Mongolian Journal of Biological Sciences 2010 Vol. 8(1): 41-50

Impacts of Open Placer Gold Mining on Aquatic Communities in Rivers of the Khentii Mountains, North-East Mongolia

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Abstract

Since the political change and due to high market prices for gold the mining sector has considerably grown in Mongolia and has become one of the most important economical sectors. With increasing mining activities the mining related environmental problems also increased, especially those, which are caused by open placer gold mining. Placer gold deposits are located in the alluvial sediments of river floodplains and the exploitation of these deposits often induces severe impacts to river ecosystem and its different components. In this paper we describe the effects of open placer gold mining on diatoms, benthic invertebrates and fish in four rivers in the north-east of Mongolia. Our findings are based on a comparative analysis of these biocoenotic groups in pristine and mining affected river sections, taking into account also abiotic habitat characteristics. Our analyses revealed that placer gold mining causes multiple stressors acting on different trophic levels. The biocoenotic groups under investigation reacted differently against stressors, and we indentified a wide range of direct and indirect effects. These findings are new for Mongolia and are essential to define adapted and successful strategies for an ecologically based management and monitoring of open placer gold mining pressures and ecological impacts.

Key words: Turbidity, suspended sediments, clogging, river continuum, fish fauna, macroinvertebrates, diatoms

Introduction

In North-East Mongolia both extremes exist: (1) large-scaled undisturbed and pristine landscapes and (2) river ecosystems, which are faced with a rapidly growing mining industry with its diverse environmental impacts (World Bank, 2006). The majority of the gold deposits of this region are located in so called ´placer deposits´ in the alluvial sediments of the river floodplains. The exploitation of these placer deposits causes diverse environmental problems influencing the river-ecosystem in multiple ways (Farrington, 2000). For Mongolia placer gold mining is seen to be responsible for the entire loss or eventually long-lasting damage of at least 29 large-scaled river eco-systems, respectively parts of it (Mongolian Ministry of Nature and Environment, 2003).

Worldwide, the effects of open placer gold mining on aquatic ecosystems are well documented. Numerous authors have reported on the effects for the ecosystem itself (Newcombe & MacDonald, 1991) or specific components, e.g. primary production (Van Nieuwenhuyse & LaPerriere, 1986), macroinvertebrates (Wagener & LaPerriere, 1985) or fish (Pentz & Kostaschuk, 1999; McLeay *et al*., 1987). Although in Mongolia mining is seen to be a major threat to river ecosystems and its biocoenoses (Grayson, 2003; Ocock *et al*., 2006), little is known about the site-specific impact and the scientific basis for targeted regional management given the specific situation for Mongolia.

The main focus of this study was, therefore, to comparatively analyze the biocoenoses in pristine and mining affected sites and to estimate the effects of open placer gold mining on different biocoenotic groups (diatoms, macroinvertebrates and fish). Based on these analyses principles for an ecologically orientated monitoring and management of the open placer gold mining in Mongolia are derived.

Study Area

Two study areas were chosen in the border area of the strictly protected area (SPA) Khan Khentii, which is located in the north-east of the capital city, Ulaanbaatar. The study areas had both features, river stretches which can be assumed to be pristine with negligible human impact, and others which are severely affected by open placer gold mining.

Table 1. Geographical location of study areas

River	Shortcut	Latitude, N	Longitude, E
Tsagaan Chuluut	Tsa	49° 02' 20"	107° 11' 58"
Barchuluut	Bar	49° 02' 11"	106° 58' 20"
Yalbag	Yal	49° 05' 56"	107° 05' 11"
Terelj	Ter	48° 13' 30"	108° 39' 08"

The Yalbag River is located in the western border area of the SPA Khan Khentii and it belongs to the Eroo watershed (Table 1). At the river Yalbag mining activities were conducted in middle and down reaches of the watershed (see Fig. 1a). Along these stretches the natural bank structures and the riparian zone were predominantly lost due to open placer mining activities which normally start with the removal of organic top soil and the turning over of valley bottom sediments to the bedrock for subsequent processing to remove gold. In addition, mining activities caused severe changes in the matter and sediment balance downstream of the mined sites. In the study area the upstream part of the river Yalbag, called Barchuluut and another confluences of the river Eroo, called Tsagaan Chuluut served as a reference.

