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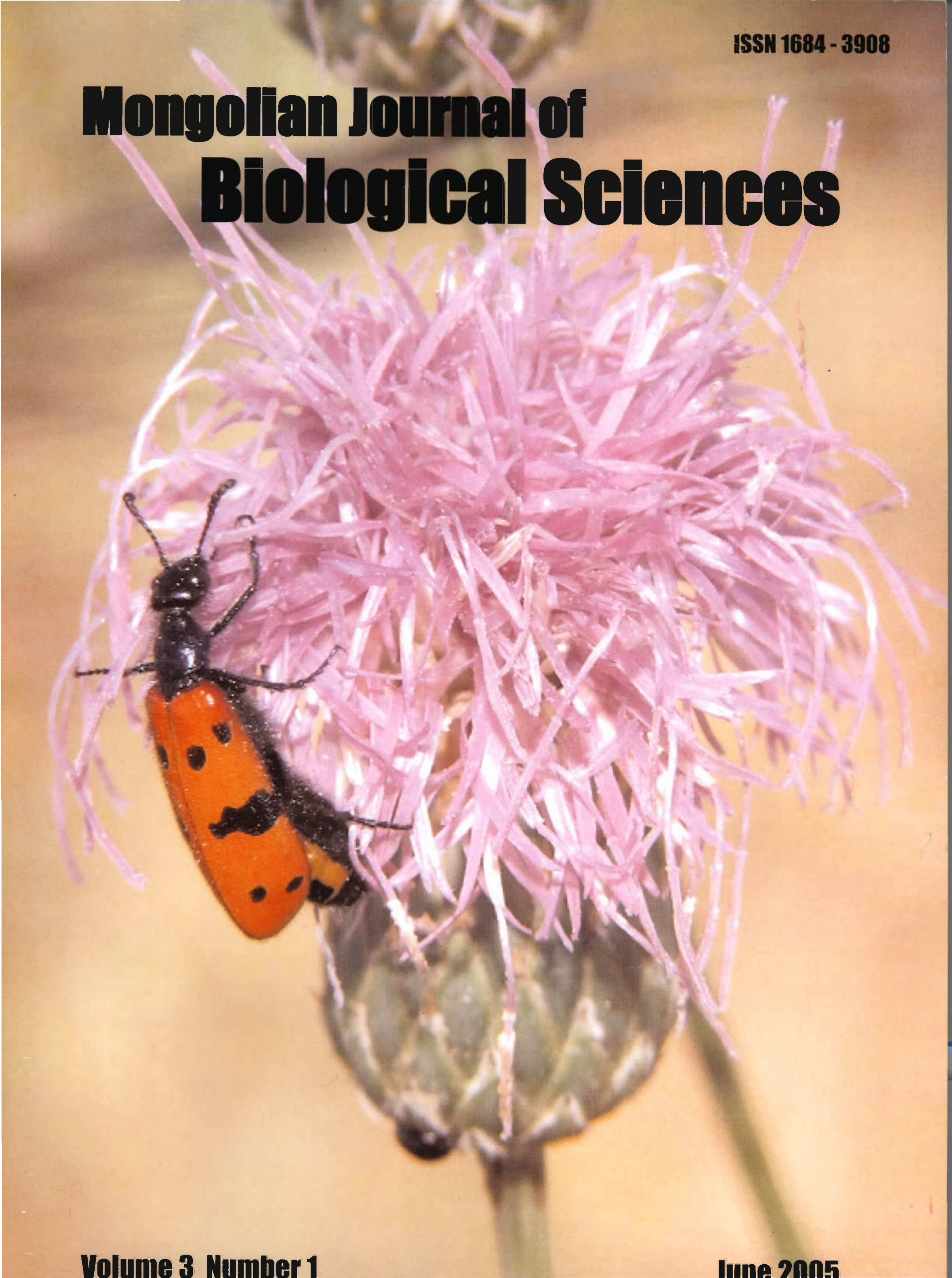

