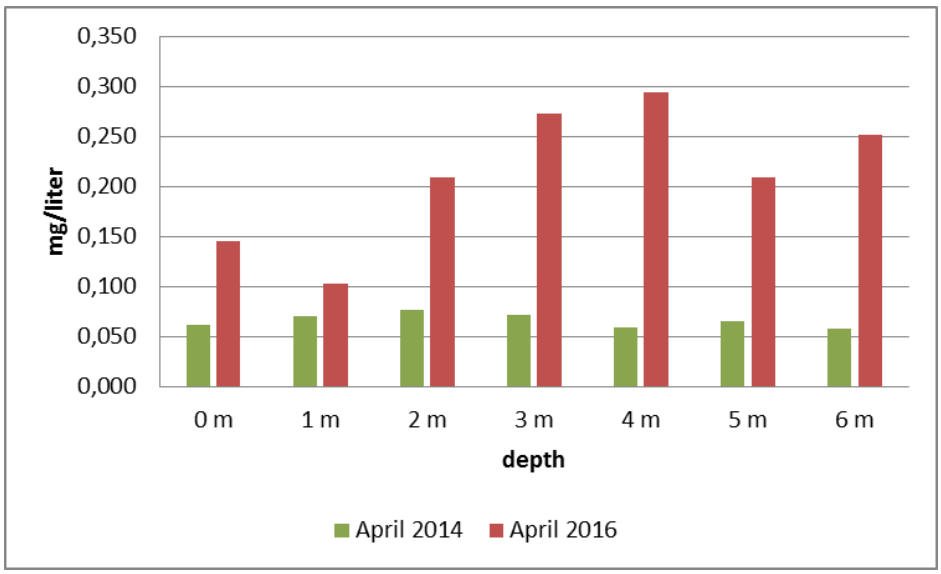

Figure 5 Total Phosphorus concentration in Lake Swarzędzkie in 2014 (Source: Joanna Rosińska)

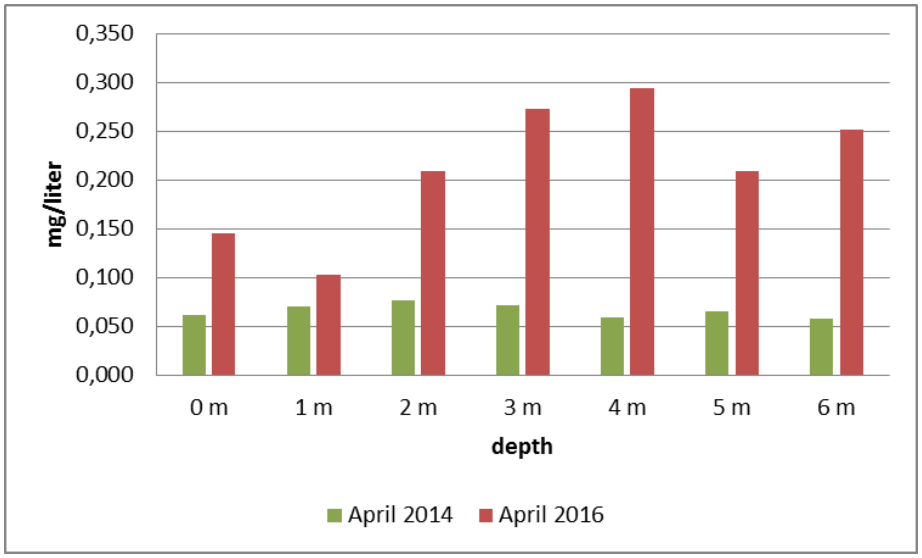

Figure 6 Chlorophyll-a concentration in Lake Swarzędzkie in 2014 (Source: Joanna Rosińska)

Up until now the state of the lake has deteriorated and recreational use is not possible. In case of Lake Swarzędzkie the renewed bloom of cyanobacteria had a negative impact on all stakeholders in general and the tourism industry and fishermen in particular.

A discontinuation of restoration measures for Lake Durowskie would most likely reverse all restoration effects achieved so far and finally result in new and probably even stronger algae bloom (please refer to the Algae report for a detailed information on underlying processes). Which would mean all steps taken on the way to top down control would be reversed. This would prevent touristic activities such as bathing, due to the negative health impacts of cyanobacteria, just as it was the case for Lake Swarzędzkie. Additionally it would result in an even smaller fish population in the lake which would negatively impact fishing activities. The continuation of restauration measures can thus be seen as a necessary means to preserve the services the lake can provide to humans and support its natural recovery. Currently, Wągrowiec has the possibility to base their tourism strategy on several pillars such as amenity of nature, fishing, bathing in the lake as well as relying on the aquapark in case of rainy weather. If management measures are discontinued and services by nature are not available anymore, only the aquapark would remain in the portfolio. The investments spent in the past 7 years would probably be lost and income earned in the tourism sector would possibly decrease.

3.2.2 Scenario B - Continue existing restoration measures

Scenario B describes a situation in which the restoration efforts as described in the introduction for Lake Durowskie do not increase considerably and even continue at a slightly decreased intensity as it has been the case in 2016. As we could see in section 2.1 the management approaches have so far provided assistance to the lake's recovery process, as far as to prevent renewed cyanobacteria blooms from appearing excessively (please refer to the respective reports for detailed analysis of water quality indicators).