Our second study area was the river Terelj, which is part of the Kherlen watershed and is located south of the SPA Khan Khentii. The mining area is situated in the upper reaches of the river Terelj (see Fig. 1b) also influencing the middle and down reaches by high emissions of suspended sediments. We focused our studies to this area along a longitudinal transect of 40 km in length. We also studied one site upstream of the mining area and three tributaries of the river Terelj serving as reference sites. All study areas

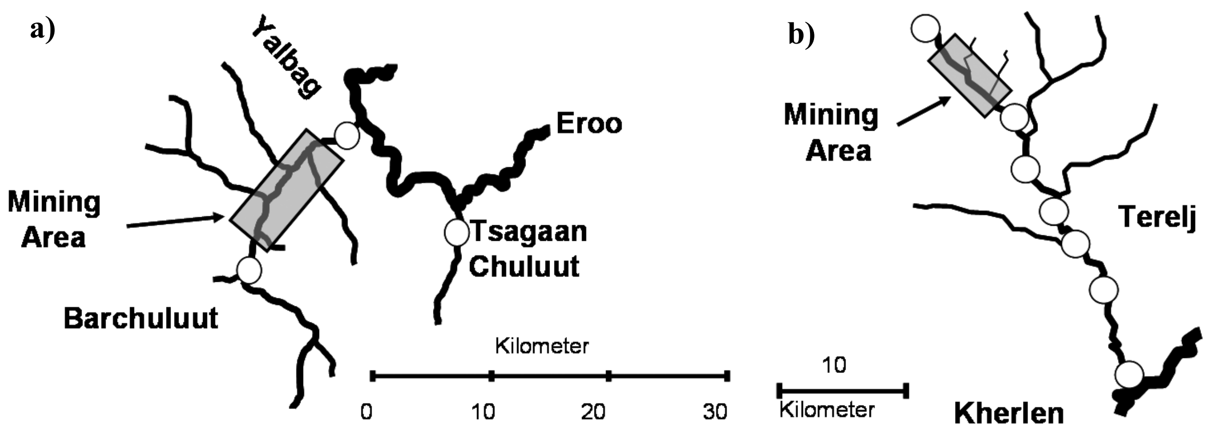

Figure 1. Study area in the western- (a) and southern Khentii (b) with study sites (white circles) at pristine and affected stretches of the river.

belong to the biocoenotical region of the Epi- to Metarhithral (Jungwirth *et al*., 2003).

Materials and Methods

The effects of open placer gold mining on the biocoenosis were studied with regard to diatoms, macroinvertebrates and fish. Field surveys for diatoms were conducted monthly during the ice-free periods in 2004 and 2005. Within the qualitative sampling program samples from stones, fine substrates and macrophytes were taken and diatoms were later analyzed in the laboratory using standard methods and equipment (Krammer & Lange-Bertalot, 1986-91).

The macroinvertebrate community was studied quantitatively synchronal with the sampling program for diatoms. Sampling was conducted at riffle, pool and bank habitats using a surber-sampler equipped with 500 µm gauze. In riffles and pools the substrate within the 32 x 42 cm frame of the sampler was kicked for about one minute to a depth of approximately 15 cm, big stones within the frame area were brushed and then set aside. In plant habitats an area equal to the frame size was washed using hands to let the currency carry the macroinvertebrates into the Surber sampler held directly adjacent to the sampling site. The material in the sampler mesh was poured through two buckets and an analysis sieve of 500 µm, and was then transferred onto white plastic trays. The samples were sorted in the field, put into glasses containing 80% ethanol and then transferred to the laboratory. In the laboratory organisms were sorted from organic matter and stored in 80% ethanol until they were identified to the lowest taxonomic level possible, usually to genus.

The fish fauna was also sampled quantitatively using electro-fishing gear (Hans Grassl GmbH, Germany; Type ELT 60). The fish were caught, determined and measured in length and weight. With the length and weight data the condition factor after Fulton (Ricker, 1975) was calculated and considered as fitness indicator. Additionally to the quantitative sampling migratory patterns of fish were studied by installing weirs at several sites. Weirs were installed downstream and inside the mining area at the river Yalbag as well as at one by-pass channel, which spans parts of the mining area (see Figure 7). This study was performed during a two-week time period in spring 2006, whereas electro fishing campaigns were carried out regularly from 2003 through 2006.

