Potential influence of different loading scenarios of Lake Peipsi (Estonia/Russia) on water quality, trophic status and the situation of fish stocks

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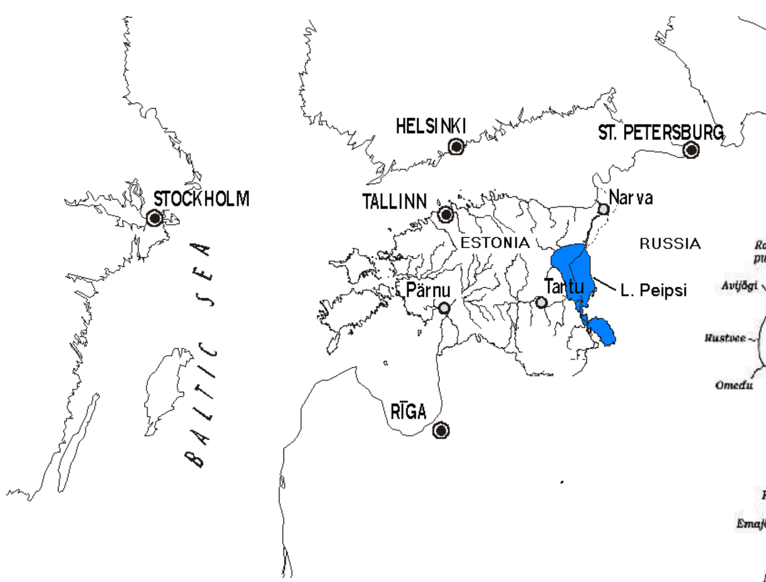
Lake Peipsi and its watershed

Lake Peipsi (3,555 km^2, mean depth 7.1 m) is one of the most important lakes in Europe and has the fourth largest surface area after Lakes Ladoga, Onega, and Vänern. Located on the Estonian-Russian border (Fig. 1), L. Peipsi is a transboundary waterbody and the largest international lake in Europe. L. Peipsi consists of three parts: northern L. Peipsi *s.s.* (2,611 km^2, mean depth 8.4 m) and southern L. Pihkva (708 km^2, mean depth 3.8 m) are connected by the narrow river-shaped L. Lämmijärv (236 km^2, mean depth 2.6 m). Residence time of the water is about 2 years, the outflowing River Narva runs its waters into the Gulf of Finland (Jaani, 2001).



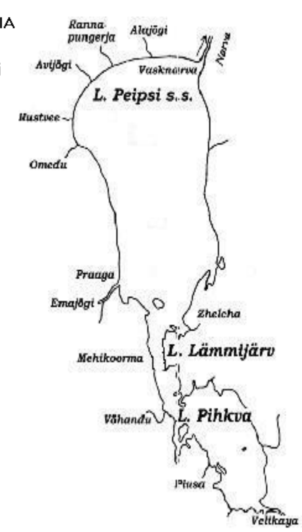


Figure 1. Location map of Lake Peipsi and its inflows

All three parts of L. Peipsi are divided between Estonia and Russia (Table 1). For calculation purposes, the drainage basin can be divided between L. Peipsi *s.s.*, L. Pihkva and L. Lämmijärv as given in Table 1. However, in reality the three parts of the lake are arranged hierarchically so that the drainage basins of lakes Pihkva and

Lämmijärv are sub-basins for L. Peipsi *s.s.* The whole drainage basin is divided between three countries: Estonia, Russia and Latvia (Table 2).

Table 1. Division of the aquatory and watershed of L. Peipsi (in km^2) between lake parts and countries according to Jaani (2001).

Lake part Aquatory or watershed	L. Peipsi *s.s.*	L. Pihkva	L. Lämmijärv	Total L. Peipsi
Estonian aquatory	1442	10	118	1570
Russian aquatory	1169	698	118	1985
Total aquatory	2611	708	236	3555
Watershed	13158	28130	2957	44245

Table 2. Division of the watershed of L. Peipsi (in km^2) between countries according to Jaani (2001).