However, this is a rather shaky situation as it merely supports the system from breaking down considering the current existing demand for recreation (bathing, fishing, biking, etc.). The slightly decreased intensity of management as reducing the applications of ferrous sulfur to bind phosphorus from 3 to 2 applications per year and using smaller predator fish than intended, had a regressive effect for the development towards top-down control. As further demand for services provided by the lake is created by enlarging recreational use, e.g. upgrading the camping grounds and increased use of motor boats, the pressure on the lake increases. What is more, the planned damming of Lake Laskowieckie would set the surroundings of the sewage plant upstream under water, which would lead to dissolution of heavy metals and nutrients currently bound in the soil close to the lake. This is a future pressure that needs to be taken into account when taking a decision on how to proceed. It is therefore very unlikely that the lake ecosystem can withstand the increase of human induced pressures without introducing further management activities to complement the restoration portfolio. Even if no further pressures were to occur, a broadening and improvement of the restoration portfolio would enable the lake to faster return to a top-down controlled system, which is no longer dependent on restoration measures. This would also help to safe expenses in the future.

3.2.3 Scenario C - Improvement of (existing) restoration measures

Scenario C includes four different categories with different management methods to improve the quality of the lake and safe future expenses. These categories are awareness raising, erosion protection, ecological approaches and technological approaches (Figure 7). Investing in the lake now will provide the possibility to accommodate more demand for

recreation in the future. This would increase the potential income the city of Wagrowiec can earn from tourism and decrease the risk of beach closure.

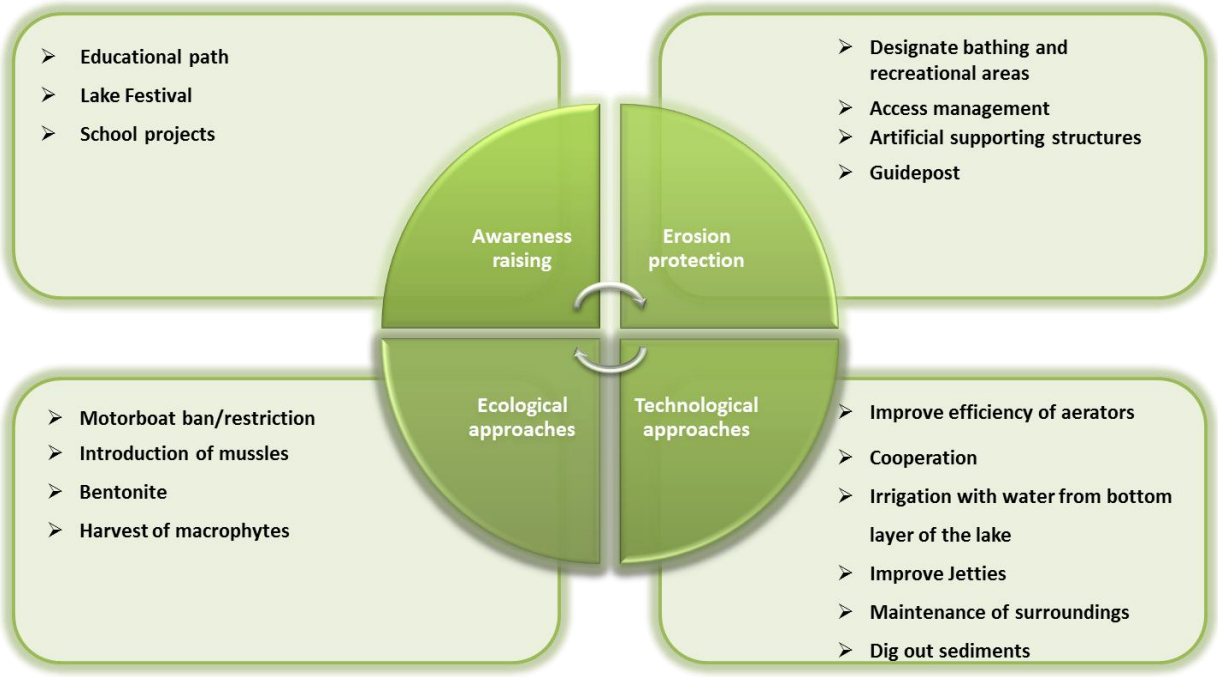

Figure 7 Summary of all Scenario C measures within the categories awareness raising, erosion protection, ecological approaches and technological approaches

C1 - Awareness raising

Many pressures on the lake can be tracked back to a general lack of awareness, e.g. unsustainable fishing practices. Currently there are 129 permanent fishing permits for Lake Durowskie. This shows that not the mere number of fishermen creates a pressure but most likely a lack of awareness that the fishing success depends on the quality of the lake. The better the water quality the higher the number of fish. At the moment the way most jetties are constructed, their inappropriately high number and the amount of bait used, lead to a decrease of water quality. Reed belts act as natural (nutrient) filters. By removing the plants the amount of nutrients will increase and cyanobacteria-bloom is more likely. The same happens when too much bait is thrown into the lake, as bait contains many nutrients. Also among motorboat users, there seems to be a lack of awareness of many essential

processes that sustain Lake Durowskie. Speeding motorboats cause waves that lead to erosion of the shoreline and their owners often seem to park their boats in the macrophytes (reed belts) around the lake and thereby decrease their natural filtering potential.