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[Notes from the field]

The Feeding Behaviour of Fish from the Upper Lake Baikal Watershed of the Eroo River in Mongolia

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Abstract

The upper Selenge watershed in Mongolia is home to some of the world's unique fish species. In this study we determined the feeding behaviour of selected fish species collected from the main stream of the Eroo River and two of its upstream tributaries, the Sharlan and Bar Chuluut rivers. Using stable isotope (carbon and nitrogen) measurements combined with qualitative and literature information, we determined that taimen (*Hucho taimen*) and pike (*Esox luceus*) were the top predators in the Eroo River. They received a substantial amount of their energy from other fish species as well as terrestrial derived sources. Percent presence of biota in lenok (*Brachymystax lenok*) stomachs demonstrated they eat zoobenthos, invertebrates, fish, and terrestrial rodents. Siberian dace (*Leuciscus baicalensis)*, a small forage fish collected from the Sharlan and Bar Chuluut rivers demonstrate these fish eat periphyton, zoobenthos and terrestrial invertebrates. In the Bar Chuluut tributary, lenok eat a combination of foods including zoobenthos and other fish species, while arctic grayling (*Thymallus arcticus*) fed primarily on zoobenthos. Percent frequency analysis showed the two game fish species collected from the Bar Chuluut tributary fed primarily on zoobenthos (85 % for lenok and 80 % for grayling), with 28 families and 10 orders represented in their stomachs. Interviews with families suggested local people fish for a variety of species and that there has been a decline in the catch of taimen and sturgeon (*Acipenser baeri baicalensis*) over time. Since fishing was poor below highly disturbed areas (e.g. mine sites), local people fished above mine locations or in areas least impacted by these anthropogenic impacts.

Key words: gold mining, Lake Baikal, Mongolia, Selenge River, Taimen

Introduction

The rivers of the Mongolian steppe are home to some of the world's unique biodiversity. The country's largest river system, the Selenge, flows north into the biologically diverse Lake Baikal. The deepest lake in the world, Lake Baikal is home to 20% of the world's unfrozen freshwater resources (Galazy, 1980). The Selenge River contains 22 fish species including natural populations of the world's largest salmonid, taimen (*Hucho taimen*) and other game fish species including lenok (*Brachymystax lenok*) and arctic grayling (*Thymallus arcticus*) (Matveyev *et al.*, 1998; Dulmaa, 1999). While a qualitative understanding of fish feeding behaviour exists for fish in the upper Selenge River, little quantitative information is presented in the scientific literature. In the upper Selenge watershed, specifically in the Eroo tributary, most fish collections are made during the summer months due to severe weather during the winter (M. Erdenebat, pers. comm.). The fish however, migrate seasonally and are feeding during all seasons. Since diet may vary based on availability of food resources, season specific data analysis may not accurately reflect the overall feeding behaviour of fish. In order to elucidate trophic relationships and diet selection, ecologists are using a combination of stable isotope measurements and diet analyses to quantify fish feeding behaviour (Vander Zanden, 1997). In this study, we calculate the trophic position of fish species using isotopic nitrogen measurements, and present qualitative dietary habits of dominant fish from the Eroo River. Quantitative dietary estimates of two game fish are made from the Bar Chuluut tributary.