Country	Area including the lake	Area without the lake
Estonia	16 323 (34.1%)	14 753 (33.3%)
Russia	27 917 (58.4%)	25 932 (58.6%)
Latvia	3 560 (7.4%)	3 560 (8.0%)
Total	47 800	44 245

Nutrient loading

The majority of phosphorous and nitrogen compounds are carried into the lake by the rivers Velikaya and Emajõgi, the former carrying biologically treated sewage from the Russian town Pskov, with ≈200,000 inhabitants, the latter transporting waste water from the Estonian town Tartu, with ≈100,000 inhabitants. The sewage water of Tartu remained untreated for a long time; the treatment plant has been in operation since 1998 but still 20% of the sewage water is not subjected to purification. In 1998 the rivers Velikaya and Emajõgi contributed, respectively, 48 and 27% of the total riverine loading of nitrogen and 63 and 17% of that of phosphorus (Fig. 2).

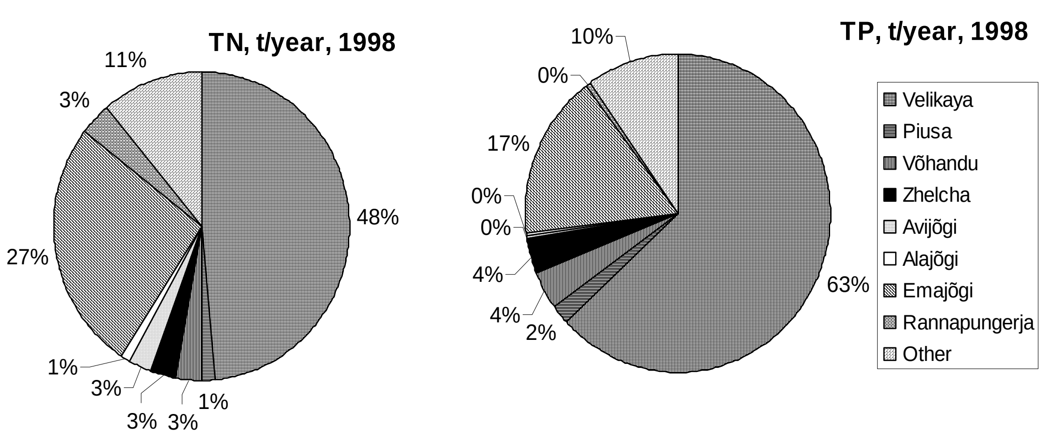


Figure 2. Share of the main rivers in the total N and P loading into L. Peipsi in 1998 (according to Nõges, P. *et al.*, 2003).

Anthropogenic stress on L. Peipsi resulted in intense agricultural eutrophication between the 1950s and the 1990s; a decrease in loadings occurred during the 1990s following the collapse of agriculture in the territory of previous Soviet Union. The greatest decrease occurred in nitrogen loading while phosphorus loading and its concentrations in L. Peipsi s.s. have been quite stable (Nõges, T. et al, 2003). In lakes Pihkva and Lämmijärv concentration of P has even increased in the last few years. In-lake nitrogen concentration has diminished up to the end of 1990s, an increase could be noticed in last 2 years (Nõges, T. et al, 2003a). N/P ratio in loadings and in the lake has decreased lower than 30 (Fig. 3), the critical value below which the risk of blue-green blooms increases (Fig. 4).