Results

Laboratory analyses identified 62 diatom species belonging to 35 genera with no significant differences in species and genera numbers between pristine and mining affected sites. However Canonical Correspondence Analyses (CCA) based on the taxa and the relative abundances pointed out differences between two groups of sites, and cluster analyses clearly separated the two groups (Fig. 2). Comparative analyses based on the ecological guilds revealed that the relative amount of mobile taxa (e.g. *Cylindrotehca, Gyrosygma, Navicula, Nitzschia* and *Surirella)* were significantly higher at affected sites, when compared to reference sites.

For macroinvertebrates the number of taxa (N) and total abundance of individuals (ind. m-2) were significantly higher in pristine sites than in affected sites, especially in pool-habitats. At the study sites in the Eroo watershed this pattern was significant (t-test, $p < 0.05$) during spring season (May and June), and visible, but not significant during the rest of the sampling season (see Fig. 3).

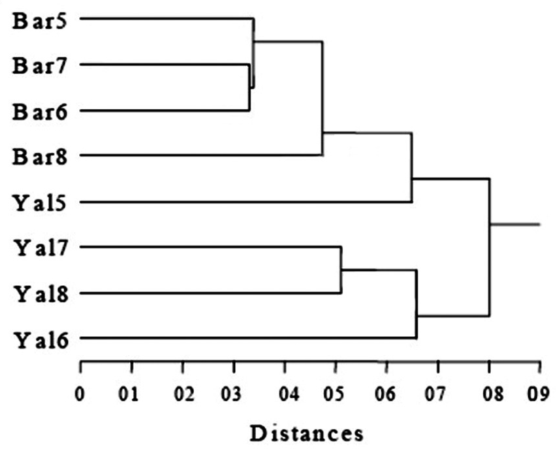

Figure 2. Cluster analyses based on diatom community structure and relative abundances at the reference sites at the river Barchuluut (Bar) and the mining affected river Yalbag (Yal). The numbers 5 to 8 indicate the month of sampling.

At the river Terelj the benthic invertebrate community was clearly different at sites downstream of the mining area. Here the abundance of macroinvertebrates decreased from more than 8.000 ind./m² upstream the mining area to only a few individuals at the site located directly downstream of the mining area (Fig. 4). Along the 40 km transect the benthic invertebrate abundances remained relatively low and reached maximum values of less than 2.000 ind./m². Regarding the habitat type, pool habitats seemed to be most affected, showing the lowest number of individuals when compared to riffle and bank habitats.

The mining activities also influenced benthic invertebrate species composition. A nonmetric, multi-dimensional scaling (NMDS) based on abundances showed that macro invertebrate communities differed significantly between pristine and affected sites (ANOSIM significance: < 0.001, see Figure 5). In Figure 5 the abiotic variables conductivity, pH, oxygen concentration, temperature and suspended sediments were included in a second step by environmental fitting. Differences between these parameters were significant between reference and downstream sites (Mann-Whitney test, $p < 0.05$) but seemed to be ecologically relevant only for suspended sediments.