Materials and Methods

Biotic collections

Fish were collected from the main stream of the Eroo River in September 2003 during a joint Mongolian-American study evaluating the impacts of mining on the water quality of Mongolian rivers (Stubblefield *et al.*, In press), and on 10 June 2002. Game fish and a forage species were obtained from the upper Eroo watershed tributaries, the Bar Chuluut and Sharlan, during joint Mongolian-German studies in August 2003 and on 10 June 2002. Fish were sampled using multiple approaches – hook and line, beach seine, gill netting, and with an electro shocker, during both day and night hours. Once identified to species, fish stomach contents were analyzed and length was measured. Due to their threatened status in the Red Books of Mongolia and Russia, taimen were sampled for isotopes and released, unless samples were obtained from fish taken by fishermen. Diets of the Siberian dace (*Leuciscus baicalensis)* and lenok collected on 10 September 2002 from the Eroo, Sharlan, and Bar Chuluut rivers were determined by calculating the percent presence of diet items. A qualitative stomach examination was employed on fish obtained from the Eroo River in August and September 2003, while a quantitative (percent frequency) approach was undertaken in the Bar Chuluut tributary. Invertebrates were identified to family and/or order and fish were identified to species. We used whole invertebrates from fish stomachs and dorsal muscle tissue for isotope analysis.

Trophic position

Stable isotopes (carbon and nitrogen) provide an integrated assessment of an organism's feeding behaviour over time (Minagawa & Wada, 1984). We used these isotopes to determine the trophic position of fish from the main stream of the upper Eroo River. Isotopic $\delta^{13}C$ can be used to determine the flow of organic matter through food webs (Gu *et al.*, 1994). The minimal enrichment (± 0.47 ‰) from lower to high trophic levels allows for the differentiation of production sources (terrestrial and benthic). With predictable enrichment (between 3-4 ‰) biotic trophic position can be determined using isotopic $\delta^{15}N$ (Minagawa & Wada, 1984; Vander Zanden & Rasmussen, 2001).

Dorsal muscle tissue and invertebrate samples were air dried for at least 48 hours in the field and re-dried in the lab at 70 °C, where they were ground into a fine powder using a pestle and mortar. After being packed into tin capsules (8 x 5 mm), a continuous flow isotope ratio mass spectrometer (IRMS) (20-20, PDZEuropa Scientific Sandbach, United Kingdom) was used to analyse the samples for carbon and nitrogen. Sample combustion to CO_2 and N_2 occurred at 1000°C in an inline elemental analyser (PDZEuropa Scientific, ANCA-GSL). A Carbosieve G column (Supelco, Bellefonte, PA, USA) separated the gas before introduction to the IRMS. Standard gases (Pee Dee Belemnite for $\delta^{13}C$ and N_2 gas for $\delta^{15}N$) were injected directly into the IRMS before and after the sample peaks.

Isotopic ratio was expressed as a per million (‰) notation. Using $\delta^{13}C$ as an example, it was defined by the following equation:

$$\delta^{13}C = [(^{13}C/^{12}C)_{sample} / (^{13}C/^{12}C)_{standard} - 1] * 1000. \quad (1)$$

A more positive $\delta^{13}C$ indicated isotopic enrichment, or contained proportionally higher concentrations of heavier ^{13}C isotope. After every twenty samples a replicate and a standard were added to the analysis sequence. Replicate variation was less than 3% and machine analytical variation was within 0.2 ‰.

Fish trophic position was estimated from fish $\delta^{15}N$ values. Individual fish signatures were corrected for baseline conditions (Vander Zanden & Rasmussen, 1997) using pooled zoobenthos (n > 5 individuals) collected from fish stomachs. We assumed that the zoobenthos (trichoptera, plecoptera and orthoptera) were primary consumers even when identified to order. Since $\delta^{13}C$ of invertebrates and fish were similar (Table 1) no baseline adjustment was undertaken with isotopic carbon. Trophic position was calculated as follows:

$$TP= ((\delta^{15}N_{fish} - \delta^{15}N_{baseline})/3.4) + 2, \quad (2)$$

where $\delta^{15}N_{fish}$ was the individual value of the fish, $\delta^{15}N_{baseline}$ is the average isotopic nitrogen value calculated from invertebrates, and 3.4 is the trophic level enrichment factor (Minagawa & Wada, 1984; Vander Zanden & Rasmussen, 2001).

