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Fishing ancient Lake Baikal, Siberia: inferences from the reconstruction of harvested perch (*Perca fluviatilis*) size

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Abstract

Fishing was the foundation for many of the world's foraging peoples and was undertaken using a variety of technologies. Reconstructing fishing technologies can be difficult because these tools were often made of perishable materials. Here we explore fishing technologies employed at the Ityrkhei site on Lake Baikal, Siberia. Specifically, we employ regression analyses to reconstruct the sizes of perch (*Perca fluviatilis*) captured through time at the site. Our analyses demonstrate that almost no juvenile perch were taken, suggesting some selectivity in harvest. We suggest this selectivity is most consistent with the use of relatively large gauge nets or traps. Such mass harvesting technologies may have been important elements of the subsistence economies of Lake Baikal's foraging peoples throughout much of the Holocene.

Keywords: Fishing; Siberia; Lake Baikal; Size reconstruction; Mass harvesting; *Perca fluviatilis*; Gear selectivity

1. Introduction

Fishing was an economic mainstay of many of the world's foraging peoples, both in marine and freshwater settings (Erlandson, 2001; Plew, 1996; Leach, 2006). A wide array of technologies were employed in fishing by these groups, from simple hooks and lines utilized by individuals on shore, to large nets deployed by sizeable groups of fishermen in sturdy boats. These technologies varied in terms of cost, their effectiveness at providing quantities of food, and the social arrangements needed to use and maintain them. Some could be used nearly anywhere fish were present, while others only were effective at specific locations. Obtaining fish was only one step in a process—equally important was the labor and technologies involved in processing, storage, and distribution. Efficient use of large quantities of fish, especially when procured over short durations, can require substantial pools of labor, organization of that labor, and storage facilities. Reconstructing fishing practices thus speaks directly to multiple aspects of subsistence systems, including harvesting, processing, storage, labor organization, and settlement patterns, and as such is ultimately informative about social complexity.

Most fishing technologies used by ancient foraging groups were of perishable materials. As a result, it is often necessary to infer these technologies through the study of their non-perishable components or through examination of the remains of harvested fish. Our study is focused on Holocene fishing practices at Lake Baikal in Eastern Siberia, Russia (Fig. 1). Here direct evidence of fishing technologies consists only of tools designed for taking individual fish, namely composite fishhooks with stone shanks, single-piece bone hooks, stone fish 'lures', and bone and antler harpoons (Okladnikov, 1936, 1948, 1950, 1955; Medvedev, 1967, 1969, 1971; Studzitskaia, 1976; Svinin, 1971, 1976; Georgievskaia, 1989). Notched stones have been found and interpreted as net sinkers, but this interpretation is difficult to test without additional data. No clear evidence of mass harvesting technologies such as nets or traps has been discovered and detailed analyses of fish faunal assemblages from the lakeshore are almost non-existent. Nonetheless, stable isotope analyses of human

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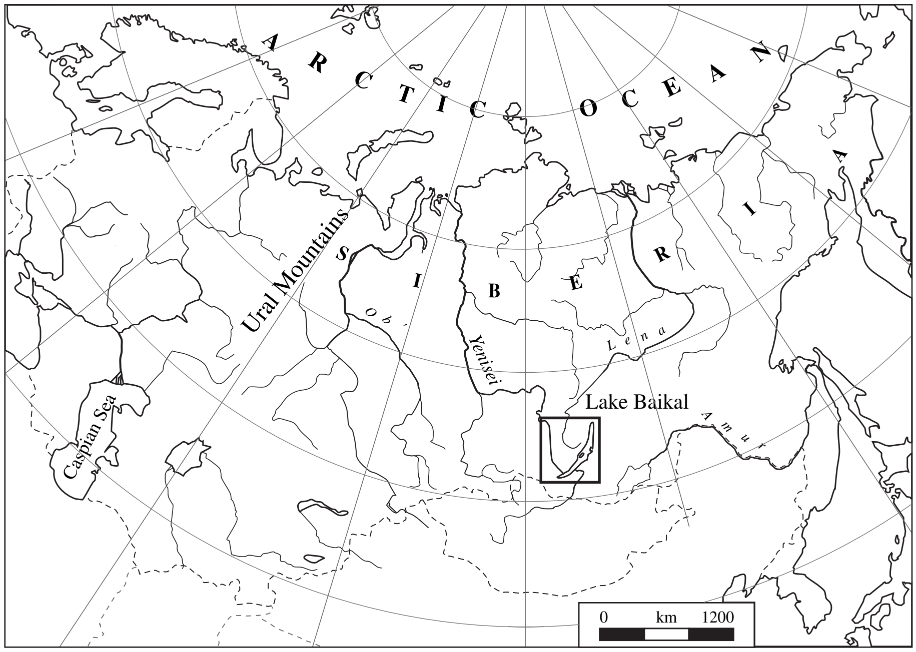