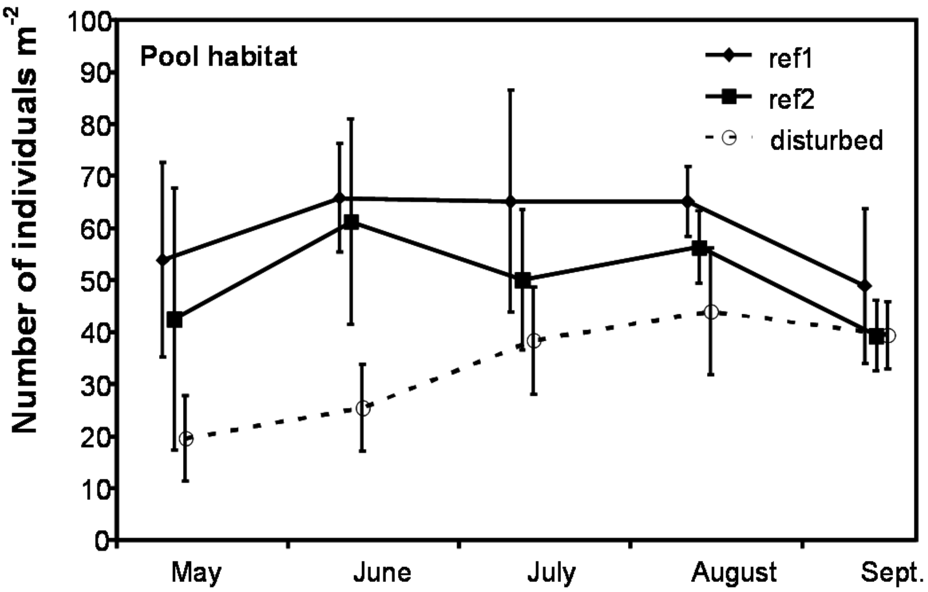

Figure 3. Abundance (ind. m-2) of macro invertebrates in reference sites (ref1 and ref2, respectively Barchuluut and Tsagaan Chuluut) and in disturbed sites (Yalbag) during the time period of May until September (Mean ± Standard Deviation).

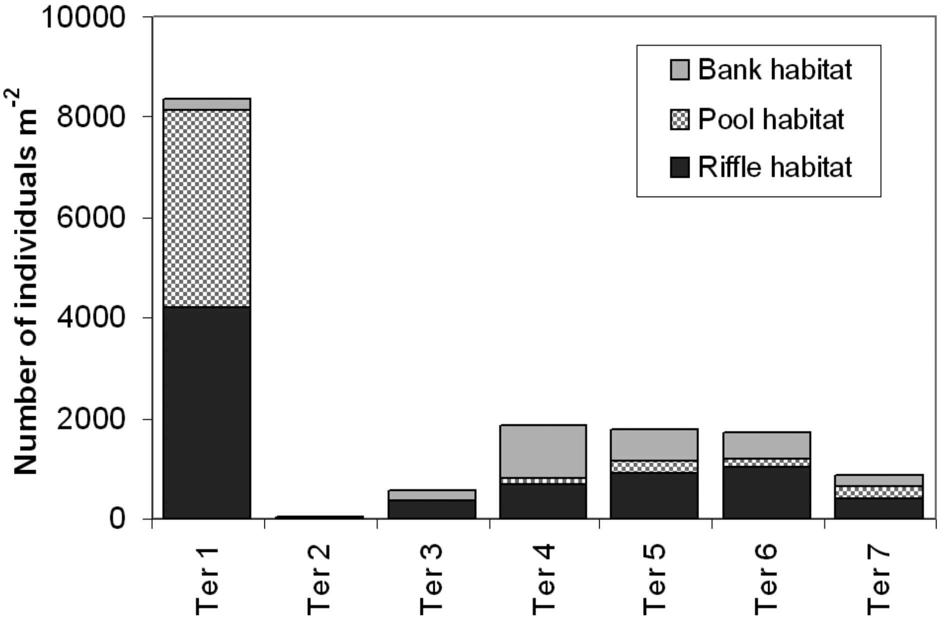

Figure 4. Abundances (Number of (ind. m-2)) of macro invertebrates along the longitudinal transect of river Terelj. Sampling site 1 (Ter 1) was located upstream and site Ter 2 to Ter 7 downstream of the mining area.

For the fish fauna the results were somehow ambiguous. Based on the species community no differences were found between reference and disturbed sites (see Table 2). In the study area of the river Yalbag the number of species was actually higher in disturbed sites than in the reference sites (8 compared to 7 and 5, respectively).

A similar pattern was found for the total abundances of fish at the river Yalbag, which were significantly higher (Mann-Whitney-Test, $p < 0.05$) downstream of the mining area. At the river Terelj no such pattern could be observed. The analyses of the fish community showed clear differences between the sites (based on a NMDS). At the mining affected sites, non-sensitive species like siberian dace and siberian stone loach were dominant, whereas in reference sites they were rare or even missing. Significant differ-