Short interviews

Short interviews were conducted to obtain a preliminary understanding of the state of the fishery in the Eroo watershed. Six families with multiple family members were asked the following

Table 1. Size range, stable isotope (carbon and nitrogen), trophic position, standard error, and qualitative stomach content measurements for selected fish species collected from the main stream of the Eroo River.

	Size range (cm)	*δN*	*Mean TP*	*TP SE*	*Mean δC*	*SE δC*	*Qualitative stomach contents*
pooled zoobenthos (n=3)	n/a	4.14	2.00		-23.9	0.7	n/a
phoxinus (n=3)	2.4- 6.1	8.19	3.19	0.4	-21.8	0.9	none taken
grayling (n=7)	6.4- 23.4	8.17	3.18	0.1	-22	0.4	trichoptera, ephemeroptera, coleoptera
lenok (n=6)	9.3- 45.6	10.2	3.78	0.3	-23.5	0.6	trichoptera, ephemeroptera, plecoptera, orthopetera
pike (n=4)	64.4- 82.6	12.8	4.55	1.6	-24.1	0.3	*Leucicus baikalensis*
taimen (n=4)	64.5- 97.3	13.1	4.63	0.8	-21.8	0.6	fish released or poached fish were empty

questions:

- How long have you lived in the Eroo watershed?
- What is your ethnic background?
- Do you fish from the rivers in the watershed?
    - If so, what do you fish for from the rivers?
    - If so, has the fishing for certain species changed over time?
    - If so, do you know why there is a change in fishing?
- Do you know other families that fish from the river?

Results and Discussion

Trophic position in the main stream of the Eroo

The isotope signatures, size, gut contents, and trophic position for fish are presented (Table 1, Fig. 1). Since $\delta^{13}C$ signals from the invertebrates were similar (range -22.83 to -25.89), we were unable to differentiate carbon source (terrestrial versus river sources) of the fish. To determine trophic position, we pooled invertebrate $\delta^{15}N$ signals to create a baseline signature from which to compare fish feeding (Table 1). The smaller forage fish Eurasian minnow (*Phoxinus phoxinus*) and grayling, an important game fish, were the lowest in the food web (trophic position of 3.19 and 3.18, respectively) indicating they receive a substantial amount of energy from invertebrates over time. While the qualitative diet for lenok showed that they fed on invertebrates during the summer of 2003 (Table 1), the percent presence analysis from 2002 showed these fish can eat mice (*Clethrionomys rufocanus*) and fish (Table 2). Their isotopic signatures indicated they received a substantial amount of energy from other fish species (Fig. 1). Research by the co-authors conducted in the Eg-Uur watershed (see http://limnology.wisc.edu/mongolia) in 2004 and 2005 support this notion since lenok fed on forage fish species (Eurasian minnow and small grayling) during early spring and fall (Gilroy & Chandra, unpublished data).

The two top game fish of the Eroo watershed, pike and taimen, clearly were the top predators in the river food web (Fig. 1). Both fish exhibited variability in their trophic position indicating they rely on other secondary and tertiary consumers (including fish) within the system. Interviews with local fisherman (see below) indicated that depending on the season, taimen eat burbot (*Lota*

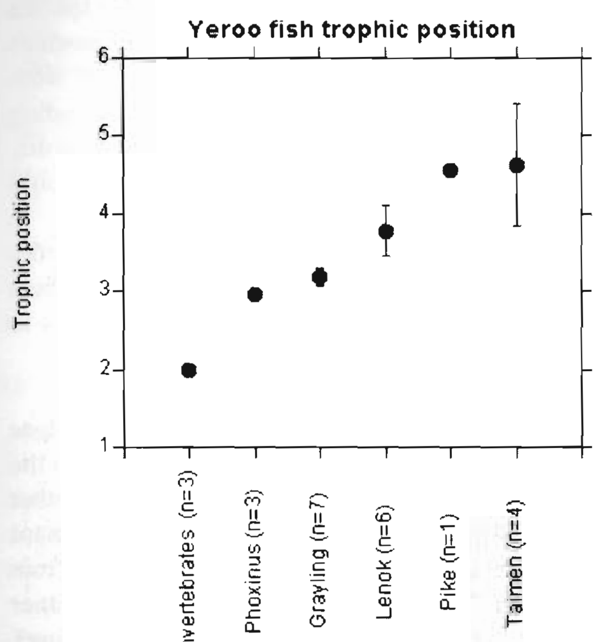

Figure 1. The trophic position determined from stable isotope measurements for six fish species collected from the main stream of the Eroo River.