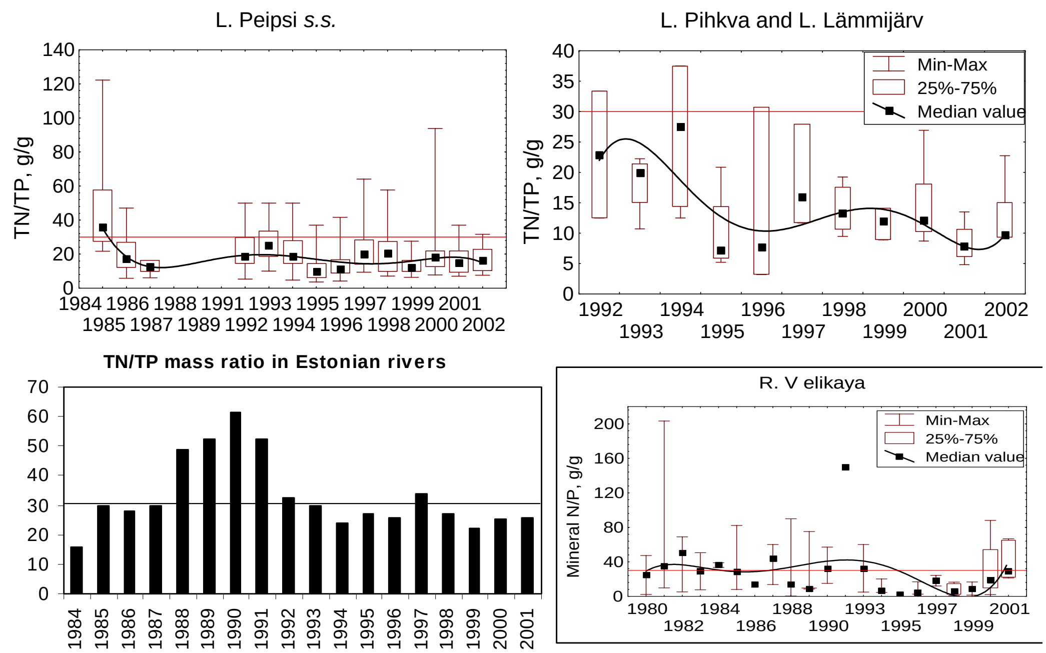


Figure 3. Nitrogen/phosphorus ratio in L. Peipsi and inflowing rivers (Nõges, T. et al., 2003a; data of Estonian and Russian State monitoring)

In the regards of nutrient concentration, the trophic status of Lake Peipsi has not increased in the last decade (Kangur et al., 2003). The water quality has, however, not improved and severe summer/autumn blue-green blooms occur during warm windless periods causing summer fish kills (the most recent occurred in 2002 and 2003).

Ecological modelling

For studying the reactions of the ecosystem to changed nutrient loading, an ecosystem model SHALMOD was developed and calibrated. This 0-dimensional model was designed applying AQUASIM software (Reichert, 1994). SHALMOD is able to simulate the growth of the main phytoplankton groups – cyanobacteria and diatoms, the dynamics of inorganic nitrogen and phosphorus and dissolved oxygen concentration. Water quality model of Lake Võrtsjärv designed by Frisk et al. (1999) and the values of kinetic parameters applied in the water quality model WASP-Eutro (Ambrose et al., 1993) served as the starting basis for SHALMOD.

In order to run the ecosystem model, the data on nutrient loadings were needed as input variables. As the loading data on the Russian part of the catchment area of L. Peipsi are scarce and not always reliable, SHALMOD was calibrated for the data measured in L. Peipsi and inflowing rivers in 1998 as this dataset was most complete considering Russian side. In 1998 L. Peipsi received 23800 t of nitrogen and 1300 t of phosphorus (Nõges, P. et al., 2003).