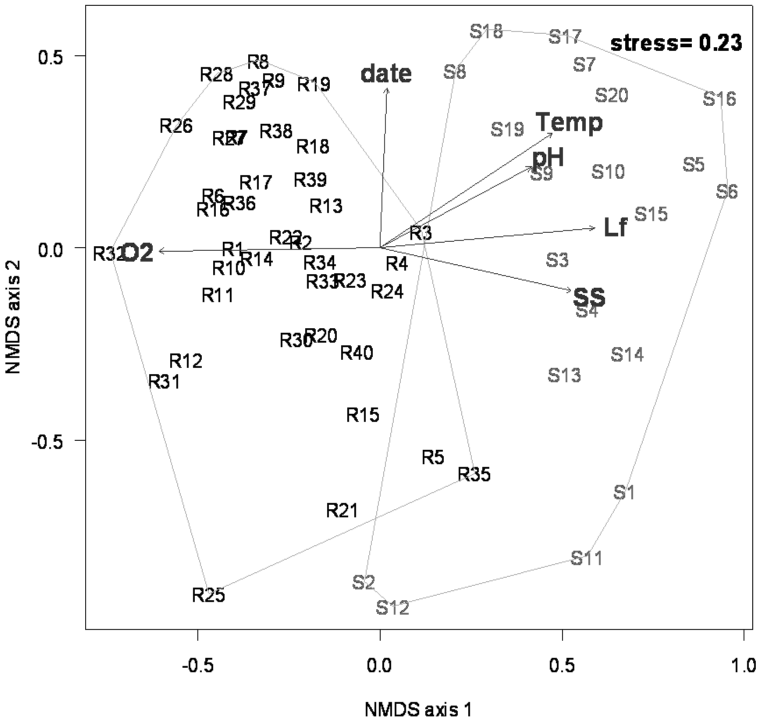

Figure 5. Non-metric, multi-dimensional scaling based on macroinvertebrate relative abundances using Bray-Curtis dissimilarity. R = reference sites in River Barchuluut and River Tsagaan Chuluut (4 sites in total). S = sediment impacted sites in River Yalbag (two sites). Continuous numbers refer to sampling dates. Abiotic variables and sampling dates were included by environmental fitting.

ences were also found for the individual fitness of some fish species (see Fig. 6). The Fulton condition factors for arctic grayling, lenok and minnow were found to be significantly lower (Mann-Whitney-Test, $p < 0{,}005$) at the affected sites (Yal). At the river Terelj only minnow displayed significant differences with individuals being less corpulent at the affected sites (Ter).

A two-week survey in 2006 revealed that mining activities also affected the migration behavior of fish. Lenok and arctic grayling were constantly caught downstream of the mining

Table 2. Fish species found at the study sites in the Eroo and the Kherlen watershed (Ter = River Terelj, Ter Ref. = Tributaries of the River Terelj).

Latin name	Common name	Eroo Watershed			Kherlen Watershed	
		Tsa	Bar	Yal	Ter	Ter Ref.
Brachymystax lenok	Lenok	X	X	X	X	X
Hucho taimen	Taimen	X		X		
Thymallus arcticus	Arctic grayling	X	X	X		
Thymallus grubei	Amur grayling				X	X
Phoxinus phoxinus	Minnow	X	X	X	X	X
Eupallasella percnurus	Lake minnow	X				
Rhynchocypris lagowskii	Eastern. siberian minnow				X	X
Leuciscus baicalensis	Siberian dace			X		
Gobio cynocephalus	Dog-faced gudgeon				X	X
Barbatula toni	Siberian stone loach	X	X	X	X	X
Cobitis melanoleuca	Siberian spiny loach	X	X	X		
Lota lota	Burbot			X	X	X
Number of species		**7**	**5**	**8**	**7**	**7**