Table 2. Percent presence of taxa found in the stomachs of lenok (*Brachymystax lenok*) from the Eroo River on 10 September 2002.

Taxa	*Percent frequency Lenok* *Eroo (n=10)*
Trichoptera (Limnephilidae, Hydropsychidae, Brachycentridae, Glossosomatidae)	50
Plecoptera (Pteronarcyidae, Nemouridae)	20
Ephemeroptera (Ephemeridae, Ephemerellidae, Baetidae, Heptageniidae)	15
Chironomidae	10
Coleoptera (Dytiscidae)	2
Ants (unidentified species)	10
Unidentified larvae	10
Locus (unidentified species)	10
Mouse (*Clethrionomys rufocanus*)	5
Unidentified fish	5

lota), grasshoppers (Orthoptera spp.), small minnows and frogs (no scientific identification provided to scientists), and sable (*Martes zibellina*). During ecological studies of taimen in the Eg-Uur watershed in 2004, Chandra & Gilroy (unpublished data) observed taimen egesting fish and voles (*Lagarus* spp.) upon their release into the river. Furthermore, research from other rivers within the Lake Baikal watershed (Matveyev *et al.*, 1998) and from other parts of their range (Hensel *et al.*, 1988) suggest that taimen are highly predatory at a young age and can feed on a variety of fish, terrestrial (small rodents) and avian (waterfowl nestlings) resources. Thus, the isotope and stomach information indicates taimen, a Red Listed species in both Mongolia and Russia, fed on resources derived both from within the river and from terrestrial energy sources. Recently expanding industries of mining and logging within Mongolia, which degrade riparian environments, should therefore be carefully developed in order to minimize impacts on taimen populations. In order to conserve taimen populations there should be a focus on protecting riparian habitats of rivers to maintain the energetic linkages to these fish.

Bar Chuluut and Sharlan tributaries

Zoobenthos, terrestrial invertebrates, and algae were present in the diet of Siberian dace from the Sharlan and Bar Chuluut tributaries in September 2002 (Table 3). Benthic insects were the dominant diet of the two game fish species collected from the Bar Chuluut tributary during the summer months (85 % for lenok and 80 % for grayling). Specifically, 28 families and 10 orders of aquatic insects (Fig. 2) were consumed by these species. The remaining diet consisted of phytoplankton and adult insects for both species. The diet of fish in the tributary was similar to the stomach diet data collected from those in the main stream of the Eroo River (Table 1); however in some cases it was dissimilar to the integrated measurements provided by the stable isotope analysis. For example, the trophic position of lenok indicates that although they fed on insects in the summer, they received energy from fish sources during other seasons (Fig. 1). In recent years, gold mining activity has increased on this tributary and within this region of the Eroo River. Future research should focus on determining whether this activity affects ecological parameters (growth, diet, spawning potential) of these fish species.