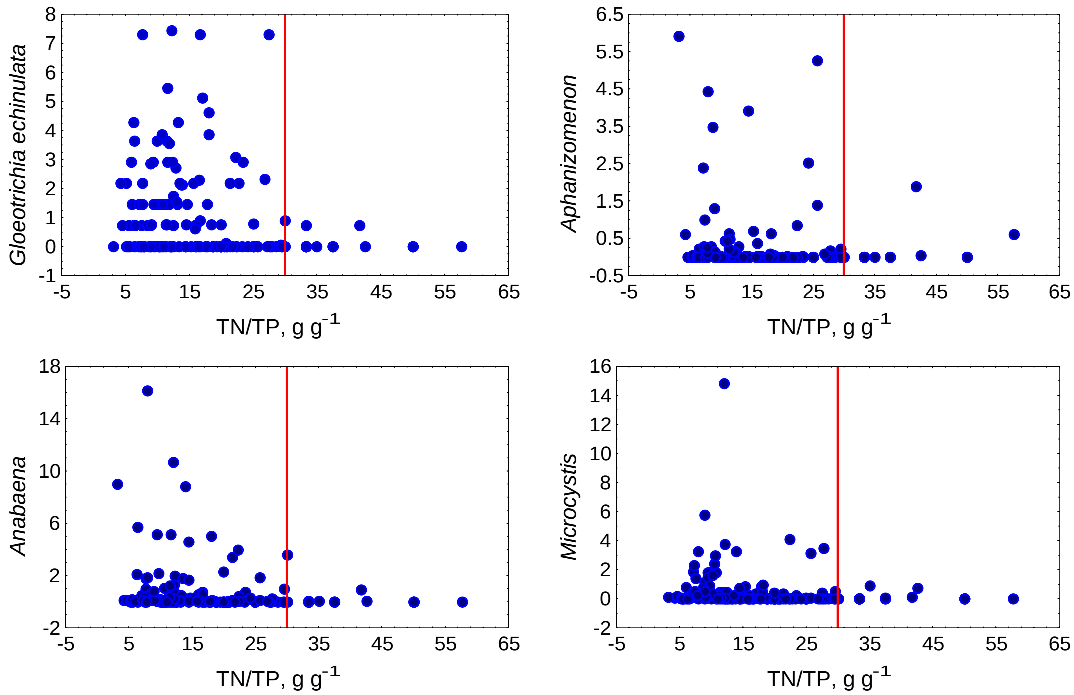


Figure 4. Biomass of dominating cyanobacteria gWW m^{-3} at different TN/TP ratios in Lake Peipsi in June-September (Nõges & Nõges, 2004; data of Reet Laugaste)

Sensitivity analysis of SHALMOD revealed that (i) reduced riverine loading of nitrogen enchances the growth of cyanobacteria; (ii) increased riverine loading of phosphorus enchances the growth of both cyanobacteria and diatoms; (iii) phytoplankton growth is strongy influenced by wheather conditions - in warmer water and at lower water levels much higher concentrations of phytoplankton may occur (Nõges et al., 2003b).

Influence of different development scenarios of Lake Peipsi region on water quality of the lake

In EC project MANTRA-East Work Package 2 the basic qualitative scenarios for the socio-ecnomic development in Estonian-Russian border region were developed for the next twelve-year period (Gooch, 2003). In regional perspective the key factors were considered economic development, and transboundary cooperation. These two axis provided four different alternatives, high economic development/a high level of cooperation; high economic development/a low level of cooperation; low economic development/ a high level of cooperation; and low economic development/ a low level of cooperation. From these four alternatives five scenarios were developed for further consideration. These scenarios were named as I: ‘Business as usual’, II: ‘Fast development’, III: ‘Crisis’, IV: ‘Isolation’, and V: ‘Uneven development’ (Figure 5.).

In MANTRA-East Work Package 5, the qualitative scenarios were ‘translated’ into quantitative loading scenarious (Table 3), the consequences of which were simulated by SHALMOD.