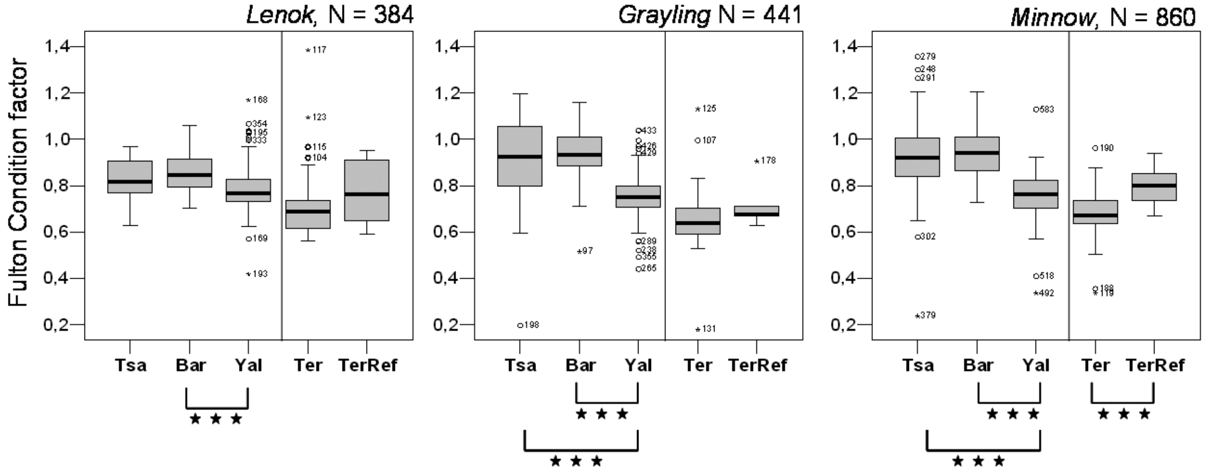

Figure 6. Fulton condition factors for lenok (B. lenok), arctic and amur grayling (*Thymallus* spp.) and minnow (*Ph. phoxinus*) at the reference sites Tsagaan Chuluut, Barchuluut and at the river Terelj (TerRef) and the affected sites Yalbag and Terelj.

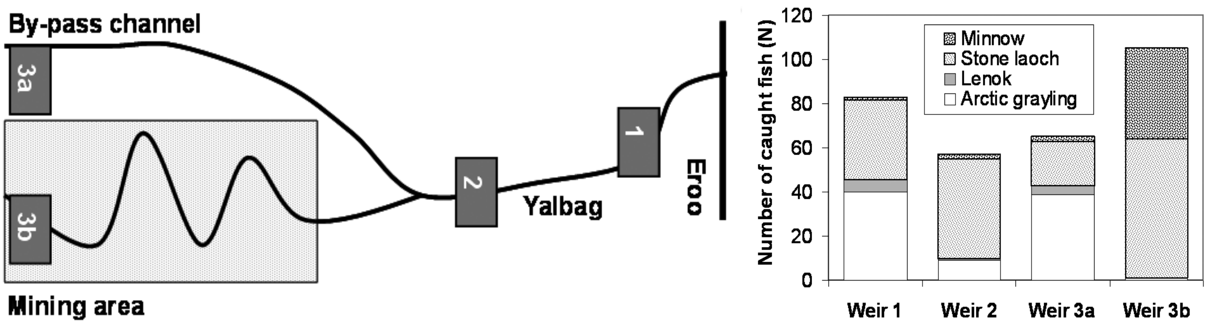

Figure 7. Location (right) of weir 1 - 3 along the river Yalbag and number of fish (left) caught in these weirs.

area and in the by-pass channel (weir 1, 2 & 3a), whereas in the weir inside the mining area (weir 3b) these species were almost missing. Stone loach on the other hand was numerously caught in all weirs, whereas minnow was found almost exclusively in weir 3b.

Discussion

Based on the comparative analyses of impacted and reference sites our study showed that the biocoenotic groups reacted differently to the disturbances caused by open placer gold mining.

For diatoms we found a change in the community structure from non-mobile (affixed) to rather mobile taxa, which could be caused by sedimentation of fine sediments (Passy, 2007). We assume that elevated loads of suspended sediments are likely to cause higher sedimentation rates. As a consequence benthic biofilms get covered with sediment. Mobile species may be able to respond to this environmental change and move to the sediment surfaces in order to get access to favorable light conditions, whereas immobile taxa get covered by sediment deposits and are likely to die off due to the lack of light. This finally causes an increase in the relative abundance of mobile species. Comparative studies showed similar results (Dickman *et al*., 2005), but these indirect effects have not been shown for gold mining areas.

In our study the macroinvertebrate communities showed direct reactions to the environmental changes downstream of the mining areas. Based on our analyses we conclude that elevated loads of suspended sediments are of major concern. Negative effects of increased suspended sediment loads are well known and have been numerously documented in literature (see review of Newcombe and MacDonald, 1991). Direct effects for example result from an increase of shear stress causing elevated drift rates of organisms (Berry *et al*., 2003) or clogging of respiratory organs. Indirect effects for macroinvertebrates result from lowered benthic biofilm biomass and food quality due to light limitation (Van Nieuwenhuyse & LaPerriere, 1986, Ryan, 1991) and deposition of fine sediments. This results in a bottom-up control of benthic invertebrate biomass and abundance (Wagener & LaPerriere, 1985; Wood & Armitage, 1997; Fossati *et al*., 2001) and benthic invertebrates diversity (Quinn *et al*., 1992). Another relevant factor is the loss of intergravel space due to clogging processes, which were found to occur at the impacted sites at river Yalbag (Ibisch *et al*., 2007). Clogging processes reduce the availability of refugial habitats in the intergravel space, which is especially important during catastrophic events like floods or temperature extremes in winter times.