Short interviews

We conducted short-interviews with families to

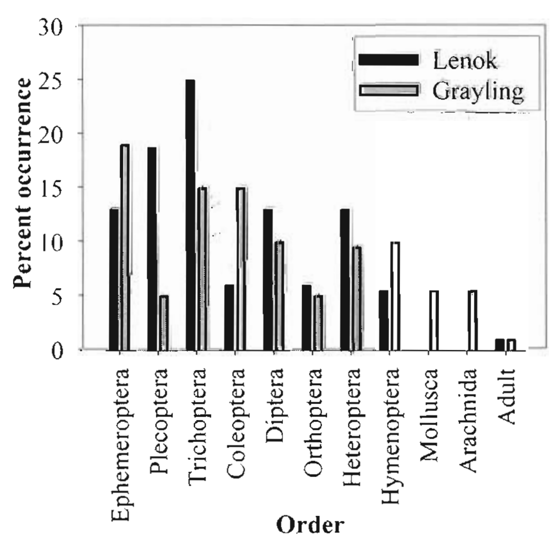

Figure 2. Quantitative diet information from gut content analysis for two game fish species, grayling (*Thymallus arcticus*) and lenok (*Brachymystax lenok*) collected from the Bar Chulut tributary during the summer of 2003.

Table 3. Percent presence of taxa found in stomachs of Siberian dace (*Leuciscus baicalensis*) from the Sharlan and Bar Chuluut tributaries on 10 September 2002.

Taxa	*Percent frequency Siberian dace*	
	Bar Chulut (n=13)	*Sharlan (n=15)*
Trichoptera (Molanidae, Hydropsychidae)	40	22
Ephemeroptera (Baetidae)	45	16
Cyanophyta (Nostos.anabaena)	100	100
Chironomidae (Culicidae)	0	45
Grasshopper	65	10
Coleoptera	0	10
Nematoda	10	0

determine the extent of fishing and the state of the fishery in the Eroo watershed. Since only a very small subset of the families (n = 6) from the watershed were interviewed, the information presented should be used only as a guide to understand the interaction between humans and fish in the area. Information from long-term residents of the watershed may provide valuable insight on changes occurring over time (Table 4).

The interviews indicated that the Mongolian, Russian and Kazakh families who have lived in the watershed from 3 - 45 years have either fished or observed other families fishing from the river for burbot, taimen, lenok, grayling, carp (*Carassius auratus gebelio*), pike (*Esox luscious*) and sturgeon (*Acipenser baeri baicalensis*) (Table 2). The three fishing families noticed a decline in the fishery. In particular, they noted that fewer and smaller taimen were caught below areas of intense human activity (e.g. mining). Sturgeon catches have also declined. This information and informal conversations with both Russian and Chinese miners indicated that catch rates were significantly lower directly below mine areas. To catch fish the miners fished above these areas or further downstream where the effects of mines were not as apparent. The qualitative information provided by these interviews matches the quantitative data regarding the effects of mining activity on water quality (phosphorus and total suspended sediments), collected from the tributaries and the main stream of the Eroo River (Stubblefield *et al.*, in press).

Conclusions

The Eroo watershed is one of the larger tributaries of the Selenge River, the primary inflow into Lake Baikal. We examined the feeding behaviour of a variety of game fish species, including taimen, the world's largest salmonid, through summer stomach content analysis and stable isotope analysis. These analyses provided

Table 4. Interview questions asked of six families in the Eroo watershed.

General questions	*Family*					
	1	*2*	*3*	*4*	*5*	*6*
How long have you lived in the Eroo watershed (number of years)?	30	45	3	11	20	20
What is your ethnic background (r-Russian, m-Mongolian, c-Chinese, k-Kazakh)?	m	r,m	m	m	k	m
Do you fish from rivers in the watershed (yes or no)?	no	yes	no	yes	no	yes
If so, what do you fish from the river (b-burbot, t-taimen, l-lenok, c-catfish, s-sturgeon, g=grayling, p- pike) for in the river?	-	b,t,l,c,s,g	-	t,l,g,p	-	b,t,l,g
If so, has the fishing for certain species changed over time (stay the same- s, improved- i, or declined-d)?	-	declined	-	declined	-	declined
If so, do you know why there is a change in fishing (ov-overfishing, l-logging, m-mining, ot-other?	-	-	-	ov,l,m	-	m
Do you know other families that fish (yes or no)?	yes	yes	yes	yes	yes	yes