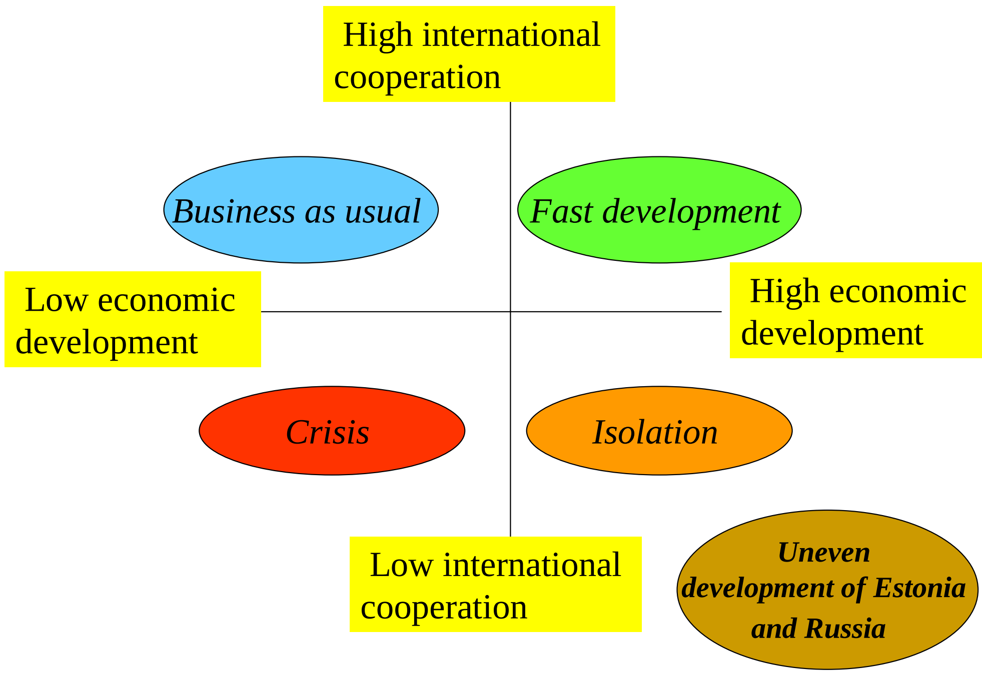


Figure 5. Development scenarious of Lake Peipsi region according to Gooch (2003)

Table 3. Nutrient loading into L. Peipsi at different qualitative scenarios according to Mourad et al. (2003).

	N-load t y^{-1}					**P-load t y^{-1}**				
Years	*1995-1999*	*2000-2004*	*2005-2009*	*2010-2014*	*2015-2020*	*1995-1999*	*2000-2004*	*2005-2009*	*2010-2014*	*2015-2020*
Usual	27635	22964	22863	22987	23162	846	688	653	618	589
Fast	27636	27001	31622	36753	42152	846	717	715	716	719
Crisis	27635	22809	22385	22124	21882	846	743	763	782	800
Isolation	27635	23180	23175	23350	23557	846	709	694	681	667
Uneven	27635	23462	23880	24561	25357	846	720	718	717	716

The ‘Crisis’ scenario leads the lake closer to some kind of ecological crisis bringing about 1.5 times higher cyanobacterial biomasses than other scenarios, especially in cold summers. In very warm summers, however, cyanobacterial biomass is higher due to climatic conditions. (Figure 6). Admitting the important role of climatic factor as *force majour*, the most important measures what could be done to achieve the further improvement of water quality in L. Peipsi would be reduction of phosphorus loading from both Estonian and Russian catchment. As the main proportion of phosphorus is coming into L. Peipsi through the two major rivers Velikya and Emajõgi, the main attention should be payed to these two rivers and wastewater treatment in their catchment basins. However, a strict control should be also established on the waste processing of small settlements and summer cottages situated close to L. Peipsi

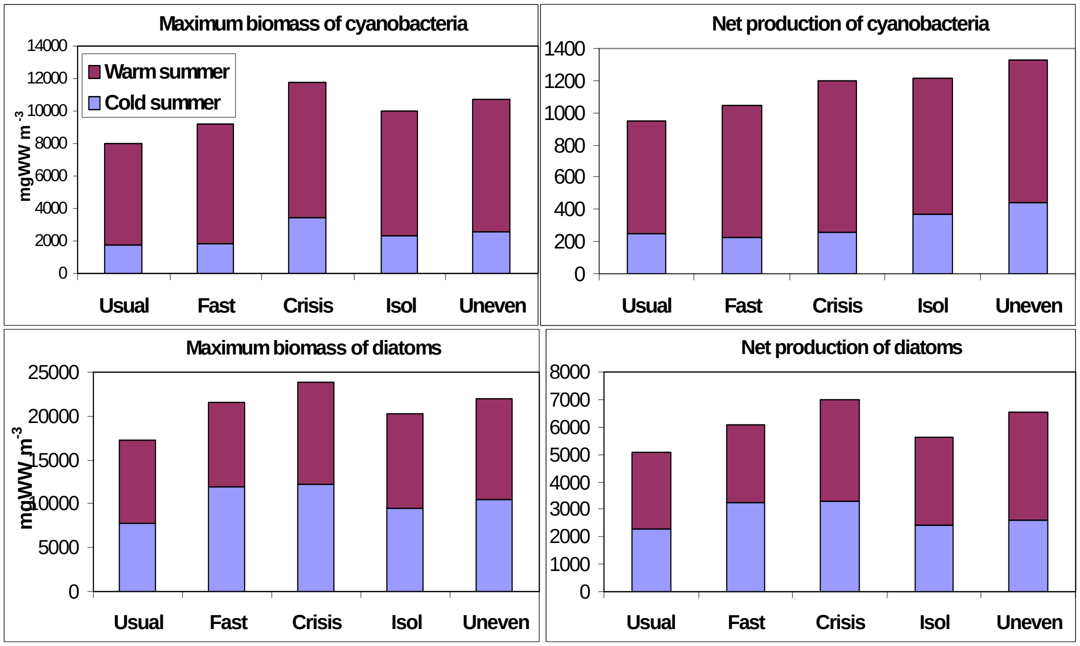
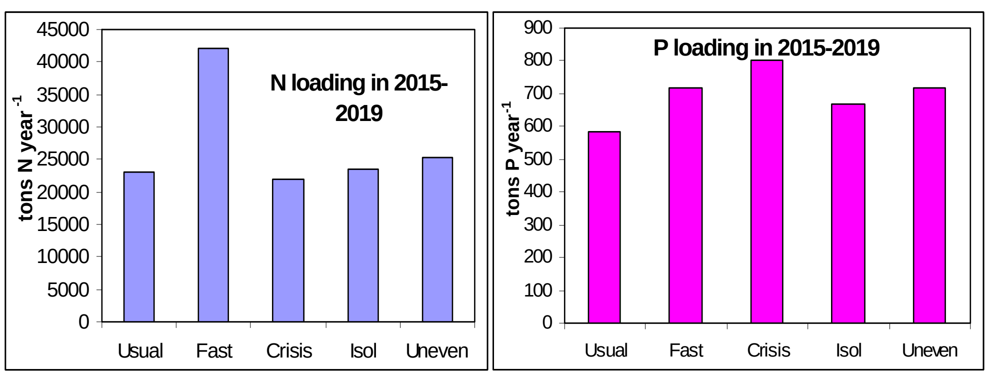