Thus, the first idea for an improvement in the **awareness raising** category is to build an educational path in cooperation with an ecologist or an expert for this region, for instance in cooperation with the local schools. The aim is to educate both children and adults to be aware of the critical state of the lake and to educate them in nature protection.

Secondly the implementation of a so called “Lake festival” gives a good opportunity to bring the importance of the restoration measures closer to the people. It provides an opportunity to inform citizens, tourists and fishermen about the (critical state of the) lake and to show them how everybody can contribute to the restoration of Lake Durowskie. For instance an information booth for the fishermen how to build an ecological jetty or a booth for children that provides information about the animals in the lake and why it is important to keep the lake clean. Additionally this type of event could create a further source of income for the city of Wagrowiec by making the lake festival a popular social event with educative value. By including musical performances it would also be possible to reach the teenagers living in Wagrowiec, who will be the ones to take care of the city in the coming decades.

The third management option is to implement a higher cooperation especially with the local high school. This approach has both a positive effect for the lake and an educational effect for the children. Ideas for this method are to introduce a day when the school children for example collect the trash, get a guided tour around the lake or collect data such as temperature or recreational use of the lake. The benefit of awareness raising by the suggested options is on the one hand to reduce pressures on the lake as described in the introduction, which would increase the benefits the city of Wagrowiec receives from the lake. Wagrowiec could moreover improve its image even further and show its sustainable character, while at the same time offering many recreational activities.

C2 - Erosion control

The category erosion protection is an important issue due to the continuously insufficient state of erosion. At the shores of the lake erosion is mainly caused by the use of trails on the slopes leading down to the lake, instead of stairs (Figure 8). Unfortunately, people who want to get to the bank of the lake choose the shortest path, probably due to the lack of information that stairs are close by. Further erosion is caused by mountain bikers, who use ramps of earth for their biking activities. Erosion is a problem, as the eroded earth and organic compounds eventually reach the lake and add to the nutrient pool ultimately increasing the risk of a new occurrence of cyanobacteria.

To improve this status it is advisable to designate bathing and recreational areas, to optimize the access management, build artificial structures and to put up guideposts. Designating bathing and recreational areas entails a targeted use of specific areas for bathing, fishing, mountainbiking etc. and the sparing of highly endangered areas which in turn enables these places to recover.

Figure 8 Intensively used beach with high state of erosion

This also relies on a good access management. One option would be to build new stairs where the most trails are or to place fences in front of highly eroded trails to prevent people from entering these places. To make the people use the stairs it is necessary to put

up guideposts with the nearest access points to the bathing and recreational areas. To adapt the new built beaches to the higher use it is necessary to fix the shoreline to prevent erosion. In addition artificial supporting structures are suggested. This option contains underwater sediment traps for beaches which catch the incoming sediments caused by erosion a steel construction for mountain bikers and a better maintenance of the bike lane.

C3 - Ecological approaches

A further pressure which could be reduced by ecological approaches is created by diverse recreational uses of Lake Durowskie. An example for this is the speeding motorboats which cause a mixing of the lake layers (and break the thermocline which works as a separation layer if it is left undisturbed). This entails an uplift of nutrients from the deeper layer, which nourish the algae population on the surface of the lake. Hence the proposed ecological approaches are the ban or restriction of motorboats, introducing more mussels in the lake, the improvement of the phosphorous inactivating adsorbents based on bentonite and partly harvesting macrophytes.

Another option to prevent further algae-blooms is the **restriction or total ban of motorboats**. Restrictions could be done by limitation of the power of the motors (e.g. no access for boats with more than 15 PS) or a restriction of lake access only at certain hours or days. Limited access to the lake is realizable by only one or two fixed access points for boats which are only accessible with an appropriate key and when the access-fee is paid. Implementing this approach the town would at least finally benefit from the motor boats by the admission fee and avoid some part of erosion caused by the unregulated launching of boats. Another suitable compromise would be a kayak-only zone for instance in the northern part of the lake where only boats without motors are allowed. The most effective alternative is a total ban of motorboats on the lake. This would also benefit the people who prefer swimming, kayaking or just sunbathing (see section 2.4 for a detailed stakeholder view).

A quite effective restoration measure is **biomanipulation** by cultivation of mussels additionally to introducing fish into the lake. . Mussels are filter feeders which feed on algae, including cyanobacteria. Hence they are suitable species to improve the water quality of the lake. There are case studies e.g. from the Netherlands which show a positive effect of this

measure and which recommend this approach (Waajen, et al., 2016, Gulati, et al., 2008, Stybel, et al., 2009).

The purpose of the introduction of fish-feeding fish (pike) is to decrease the number of zooplankton feeding fish which in turn increases the number of zooplankton which feed on algae. Last year's problem was that the size of the introduced fish was too small. This caused a decrease of the zooplankton community (which prevent cyanobacteria from spreading) as they were too small as to predate the plankton predators. Additionally the small fish were eaten by other fish. Consequently attention should be paid to the size of the fish. Instead of putting 33 000 small fish in the lake that could act rather counterproductively, less but bigger individuals could be introduced. The fish should be at least 10 cm long, so they are big enough to predate the plankton predators. In case mussels are introduced as well, the decision of which mussel species is chosen needs to be carefully analyzed. It is recommendable to use native species instead of invasive species to reduce the risk of expelling native species.