an integrated assessment of energy assimilation. While game fish fed primarily on invertebrates during the summer, the trophic calculations demonstrated that lenok received energy from fish sources, while taimen obtained their energy from secondary and tertiary consumers. Since the isotopic carbon signals were similar, the specific energy source (terrestrial versus aquatic) was not discernable. Interview information combined with other literature however, indicated that taimen rely on aquatic and terrestrial mammals, and other fish species (other taimen, lenok, grayling) for food. Finally, our interviews with families suggested that local people utilized fish resources from the Eroo River. Furthermore, there was a decline in some fishes (taimen and sturgeon) from the river, which was due to over fishing, logging and mining within the region. Future investigations should focus on understanding the impacts of mining on the fishery and the taimen, a listed species in both Russian and Mongolian Red Books.

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Хураангуй

Сэлэнгэ мөрний эх орчмын ай сав нь нэн өвөрмөц хэд хэдэн зүйлийн загасны өлгий нутаг юм. Энэхүү судалгаагаар Ерөө гол болон түүний цутгал Шарлан, Бар Чулуут зэрэг голуудаас цуглуулсан зарим зүйлийн загасны идэш тэжээлийн бүрэлдэхүүнийг тодорхойлсон юм. Тогтвортой изотопууд (нүүрстөрөгч ба азот)-ыг ашиглан тоон мэдээллүүдийг цуглуулж, бусад судалгааны бүтээлүүдийн дүн мэдээтэй нэгтгэн тодорхойлсоны үндсэн дээр тул (*Hucho taimen*) болон цурхай (*Esox luscious*) нь Ерөө голын гол махчин загас болохыг тогтоов. Эдгээр загаснууд энергийн гол эх үүсвэрээ бусад загас болон хуурай газраас үүсэлтэй органик тэжээлээс авдаг болох нь илэрсэн

юм. Зэвэг загасны (*Brachymystax lenok*) ходоодон дахь идэш тэжээлийн бүрэлдэхүүнд хийсэн анализд үндэслэн тэд бентос амьтад, сээр нуруугүйтэн, бусад загас болон хуурай газрын амьдралтай мэрэгчдээр хооллодог болохыг тогтоов. Шарлан болон Бар Чулуут голуудаас цуглуулсан Сибирь сугас (*Leuciscus baicalensis)* зүйлийн жижиг загас перифитон, бентос амьтад болон хуурай газрын шавьжаар хооллодог болох нь илэрлээ. Бар Чулуут голоос цуглуулсан зэвэг загасны идэш тэжээлийн бүрэлдэхүүнд бентос амьтад болон бусад загас орж байсан бол хадран загасны (*Thymallus arcticus*) идэш тэжээлийн үндсэн хэсгийг бентос амьтад бүрдүүлж байв. Тэдгээр загасны идэш тэжээлийн бүрэлдэхүүний анализийг авч үзвэл энэхүү 2 зүйлийн агнуурын загас голчлон бентос амьтдаар (зэвэгний идэш тэжээлийн 85%-ийг, хадрангийн идэш тэжээлийн 80%-ийг зообентосууд бүрдүүлж байв) хооллодог нь тогтоогдсон бөгөөд нийт 10 багийн 28 овгийн зообентос амьтан тэдгээрийн ходоодноос илрэв. Орон нутгийн иргэдтэй ярилцлага хийхэд тэд янз бүрийн зүйлийн загасыг барьж ашигладаг бөгөөд сүүлийн жилүүдэд тул болон хилэм (*Acipenser baeri baicalensis*) загаснууд баригдах нь ховор болж байгаа тухай мэдээлж байв. Хүний нөлөөнд өртөж сүйдсэн газруудаас (жишээлбэл уул уурхай орчим) доош орших голын хэсэгт загас ховордсон тул нутгийн иргэд уурхайнаас дээш орших хэсэгт юмуу хүний нөлөөнд бага өртсөн газруудаас загас барьж байна.

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