Fig. 1. Map of Siberia with Lake Baikal indicated.

skeletal remains from the Baikal area indicate fish were important components of the diet during much of the Holocene (Katzenberg and Weber, 1999; Weber et al., 2002). Basic questions remaining unanswered include (but are not limited to) how such fish were procured and how fish and fishing functioned within the subsistence and settlement patterns of Lake Baikal's foraging cultures.

As a starting point, we reconstruct fishing practices at the Ityrkhei site, on Lake Baikal's northwest coast (Fig. 2). This study is the first comprehensive analysis of faunal remains recovered from any Lake Baikal archaeological site. We focus on the harvest of European perch (*Perca fluviatilis* L.), the dominant fish in the site assemblage, and a widely used species in Eurasia. We specifically examine perch size as a way of assessing the fishing technology employed at the site. While fish size is relatively commonly examined in archaeological studies (Butler, 1996, 2001; Casteel, 1974; Desse and Desse-Berset, 1996; Leach and Davidson, 2000, 2001; Leach et al., 1997; Luff and Bailey, 2000; Owen and Merrick, 1994a; Van Neer and Depraetere, 2005), it often has not been used to infer harvest technology (but see Greenspan, 1998; Owen and Merrick, 1994b; Zohar et al., 1997). Using a modern sample of perch from Lake Baikal, we develop regression formulas for estimating the size of archaeological perch. The size range of these fish, and behavioral and morphological characteristics of other fishes taken at the site, allow us to make inferences regarding fish harvest technologies. We begin by discussing general characteristics of Lake Baikal, and then describe Ityrkhei and its fauna. Following this, we outline our methods and discuss selectivity of fishing gear. Inferences are made about technologies used for harvesting fish at the site, and we conclude with suggestions for additional studies.

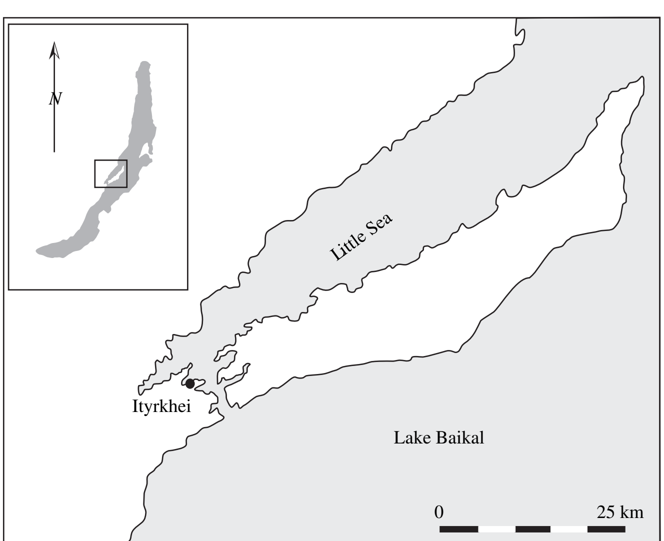

Fig. 2. Map of Lake Baikal, Russia, with Ityrkhei indicated.

2. Fishing Lake Baikal

Lake Baikal is in Eastern Siberia a few hundred kilometers from the border between Russia and Mongolia, and stretches from 52° to 56° north latitude. This freshwater lake is generally flanked by mountain ranges and hills. The climate varies by micro-region, but overall is markedly continental, with relatively warm summers and very long and cold winters. The lake surface is ice covered by midwinter, usually with the exception of the very headwaters of the Angara River, the lake's only outlet. Many vegetation zones intersect the lake, but the southern boreal forest is dominant in most areas. However, steppe vegetation can be found along the lake, most notably in the Little Sea micro-region of the lake's west shore where our study is situated (Weber, 2003).