Figure 6. Reaction of phytoplankton to different loading scenarious in 2015-2019

N/P mass ratio in loadings will remain below the critical value 30 in case of the ‘Crisis’ scenario due to the most drastic increase of phosphorus loading (Figure 7). In



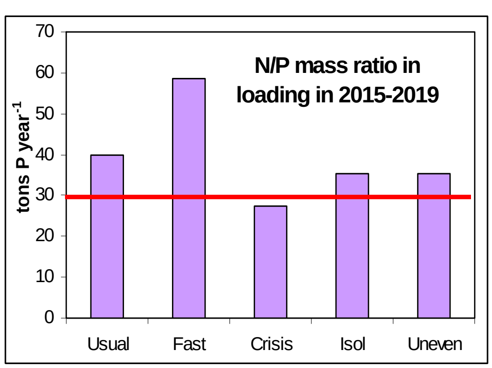


Figure 7. Changes of N and P loading and N/P mass ratio in loadings according to the development scenarious presented in Fig. 5 and Table 3 in years 2015-2019

this case the enchancement of blue-green blooms would be expected. The highest N/P ratio and the less favourable conditions for cyanobacteria would be expected in case of ‘Fast development’ scenario.

In L. Peipsi the prevalence of ‘grazing food chain’ and modest ‘microbial loop’ are responsible for high fish production. The higher is the ratio of piscivorous to planktivorous fish, the less phytoplankton and the higher water quality is assumed (Nõges et al. 2003b). For the protection of Lake Peipsi ecosystem the **reduction of phosphorus** loading is inevitable to reduce water blooms and fish-kills while **protection of piscivorous fishes** is suggested for keeping food chain transformation effective and sustaining high water quality.

Influence of different development scenarios on fish stocks.

Most negative human impact to fisheries is overfishing. This results both in decreased economic performance in long run (i.e. significantly lower revenue than possible due to the lower catches) and negative effect to fish fauna (e.g. to the species composition: decrease of share of the large piscivorous fish etc.). Basically, overfishing is a result of lack of sufficient control over fishing operations. L. Peipsi fishing is managed by rather sensible management system, which limits the fishing effort and catches. The maximum allowed number of fishing gears and quotas for all commercial species are set for each year. Also, the minimum landing sizes for most of critical species such as pikeperch are determined. However, a good system might be of little use if not fully enforced. There are two main problems, hindering enforcement: a) lack of cooperation between two states, and b) corruption. Both those problems lead to overfishing (i.e. higher than optimal catches). **So, the axis “high – low level of cooperation” is in strong positive relation with the development between “good state of fish stocks – bad state of fish stocks”.**