The use of **adsorbents based on bentonite** is a further approach to complement or replace ferrous sulfate input for phosphorus fixation. Different products such as Phoslock and Sinobent exist to permanently trap and lock phosphorous and phosphate compounds in the sediments as well as free flowing compounds. These adsorbents only present a very low risk to the aquatic flora and fauna and improve the water quality tremendously.

A new product named Sinobent (patent in 2013) has been developed in Poland on the basis of minerals. It is based on bentonite, iron, magnesium, calcium and nitrate. According to laboratory tests it is effective even at a dose of 20 g m -2 and thus 4-fold lower than other conventional phosphate lockers e.g. PhosLock. It is thus more effective and less harmful to ecosystems than other conventional phosphate lockers (Gołdyn et al., 2010). Besides, it is much less costly. A three-month test carried out on Lake Sławskie in special enclosures confirmed the effectiveness of inactivation of phosphorus using Sinobent (Dondajewska et al., 2010). Iron, the main ingredient of Sinobent, is a normal element in the lakes, and is supplied from the catchment.

The **harvesting of macrophytes** can have positive as well as negative effects on the lake. The final result will depend largely on the timing and manner of harvesting. Odds are that the water quality will be influenced in a negative manner by removing the reed stalks which are necessary to pump up the nutrients from the roots, if they are harvested too late in the year. Instead harvesting the macrophytes in July or early August, when they have reached their maximum in nutrient uptake, would prevent their decomposition and, thereby reduce secondary pollution. There would still be enough time for the reed belts to accumulate enough nutrients to regrow the following year. Partly removing submergent macrophytes would also facilitate recreational activities in certain parts of the lake. However, one would have to prevent negative effects on nesting birds, which choose the reed belts as their habitat and consider the reduced ability of the reed belts to prevent eroded material from entering the lake. Suitable species for this approach are *Phragmites australis* and *Typhetum angustifoliae* (76.16% and 11.02% of total coverage). If this method is applied, appropriate infrastructure would need to be constructed close to Lake Durowskie to derive economic use from the reed material (e.g. material for roof tops, hats, paper and baskets).

C4 - Technological approaches

The last of the four subcategories to complement existing management options are several technological approaches.

The first approach in this category is to improve the **efficiency of the two aerators** by additional electricity supply especially during the summer months when the wind velocity is low and not able to power the aerators when they are most needed. A possibility would be to install solar panels with a connected storage unit (e.g. a redox flow battery) on top of the aerators or on the surroundings of the lake which would drive the aerators in case of calm weather. Another possibility would be to connect the aerators to another land based electricity supply via underwater cable. However, these options are not mutually exclusive. To monitor the economic efficiency of the aerators a counter could be installed to count the average aerator rotations per month. The water at the inflow from Lake Kobyleckie upstream of Lake Durowskie contains a high concentration of nutrients that enhance its

eutrophication. Thereby, favorable conditions for the undesired cyanobacteria are created. Agricultural land use with intensive fertilization and a steady flow of waste water probably has a direct impact on reducing the ecological status in the whole catchment.

In order to improve upstream water quality and increase overall stakeholder value, a further approach would thus be to **cooperate** with the upstream communities as it has already been proposed in last years' reports. Please refer to previous reports for detailed information.

Additional to the already proposed restoration measures to improve water quality in the upstream lakes and business opportunities to create incentives for restoration, irrigation practices in the catchment area could be altered. This could potentially decrease fertilizing intensity and remove nutrients from upstream lakes at the same time. This would benefit both Lake Kobyleckie and Lake Durowskie. A way to achieve this is to **irrigate with water from the bottom layer** of the lake, instead of taking water from the surface. For this, some farmers would need to replace their pumps. Replacing pumps is a one-time investment. In this way, the nutrients accumulating at the bottom of the lake would become available for agricultural use as fertilizers and thereby save costs for additional mineral fertilizers. Calculations based on measurements carried out in 13 m depth revealed that a removal of about 300 kg of phosphorous would be possible in only four months (May to August) for the amount of water needed for the irrigation of the whole agricultural area of the catchment. By this approach both communities would benefit from improved water quality which reduces the risk of beach closure. Analogously the sport field in Wagrowiec could be irrigated by the water of the bottom layer instead of surface water of Lake Durowskie.

At the moment there are about 90 **jetties** around the lake and 129 fishing permits are given out to the local fishermen. The ratio of the number of jetties and fishing permits seems to be quite high, assuming that not every fisherman with a fishing permit goes fishing every single day. The problem with the high number of jetties is that big parts of the reed belts, essential for water filtration are replaced by wood constructions. Instead of having a slender beginning of the jetty that becomes wider in the water, a lot of plants are cut and one broad jetty is built from the shoreline into the water. According to the pre-existing number it is a reasonable approach to prohibit the construction of new jetties. In

compensation the authors of last year's Management report proposed to build more platforms with one common access, so called triple-jetties (Figure 9). To arrange the use of jetties more efficient it is advisable to make them public and prohibit private jetties. If the town of Wagrowiec provides enough sustainable triple-jetties there will be no need to build unecological, private ones.