In many ways, Lake Baikal is a unique aquatic environment. It is the largest freshwater lake in the world, largely due to its immense depth (1620 m). Its vertebrate fauna includes over 30 endemic fish species, most of which are members of the Cottidae, Comephoridae, and Abyssocottidae families (sculpins) (Sideleva, 2003). The lake also shares several fish species with other Eurasian freshwater systems, such as pike (*Esox lucius*), European perch, roach (*Rutilus rutilus lacustris*), dace (*Leuciscus leuciscus baicalensis*), ide (*Leuciscus idus*), burbot (*Lota lota*), taimen (*Hucho taimen*), and whitefish (*Coregonus lavaretus*). Other widespread genera have evolved into unique local forms. Important examples include Baikal black and white grayling (*Thymallus arciticus baicalensis* and *T. a. b. brevipinnis*), omul' (*Coregonus autumnalis migratorius*), and Baikal sturgeon (*Acipenser baerii stenorrhynchus natio baicalensis*). The lake's most unexpected inhabitant is perhaps the freshwater seal (*Phoca sibirica*).

Archaeologists have for decades speculated on the role of fish and fishing in the ancient economies of Lake Baikal (Khlobystin, 1969; Okladnikov, 1936; Petri, 1926). Despite this, studies of fish remains from sites on the lake are extremely rare; prior to this study only a single assemblage (Ulan-Khada) of 78 specimens was described (Tsepkin, 1966, 1976). Most faunal studies in the Lake Baikal region have tended to only list the presence or absence of fish, with little identification and quantification provided (but see Tsepkin, 1965, 1966, 1979, 1980, 1986, 1995; Mamontov et al., 2006). As such, most speculation about the roles of fish and fishing at Lake Baikal has been based on patterns in site distribution and the abundance of and diachronic changes in fishing technologies.

Many scholars have argued that people were fishing in the Baikal area since the upper Paleolithic, but most suggest it was not a major focus of subsistence until the Holocene (Everstov, 1988; Khlobystin, 1965, 1969; Okladnikov, 1950, 1955; Medvedev, 1967, 1969, 1971). No Pleistocene sites with fish remains have been identified on Lake Baikal, but several such sites have been found nearby on the lake's tributaries (Tashak, 1996; Abramova, 1962). Several scholars have argued that harpoons and barded bone points are the earliest identifiable fishing implements, and these appear here during the late Pleistocene (Okladnikov, 1955; Medvedev, 1967, 1969, 1971). However, such implements could have been used to harvest fauna other than fish. Single-piece bone and antler fishhooks first appear in the Mesolithic (early Holocene) period (Okladnikov, 1955; Medvedev, 1967, 1969, 1971; Svinin, 1971, 1976; Novikov and Goriunova, 2005). Composite fishhooks with stone shanks and barbs of bone and antler also appear at this time, but reportedly are not abundant until about 6500 BP (Okladnikov, 1950, 1955; Medvedev, 1971; Svinin, 1976; Novikov and Goriunova, 2005). Possible stone fish lures also appear around this time (Georgievskaia, 1989; Okladnikov, 1936, 1948, 1950; Studzitskaia, 1976).

Direct evidence for fish mass harvest equipment is lacking on Lake Baikal, but many investigators have argued for its presence in the mid- to late Holocene. Supposed net sinkers (notched stones), bone needles (interpreted as netting needles), and cordage impressions on pottery have all been used to argue for the presence and use of fish nets (Georgievskaia, 1989; Novikov and Goriunova, 2005; Okladnikov, 1950, 1955). Several researchers have suggested that the employment of nets on the lake required the use of boats (Georgievskaia, 1989; Medvedev, 1971; Okladnikov, 1955), but no ancient boats have been found. Some place the appearance of boats during the Developed Neolithic period (~5500 BP) (Novikov and Goriunova, 2005) or the Bronze Age (~4000 BP) (Khlobystin, 1963).

Many researchers have suggested that omul' was the most important fish to ancient foragers of Lake Baikal (Everstov, 1988; Svinin, 1971, 1976; Novikov and Goriunova, 2005). Omul' today are the most important fish commercially harvested from the lake (Khozhova and Izmest'eva, 1998; Bronte et al., 1999). They are primarily associated with the colder and deeper regions of the lake (pelagic areas), and today are commercially taken by trawls and gill nets. Several forms of omul' exist, some of which in autumn move into tributaries of the lake to spawn, while other forms spawn in shallow areas of the lake itself (Khozhova and Izmest'eva, 1998). Tsepkin (1966, 1976) identified 48 omul' bones at Ulan-Khada on Lake Baikal, but we consider these identifications suspect as all of the Coregonidae are very similar osteologically.