For fish we found a negative effect of gold mining on the corpulence factors of selected species. Several aspects have to be taken into account in order to explain this contradictory finding. For some fish species it is well documented, that turbidity and elevated sediment loads lower the efficiency of food intake, and thus lowers growth rates of fish (Lloyd *et al*., 1987; Rowe & Dean, 1998). Another factor can be seen in the bottom-up control of fish biomass by productivity of lower trophic levels. Reduced macroinvertebrate biomass and abundances are likely to affect fish biomass and abundances and may at the end also reduce fish stocks (Harding & Boothroyd, 2004; Rowe & Dean, 1998). Our study also revealed effects of gold mining on the migratory behavior of fish and thus on the river continuum. Numerous authors have been described the impact of suspended sediment on the behavior of fish (Newcombe & MacDonald, 1991) with some studies also reporting the fact that fish do interrupt the migration further upstream (McLeay *et al*., 1987). No direct effects of gold mining on fish species richness or abundance were found in this study. This is possible due to relatively low suspended sediment concentrations at the studied river sections with concentrations below 200 mg/l (Ibisch *et al*., 2007). Following the review of Newcombe & MacDonald (1991) these values can be ranked as marginally or moderately harmful, which might be an explanation for our findings.

Clear effects on the other hand were detected for fish community structure, with habitat alterations assumed to be a major cause for these effects. Additionally, water temperatures in Yalbag river downstream the mining sites were significantly elevated (1.92 ± 4,40°C upstream, versus 4.07 ± 6.73°C downstream, yearly average values based on continuous temperature measurements, Ibisch *et al*., 2007). This elevation in stream temperatures

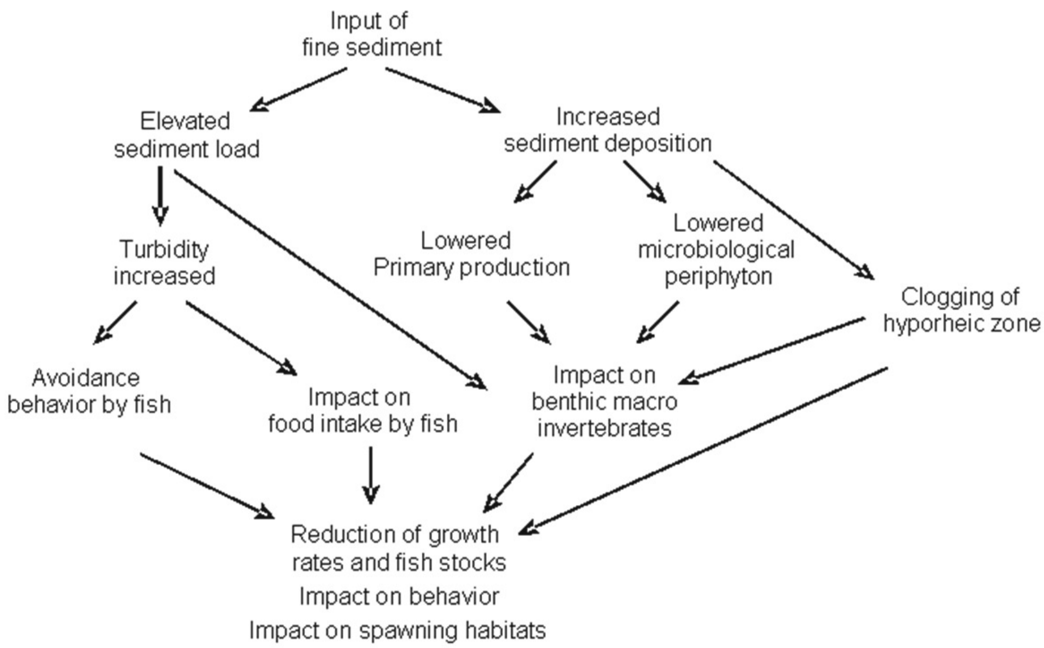

Figure 8. Schematic model of effects of elevated sediment loads on different biotic components in a river ecosystem (following Rowe & Dean, 1998, modified).

are likely to cause changes in the fish community (Reeves *et al*., 1987), and may promote the dominance of siberian dace in our case. Major impacts on fish also result from clogging of the river bed (Ibisch *et al*., 2007) regarding habitat quality and habitat availability in the hyporheic zone (see detailed discussion in Krätz, 2009).