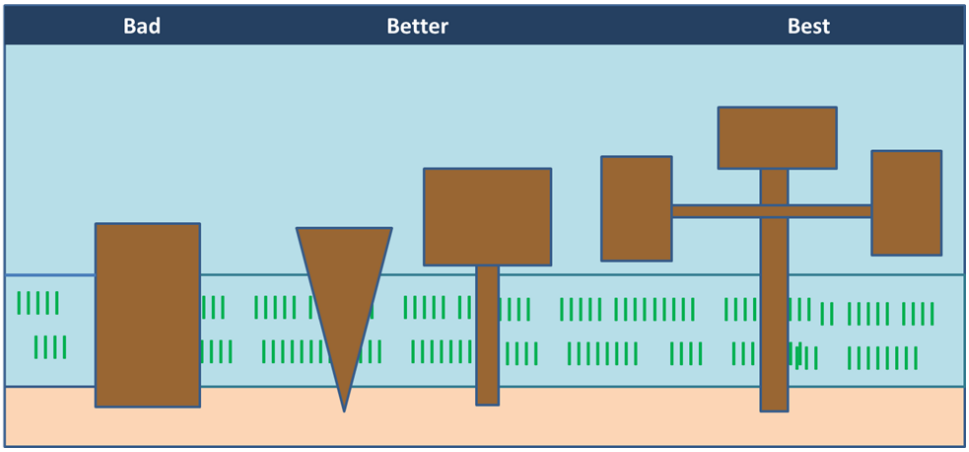

Figure 9 Good and bad possibilities to build jetties

Also many fishing places without a jetty are not sufficiently embattled and are thus subject to erosion. At the same time they are pathways for already eroded material to enter the lake. An improvement proposal is to build stabilizing structures at the shoreline (Figure 10).

Figure 10 Stabilized jetty

Based on the fact that the phosphorous accumulates on the bottom of the lake, the **removal of the sediments** implies the permanent removal of the nutrients in the sediment. Although, few case studies exist due to the high expenses for this approach (UNEP, 1999).

Another noticeable pressure is the litter at the sides of footpaths and floating in the water. This pressure is most likely caused by increasing recreational activities (Figure 11). To avoid this negative impact, some more waste bins around the lake could be helpful.

Figure 11 Litter around Lake Durowskie (Source: summer school 2015)

3.3 Suitability analysis

Apart from the expected effect the different management options would have on the state of the lake, it is important to analyze their applicability. As was already mentioned in the previous section, the level of cooperation is a variable influencing the practicability of certain management measures. Furthermore, time and effort play an important role in the selection of management approaches aside from their efficiency. Hence,

Table 2 provides an overview of the possible management options of Scenario C presented in the previous section according to the mentioned criteria.

Table 2 Suitability analysis according to the criteria level of necessary cooperation, time and effort, expected efficiency

Scenario and measure		Level of necessary cooperation	Time and effort	Expected efficiency
C1	Educational path	medium	medium	medium
	Lake festival	medium	medium	high
	School projects	medium	low	medium
C2	Designated bathing and recreational areas	medium	medium	high
	Access management	medium	medium	high
	Artificial supporting structures	medium	medium-high	high
	Guideposts	medium	low	high
C3	Restriction/ban of motorboats	low	low	high
	Introduce mussels	medium	low	high
	Bentonite	low	high	high
	Harvesting macrophytes	high	high	medium
C4	Improve efficiency of aerators	low	medium	high
	Cooperation with upstream communities	high	medium	high
	Irrigation with water from bottom layer of the lake	high	medium-high	high
	Improve jetties	medium	medium	high
	Maintenance of surrounding	medium	medium	high
	Dig out sediments	high	high	high

Each management option was classified on a low-medium-high scale. In the **awareness raising** category the **educational path** and the **lake festival** are expected to involve a medium amount of necessary cooperation as mainly inhabitants of Wagrowiec, local businessmen, performers and maybe a local ecologist or supporting staff from Adam Mickiewicz University would be involved. The Lake festival could be organized annually whereas the installation of an educational path would be a one-time effort. Whereas the educational path would mainly address school children with their parents the Lake Festival

could also reach out to the teenagers and other adults of Wagrowiec and increase their interest in the lake's state. Therefore a higher efficiency was assigned to the Lake Festival. Both approaches are easily applicable, affordable and have a positive effect on the education of locals and tourists. In comparison to the educational path the effort and costs for broadening the already existing **school projects** as to also involve High School students is comparatively lower. The efficiency is assumed to be comparable to an educational path.

Leading over to **erosion prevention**, all approaches need a medium level of cooperation with the Gmina Wagrowiec assigning, as not the whole lake is administered by the city of Wagrowiec. Creating **additional recreational and bathing areas** is a task that requires some effort as intensively used spots need to be identified, to in a next step provide structures such as fixed beaches to prevent erosion. However, the result would have a high efficiency for the state of the lake. The same is true for access management. The most advantageous positioning and construction of stairs and fences at hotspots of erosion would require some effort and time. This effort would in return be rewarded by a high benefit for the state of the lake and also increase the capacity of the lake to accommodate growing demand for recreation.

In places where access to assigned beaches is provided it would make sense to **install artificial supporting structures**. The effort for building these structures depends on the type and size of the structure (e.g. sediment traps for a whole beach comparable to a boat access point) and is thus either moderate or high but would create a very efficient outcome.