This relation, however is not quite straightforward, because the effects of economic growth might be different to the fish stocks and to the fishing community. First of all, fisheries are rather special branch of national economy. Quick economic development is negative to employment in fisheries. Today in Estonia most of the catch is exported to the western market and revenues are high. Salaries in the remote areas like L. Peipsi region are, however, rather low. Quick development of the whole Estonian economy (the scenario for Russia is not much different) will cause increase in average salaries and also fishing costs. This, in turn, results in situation when aggregate revenue of L. Peipsi fisheries is not any more sufficient to cover all the needs of fishermen employed today. Such a development is dangerous, because in aim to keep their living standard fishermen are forced to fish more. If enforcement is weak, then overfishing is the result. However, there is also another general tendency, which works into opposite direction, i.e in favour of fish stocks. If to compare the employment pattern in developed and less developed countries, it is easy to see that in more developed countries dependence on inland fishery (as a main source of income of households) is much smaller. In developed countries many other employment possibilities are usually more attractive and profitable than inland fishery, which uses rather old-fashioned methods and generates quite low revenues. So, even if the total value of L. Peipsi fish catches could be somewhat increased through a better management, the decline in the number of full-time commercial fishermen, as well as in the general importance of the fishery to the economy of the region, is still unavoidable in the long run. And the final conclusion is that **the fall of dependence**

of regional economy on fisheries favours fish stocks. This conclusion is not only theoretical, but also supported by many observations in world fisheries. So, the **'Fast development' scenario would be still the most favourable to the fish stocks, while the 'Crisis' would be the worst case** (Fig. 8)**.** Since the international cooperation is more important to the health of fish stocks than quick economic growth, the **'Business as usual' scenario is better than the 'Isolationist'.**

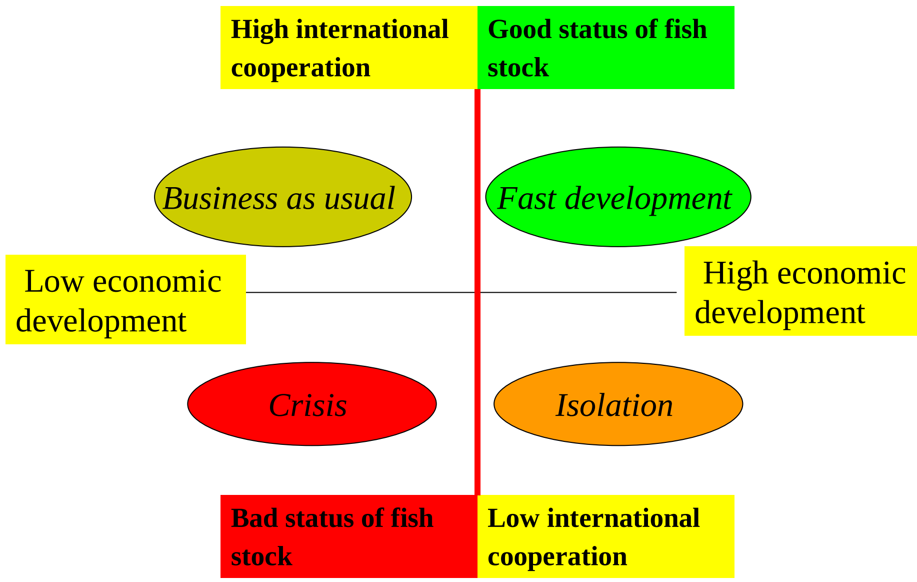


Figure 8. Status of fish stock in L. Peipsi at different scenarios for the Estonian-Russian border region according to Gooch et al. (2003)

Conclusions

The most important measures to achieve the further improvement of water quality in transboundary Lake Peipsi would be: (i) reduction of phosphorus loading from both Estonian and Russian catchment; (ii) protection of piscivorous fishes which is important for sustaining high water quality. As the main proportion of phosphorus is coming into L. Peipsi through the two major rivers Velikya (Russia) and Emajõgi (Estonia), the main attention should be paid to these two rivers. Considering fishery regulation (i) effective protection measures of piscivores - pike-perch, perch and pike should be worked out and implemented; (ii) good cooperation of the regulation of fisheries and avoiding overfishing should be sustained and developed between Estonia and Russia.

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