Our analyses showed that open placer gold mining causes multiple stressors in riverine ecosystems. However, these stressors act on different levels. Focusing only on the input of fine sediments one realizes, that the observed effects are highly interlinked (see Fig. 8). Besides the input of fine sediments, there are other important disturbances caused by open placer gold mining related to the hydrological regime, chemical contaminants or loss of the natural riparian zone. These disturbances on the other hand each cause another cascade of effects, which are still barely understood and where future research still needs to be conducted.

In our study the biocoentic groups reacted differently to stressors and we indentified a wide range of effects, both direct and indirect ones. The following table summarizes the results for diatoms, macroinvertebrates and fish. We classified the observed effects systematically in large, moderate or minor effects.

Table 3. Effects of open placer gold mining on diatoms, macro invertebrates and fish in different categories (+++ = significant negative effect; ++ = moderate negative effect; + = minor or no effect; n.s. = not specified).

	Diatoms	Macro invertebrates	Fish
Number of species	+	+ + +	+
Species community	+ + +	+ + +	+ +
Abundance	n.s.	+ + +	+
Individual fitness	n.s.	n.s.	+ +
Migration / Behavior	+ +	n.s.	+ + +

For the majority of open placer gold mines in Mongolia best management practices are not implemented (World Bank, 2006), and functional monitoring programs are not established by the official administration. This is also true for the mining areas assessed in this study. This observation is in clear contrast to the results of numerous reports, which concentrated on mining and environmental issues (Farrington, 2000; Grayson, 2003; World Bank, 2006). Here the urgent need for targeted and effective management strategies and observation programs are emphasized. Our findings contribute to better understand environmental effects of mining and may serve as a scientific basis for the formulation of adapted management and monitoring strategies for the Mongolian placer mining industry.

Acknowledgement

This project was funded by the German Federal Ministry of Science and Research (BMBF), Funding-ID 0330398.

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Хураангуй

Монгол оронд алт олборлолтын салбар улс төрийн өөрчлөлт бий болсон цаг үеэс хойш, түүнчлэн зах зээл дээрх үнэ ханш нь өсөн нэмэгдсэнээс ихээхэн хөгжиж, эдийн засгийн чухал салбаруудын нэг болсон байна. Уул уурхайн салбар, ялангуяа алтны ил шороон ордны олборлолтын үйл ажиллагаа идэвхижихийн хирээр үүнээс үүдэлтэй хүрээлэн буй орчны асуудлууд урган гарсаар байгаа юм. Алтны ил ордууд нь аллювын хурдас бүхий голын сав газарт байрших ба эдгээр ордуудын олборлолтын ихэнх нь голын

экосистем, түүний ялгаатай бүрэлдэхүүн хэсгүүдэд ноцтой нөлөөллийг үзүүлдэг.

Бид энэхүү өгүүлэлд алтны ил шороон ордны нөлөөллийг Монгол орны зүүн хойд хэсгийн дөрвөн голд тархсан загас, ёроолын сээрнуруугүйтэн, цахиурт замгийн жишээн дээр тодорхойлсон юм. Судалгааг хүний үйл ажиллагаанд бага өртсөн болон уул уурхайн олборлолт бүхий голын хэсгүүд дэх биоценозын бүлгүүдийг, мөн орчны абиотик хүчин зүйлийг харгалзан үзэж харьцуулсан байдлаар дүгнэн үзсэн. Бидний судалгааны үр дүнд алтны ил шороон ордны олборлолт нь усан орчны идэш тэжээлийн ялгаатай түвшнүүдэд хэд хэдэн нөлөөлөл үзүүлдэг болохыг тогтоосон юм. Судалгаанд хамрагдсан биоценозын бүлгүүд эдгээр нөлөөлөлүүдэд ялгаатай байдлаар хариу үйлдэл үзүүлсэн ба өргөн цар хүрээ бүхий шууд болон шууд бус нөлөөллийг тодорхойлсон болно. Эдгээр судалгааны үр дүн нь Монгол орны хувьд шинэлэг бөгөөд экологид үндэслэсэн менежментийг явуулах зөв зохистой стратегийг боловсруулах, алт олборлолтоос үзүүлэх нөлөөллийн мониторинг хийхэд зайлшгүй чухал юм.

Received: 18 December 2009
Accepted: 25 May 2010