Guideposts leading to the available access points would be a measure only requiring a low effort when on the same time being very efficient.

Leading over to the ecological approaches, implementing a **motorboat ban or restriction** is a relatively easy measure, as access to the lake can be prevented by locking the gates to the access points without needing a lot of effort or cooperation, while being very beneficial for the system. A Kayak only zone would need more effort, as enforcement measures would need to be set in place.

The **introduction of mussels** as natural filtrators could for example be achieved by cooperation with Adam Mickiewicz University. Cultivating mussels is a very simple task which is estimated to be highly efficient.

Adsorbents based on bentonite were suggested as a very effective alternative to the current iron fertilization which could be easily implemented by instructing the company in charge of iron fertilization to use a different substance. However, this method could be more cost intensive and would have to be evaluated in a cost-benefit analysis.

Harvesting macrophytes on the other hand is an endeavor requiring a lot of specialist knowledge to ensure the continuous functioning of the reeds as filtrators and as not to heavily impact important habitats. As the macrophytes would have to be harvested in summer, the plants would have a high water content and would thus be very heavy. Hence, cooperation with specialists and the use of special devices would be required. Additionally, infrastructure for the processing of the raw materials would have to be created close to the lake. The efficiency for this approach is estimated to be moderate.

In the category of **technological** approaches, the measure of **improving the efficiency of the aerators** appears to be the approach requiring the lowest level of cooperation. This is the case as the company renting the aerators to the town of Wagrowiec could be instructed to take necessary actions to provide electricity supply to the aerators. However, this measure is estimated to involve some financial effort but would most likely be very efficient.

Cooperation with upstream communities is obviously cooperation intensive and would require some time and effort (medium extent) this is a very promising approach in terms of efficiency for Lake Durowskie.

For **irrigating the fields** around Lake Kobyleckie, the rest of the catchment area and the sport field in Wagrowiec respectively, with water from the bottom layer of the lake(s) for instance, upstream farmers would need to be asked to collaborate. Depending on what pumps are used for lake water extraction, the effort to replace them by pumps able to pump up water from greater depths is estimated to be medium to high. This approach would permanently remove nutrients from the upstream lake(s) and Lake Durowskie, reduce fertilizing intensity in the surroundings and thereby reduce the nutrient load reaching Lake Durowskie. This approach is thus most likely highly efficient.

The often discussed possibility to **improve jetties** is highly efficient and would require the cooperation of the fishermen's association. The implementation could take some time but would in the end be beneficial to all parties as will be elaborated in the following section.

Maintaining the surroundings is a task that requires a medium level of cooperation as ideally the inhabitants of Wagrowiec would take part in this process. The effort is estimated to be moderate while being very efficient.

As mentioned in the previous section **digging out the lake sediments** would be very efficient as it would permanently remove pressures from the lake. At the same time this method is very expensive and would require cooperation with experts and the use of heavy machinery.

Naturally, the three scenarios and management options do influence diverse groups of people in different extents. The following section is thus dedicated to analyzing the effects the action alternatives have on the stakeholders of Lake Durowskie. For this analysis only the most applicable management options identified from Table 2 were analyzed. Some of the less complex but applicable management options (e.g. setting up guideposts or maintenance) are omitted for the following step of analysis.

3.4 Stakeholder analysis

Several interest groups are affected by the different scenarios and management options. In the case of Lake Durowskie the affected parties are the inhabitants of the town, tourists, tourist offices and/or administration, fishermen (association), forestry agency, private investors and farmers living upstream of Lake Durowskie. The following Table 3 describes the benefits and disadvantages the different scenarios including the most suitable restoration measures of Scenario C (see 2.3) have for each stakeholder. It is important to mention that all expenditures by the inhabitants of Wagrowiec are indirect payments via taxes.

Firstly **Scenario A - Stop of restoration measures** was discussed. In this scenario the negative effects predominate clearly. Only the people of Wagrowiec would benefit by saving restoration expenditures and the forestry agency as a result of less erosion caused by visitors (assuming that less people will visit the lake due to the worsening recreational conditions). An important negative issue is the high risk of losing the already invested money by the town of Wagrowiec (about 500 000 zl).

In **Scenario B - Stagnation** the pros and cons are mixed. On the one hand the fisherman association and tourists would only benefit, whereas for inhabitants of Wagrowiec, tourist offices and private investors there are positive effects such as the income for the tourist offices from the tourism and negative effects like investments for the restoration measures that need to be paid by the town of Wagrowiec. The forestry agency clearly suffers by this approach since no restoration measures regarding erosion would be implemented.

Scenario C1 - Awareness raising could be implemented without any negative effects. Every party would benefit from the Lake Festival and the implementation of High School Projects. Especially the private investors and tourist offices profit by the higher recreational value in the long-run

The situation for **C2 - Access Management** is similar. Most of the stakeholders solely benefit by this approach. Only the inhabitants of Wagrowiec would have to pay for the investments that are necessary to build new structures, but ultimately benefit the most from the new convenient infrastructure.