Stable isotope studies have been made on human remains from multiple Holocene sites in the Lake Baikal area (Katzenberg and Weber, 1999; Weber et al., 2002). These studies indicate all groups in the area were eating fish, but fish use was variable depending upon time period and location. The period prior to about 6900 BP (the Late Mesolithic to Early Neolithic periods) may have witnessed the most extensive use of fish, although fishing was fairly localized—people were consuming mostly locally available species. After about 6200 BP (middle Neolithic through early Bronze Age), fish use was apparently less localized, suggesting people were traveling and fishing throughout the western Lake Baikal area. During these periods, fish may have constituted less of the overall diet for most individuals. Isotopic analyses of human remains from cemeteries in the Little Sea region suggest people here primarily consumed littoral fishes such as pike, perch, and roach (A. Weber, personal communication, 2006). All isotope data suggests omul' were likely not important in the overall diet of groups on the lake or its tributaries.

3. Ityrkhei and its fauna

Ityrkhei is located on the western part of Ityrkhei Cove (Fig. 2) on the southeast coast of the Kurkut Gulf in the Little Sea area. This bay is relatively shallow (<3 m deep) and is inhabited by most Baikal littoral fish species. The site was first excavated by Goriunova in 1975–1976 (Goriunova and Savel'ev, 1976; Goriunova and Kuz'minskii, 1976; Goriunova, 1978, 1984). Excavations focused on the southwest portion of Ityrkhei Cove, with an area of 127 m^2 (~290 m^3) being sampled (Goriunova, 1984). Ten layers were defined based on stratigraphy, typological data, and seven radiocarbon dates (Table 1). Occupation appears to have spanned most of the Holocene, but was most intense from the Late Mesolithic through Developed Neolithic (~8000 to 4300 BP).[1] All layers reportedly contained faunal remains. Khamzina (1991) completed a partial analysis of the non-fish vertebrate remains from these excavations (93 identified specimens). She reports the dominant species were seal (~38% of identified specimens), red deer (*Cervus elaphus*, ~30%), and roe deer (*Capreolus pygargus*, ~17%), but a close reading of her report reveals fish remains were numerically dominant. Possible fishing-related implements recovered include a Mesolithic bone harpoon and a single ground stone fishhook shank and 'netting' needle from the Developed Neolithic. An unspecified number of notched stones, interpreted as net weights, were also found in the Developed Neolithic deposits. Field notes indicate that many fish remains were found in concentrations, but such spatial data were not maintained in organization of the assemblage upon curation. Given the lack of sieving during these excavations, we suspected this sample was biased towards larger fauna and larger elements, and Nomokonova and Goriunova re-excavated the site in 2005. At this time 3 m^2 (~7 m^3) was sampled and 2 mm mesh sieves were used to screen all sediment. Layers 0, III, V, and IX lacked faunal remains, but all other layers (I, II, IV, VI, VII, VIII) produced relatively well-preserved specimens.

Faunal remains from the 1970s and 2005 samples were identified by Nomokonova and Losey using locally derived comparative specimens, published guides, and comparative materials of the University of Alberta (Edmonton, Canada), Limnological Institute of the Siberian Branch of the Russian Academy of Science, and Irkutsk State Academy of Agriculture (both in Irkutsk, Russia). The fish remains recovered in the 1970s from layer IV could not be located for analysis. The total NISP is 19,729, of which 19,510 are fish (Table 2). Of the total, 11,290 specimens were excavated in 2005, suggesting that sieving dramatically improved the recovery rate. In the 2005 sample, fish remains were found in all layers, excluding layer IV and VIII, and were found scattered in the excavated sediments. All fish remains from layer IV were recovered from a single discrete cluster, and 97% from layer VIII were also found in a single concentration.

Table 2 shows identified taxa by layer and excavation year. Fish remains overwhelmingly dominate the samples by NISP and dominate all layers with the exception of layer I (Iron Age), which produced only a handful of specimens. Of the 3698 identified fish specimens, just over 65% are perch, 28% are Cyprinidae, 5% are Coregonidae, and 2% are pike.