Almost no expenditures are necessary for Scenario **C3 - Ecological approaches**. A restriction or ban of motorboats or a kayak-only zone respectively provides benefits for all parties involved. Particularly the private investors would increase their income, e.g. by renting more rowing or bicycle boats. Even so the inhabitants of Wagrowiec would profit from the access-fees motorboat users would have to pay for entering the lake (assuming that the restriction is implemented, not the ban). In case of a total ban the disadvantage is that tourists and locals who like to use the motor boat are not allowed to boat on the lake anymore. However, the noise pollution would decrease considerably, benefiting other visitors of the lake. Introducing mussels implicates only benefits for each party and an increased income from tourists. Scenario C4 includes the **technological approaches**. The first measure is to improve the efficiency of the aerators by the application of solar panels and/ or additional electricity supply. Almost all stakeholders (except the forestry agency) would gain from the higher recreational value entailed by this approach. It is only a one-time investment for the inhabitants of Wagrowiec for the solar panels and/ or the electricity supply. Same holds true for the next option- the irrigation of agricultural areas with water from the bottom layer of

the upstream lakes. It is of advantage for all parties (except the forestry agency) and also the farmers using the water for irrigation of their fields. This involves a one-time expenditure for new pumps that can be shared by the town of Wagrowiec and the affected farmers. Whereas the sport field in Wagrowiec could be irrigated with the water from the bottom layer of Lake Durowskie without any cooperation. The last technological approach is an improvement of the jetties. It is associated with possible investments for new jetties for the inhabitants of Wagrowiec and the disadvantage for the fishermen who would not be allowed to build private jetties anymore. But on the other hand all stakeholders, including the inhabitants of Wagrowiec and the fishermen, would profit in the long-run due to a better water quality. The inhabitants of Wagrowiec would benefit from a higher recreational value of the lake and the fishermen from more fish in the long-run and an easier access to the lake.

Table 3 Stakeholder analysis for Lake Durowskie

Scenarios			Stakeholder perspective						
			Inhabitants of Wagrowiec	**Fishermen-Association**	**Tourist offices/ Administration**	**Private investors**	**Tourists**	**Forestry agency**	**Farmers living upstream**
Scenario A	**Discontinuation of Restoration**	Pro	Saving restoration expenditures						
		Con	Very limited recreational options; Failed past investement	No fish to catch	Less income from Tourism	Less income for shops depending on the recreational services of the lake	No incentive to visit the lake	Increased erosion of the forest	
Scenario B	**Continuation of existing restoration methods**	Pro	Profit from recreational value	Moderate amount of fish in the lake	Income from Tourism	Income for shops depending on the recreational services of the lake	Profiting from services provided by lake		
		Con	Investments need to be continued		Possible loss of investment in new infrastructure if lake cannot accomodate increasing demand	Possible loss of income if lake cannot accomodate increasing demand	Possible loss of income if lake cannot accomodate increasing demand	No extra measures preventing erosion	
C 1	**Lake festival**	Pro	Increased recreational and social value	More fish in the longrun	New source of income	Business opportunities for small shops	New recreational opportunity Higher recreational value in the longrun		
		Con							
	High School Projects	Pro	Enjoyment an knowledge for children and teenagers	More fish in the longrun			Higher recreational value in the longrun		
		Con							

Table 4 Stakeholder analysis for Lake Durowskie (continued)

Scenarios			Stakeholder perspective						
			Inhabitants of Wagrowiec	**Fishermen-Association**	**Tourist offices/ Administration**	**Private investors**	**Tourists**	**Forestry agency**	**Farmers living upstream**
C 2	**Access management**	Pro	More comfortable access to recreational activities	More fish in the longrun, Easier access to the lake			More comfortable access to recreational activities	Less erosion of forest area	
		Con	Investments need to be made						
C 3	**Motorboat ban**	Pro	Higher recreational value	More fish in the longrun	Sustainable tourism strategy for income intensive beach tourism	Higher income for rowing boat rentals	No noise pollution Higher recreational value	Less erosion of the river bank impacting the forest	
		Con	Some can not recreate on their boats				Motorboat tourists can no longer enter the lake		
	Introduce mussles	Pro	Higher recreational value	More fish in the longrun	Increased income from Tourism	Increasing income for shops depending on the recreational services of the lake	Profiting from better services provided by lake		
		Con							

Table 5 Stakeholder analysis for Lake Durowskie (continued)

Scenarios			Stakeholder perspective						
			Inhabitants of Wagrowiec	**Fishermen-Association**	**Tourist offices/ Administration**	**Private investors**	**Tourists**	**Forestry agency**	**Farmers living upstream**
C 4	**Improve efficiency of aerators**	Pro	Higher recreational value	More fish in the longrun	Increased income from Tourism	Increasing income for shops depending on the recreational services of the lake	Profiting from better services provided by lake		
		Con							
	Irrigation with water from bottom layer of the lake	Pro	Higher recreational value	More fish in the longrun	Increased income from Tourism	Increasing income for shops depending on the recreational services of the lake	Profiting from better services provided by lake		Less expenditure on fertilizers
		Con							One-time investment in better pumps
	Improve jetties	Pro	Higher recreational value	More fish in the longrun, Easier access to the lake	Increased income from Tourism	Increasing income for shops depending on the recreational services of the lake	Profiting from better services provided by lake		
		Con							

4. Conclusions

In sum discontinuing restoration measures bears a high risk of a degradation to bottom up control and therefore a hypertrophic state of the lake which in turn leads to a closure of beaches. Stopping the restoration measures therefore implies a misinvestment of the approximately 500 000 zl that were already invested, since the state of Lake Durowskie is expected to worsen rapidly if one were to follow Scenario A.

Due to the increasing pressures (camping site, motorboats, damming of Lake Laskowieckie) an increase in restoration measures is necessary, too, since the state of the lake is still not in a stable condition and it is very unlikely that it will tolerate the additional stress. Scenario B does not include further approaches to accommodate the additional demand and provide buffer capacity against the increasing pressures. Scenario C is therefore most apt to ensure a continuous improvement of the water quality. Although in this scenario many measures come along with costs, ultimately the town of Wagrowiec would invest with profitable success. Because the restoration of the lake leads to a lower risk of new algae-bloom, the quality of the water becomes better and the risk of beach closure decreases. Therefore a higher (recreational) value of the lake is provided which in turn comes along with higher incomes from tourists and visitors of the lake. In the long-run following Scenario C would support the positive development of the lake on its way to a top-down control associated with a self-regulating, oligotrophic state (Figure 12).

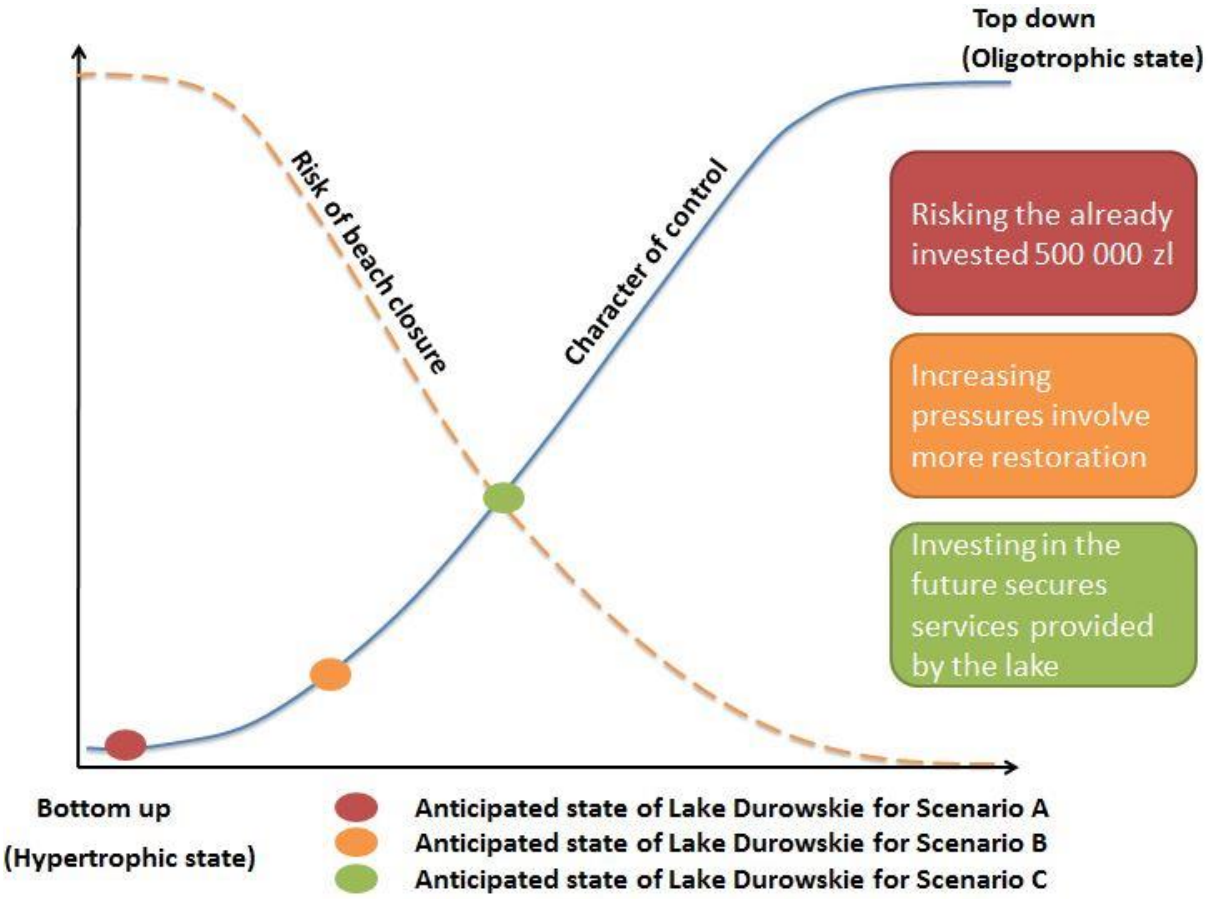

Figure 12 Bottom up and Top down control regarding the risk of beach closure of Lake Durowskie including Scenario A-C

It needs to be stressed that cooperation with the Gmina Wagrowiec and the upstream communities as well as other stakeholders is key for success and needs to be continued and or established. In case of the local population a sense of ownership and responsibility for the lake could be developed for long-term success. In general, the proposed management measures do not mutually exclude each other but a combination of different measures could even lead to higher overall restoration success.

The suitability analysis as well as the stakeholder analysis aimed at pointing out possible evaluation methods and criteria to facilitate decision making. They ultimately intend to empower the authorities of Wagrowiec to take an informed decision.

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