Table 1
Cultural periods and chronology for Ityrkhei

Cultural layer	Period	Uncalibrated radiocarbon dates
0	Iron Age (2000–550 BP)	
I	Early Bronze Age (4000–3300 BP)	
II	Developed Neolithic (5500–4300 BP)	4485 ± 45 (SOAN-1585)
III	Developed Neolithic (5500–4300 BP)	
IV	Developed Neolithic (5500–4300 BP)	4740 ± 155 (SOAN-3342)
V	Early Neolithic (6500–5500 BP)	5680 ± 60 (SOAN-3341)
VI	Early Neolithic (6500–5500 BP)	5700 ± 200 (GIN-4881)
VII	Late Mesolithic (8000–7000 BP)	7300 ± 290 (IMSOAN-402)
VIII	Late Mesolithic (8000–7000 BP)	8010 ± 100 (GIN-4882)
IX	Middle Mesolithic (9300–8000 BP)	8720 ± 210 (COAH-3171)

All radiocarbon ages are on charcoal. Chronological periods are those originally defined for the site by Goriunova (1984, 2003), Goriunova and Novikov (2000) and Goriunova et al. (1996).

Most members of the Cyprinidae family are osteologically quite similar (Le Gall, 1984), and identifications were made to species only for pharyngeals, basioccipitals, and parasphenoids. Two Cyprinidae species were identified, including roach (*Rutilus rutilus lacustris*) and dace (*Leuciscus leuciscus baicalensis*), with roach being far more common. Coregonidae too are very similar osteologically, and we were unsuccessful in assigning elements to species.

Perch, roach, dace, and pike are commonly found in lagoons and other shallow and warm littoral waters of Lake Baikal, and are particularly abundant in the Little Sea, including Ityrkhei Cove. All are year-round inhabitants of the area, and today are caught using hook and line and gillnets in open water and through the ice. All of these fishes spawn in shallow water in the spring. Most of the Coregonidae are also present in the general Little Sea area year-round, with the exception of omul', which tend to inhabit only the deepest areas of the Little Sea during periods when the water is relatively cool (Kozhov, 1963; Bronte et al., 1999; Smirnov, 1992; Khozhova and Izmest'eva, 1998). Some omul' use shallow waters of this region for spawning in the fall. All of the whitefishes and omul' (Coregonidae) have very small mouths and are very difficult for anglers to harvest without using very small hooks; all spawn in the fall. Overall, the assemblage is consistent with a fishery focusing on species that prefer shallow warm water, and a range of fishing technologies was potentially used.

4. Reconstructing perch size

Fishing technologies are often selective in terms of the size of particular species they capture. One means of assessing the

[1] All dates are in uncalibrated years before present. For the sake of simplicity, we use the chronological periods originally defined for the site by Goriunova (1984, 2003), Goriunova and Novikov (2000) and Goriunova et al. (1996). However, recent reevaluation of radiocarbon dates on human skeletal remains from the Little Sea region of Lake Baikal (Weber et al., 2007) suggests that some of these chronological divisions need to be revised. Using this new culture history model, layers V and VI would fall in the Middle Neolithic period, and layers II through IV would be Late Neolithic.

Table 2
Faunal remains from the 1970s and 2005 Ityrkhei excavations

	Iron Age		Early Bronze		Developed Neolithic						Early Neolithic				Late Mesolithic				Middle Mesolithic		Total	
	0		I		II		III		IV		V		VI		VII		VIII		IX			
	N	Wt.	*N*	Wt.	*N*	Wt.	*N*	Wt.	*N*	Wt.	*N*	Wt.	*N*	Wt.	*N*	Wt.	*N*	Wt.	*N*	Wt.	*N*	Wt.
1975–1976																						
Mammalia unidentified	1	21.40			3	11.35	5	6.55	8	12.62	2	4.63	2	8.09	8	101.54	35	120.48	27	33.00	91	319.66
Artiodactyla			1	2.26	1	6.68	1	13.26	3	41.03			1	24.37			9	204.63	1	15.40	17	307.63
Alces alces					2	75.71															2	75.71
Capreolus pygargus	1	3.17							6	70.58									1	4.08	8	77.83
Cervus elaphus			2	15.28	6	29.16	2	221.63	3	59.87											13	325.94
Canis familiaris									1	13.05											1	13.05
Gulo gulo	1	7.11																			1	7.11
Phoca sibirica					2	8.09	7	30.67	8	36.73	4	33.06	9	80.30	8	73.76	11	74.92	2	22.09	51	359.62
Total mammal	3	31.68	3	17.54	14	130.99	15	272.11	29	233.88	6	37.69	12	112.76	16	175.30	55	400.03	31	74.57	184	1486.55
Pisces unidentified			229	3.02	1407	22.85	322	3.18			2106	45.07	693	15.85	1469	17.32	236	7.82	13	0.72	6475	115.83
Cyprinidae					6	0.28	4	0.31			111	4.26	96	2.78	15	0.55	4	0.58			236	8.76
Rutilis rut. lacustris					1	0.05	1	0.05			39	4.71	14	1.93	2	0.12	5	0.43			62	7.29
Leuciscus leucis													1	0.09							1	0.09
Coregonus spp.					4	0.04					96	1.72			27	0.52	17	1.33			144	3.61
Perca fluviatilis			23	3.19	137	11.83	21	3.02			525	49.38	209	15.70	285	13.69	35	6.25	10	1.69	1245	104.75
Esox lucius					1	0.88	3	0.99			30	10.47	11	11.12	4	2.54	5	3.91	3	0.78	57	30.69
Total fish			252	6.21	1556	35.93	351	7.55			2907	115.61	1024	47.47	1802	34.74	302	20.32	26	3.19	8220	271.02
Aves unidentified											2	1.23	3	2.18	9	8.22	2	0.30	4	1.56	20	13.49
c.f. *Anas* spp.											1	0.31									1	0.31
Total bird											3	1.54	3	2.18	9	8.22	2	0.30	4	1.56	21	13.80
1970s totals	3	31.68	255	23.75	1570	166.92	366	279.66	29	233.88	2916	154.84	1039	162.41	1827	218.26	359	420.65	61	79.32	8425	1771.37
2005																						
Mammalia unidentified			2	0.32	1	0.08			2	0.17			4	0.97			2	0.32			11	1.86
Phoca sibirica																	3	3.52			3	3.52
Total mammal			2	0.32	1	0.08			2	0.17			4	0.97			5	3.84			14	5.38
Pisces unidentified									2297	29.52			1647	15.86	1275	9.41	4118	26.23			9337	81.02
Cyprinidae									135	4.7			126	2.08	67	1.48	374	6.14			702	14.40
Rutilis rut. lacustris									9	0.08			7	0.40	2	0.27	5	0.24			23	0.99
Leuciscus leucis													2	0.02			5	0.06			7	0.08
Coregonus spp.									6	0.07			10	0.09	8	0.12	5	0.06			29	0.34
Perca fluviatilis									449	22.01			194	7.46	94	2.70	440	16.74			1177	48.91
Esox lucius													3	0.11	7	0.41	5	0.21			15	0.73
Total fish									2896	56.38			1989	26.02	1453	14.39	4952	49.68			11290	146.47
2005 totals			2	0.32	1	0.08			2898	56.55			1993	26.99	1453	14.39	4957	53.52			11304	151.85
All samples total	3	31.68	257	24.07	1571	167.00	366	279.66	2927	290.43	2916	154.84	3032	189.40	3280	232.65	5316	474.17	61	79.32	19729	1923.22

fishing technologies used at Ityrkhei thus was to examine the size of perch being harvested. In May, 2006, we acquire 51 perch taken with gillnets from Uliarba Cove, about 6.5 km west of Ityrkhei Cove on Lake Baikal. The fish ranged from 10.7 to 31.5 cm in total length. Whole fish were weighed to the nearest tenth of a gram, and their total length and fork length were measured to the millimeter. All fish were individually gently boiled for 3–4 min, and skeletal elements were collected, cleaned, and labeled.

Brinkhuizen (1989) developed regression formulas for estimating perch total length and weight based on a comparative sample of 36 perch from the northern Netherlands. We measured (to a tenth of a millimeter) the skeletal element dimensions he described on our modern sample using a dial calipers and applied his total length regression formulas. These nearly always underestimated the total length of our comparative sample, typically by 1–3 cm. It is unclear why such errors occurred. One possibility is that we failed to take element measurements precisely as Brinkhuizen describes, resulting in error. This does not seem likely, as Brinkhuizen measurements are clearly illustrated and most dimensions are at well defined landmarks not overly susceptible to undetectable erosion/damage. It is also unclear why measurement error would consistently result in underestimations of total length. Another possible explanation, and one that we favor, is that morphological differences exist between Brinkhuizen's and our perch sample populations. These populations are widely geographically separated and likely evolved independently to local conditions for thousands of years. As such, we felt it logical to develop regression formulas based on our comparative sample. Our formulas are not meant to replace those of Brinkhuizen (1989), especially for studies on perch size estimations in the Netherlands, but we believe them to be more reliable for Lake Baikal archaeological samples. Tsepkin (1965, 1976, 1979, 1980, 1986, 1995) estimated harvested perch size in the Baikal area, but employed a direct proportional method. These proportions are of unknown accuracy and were apparently based on very few comparative specimens. In addition, his proportional methods are not published in any form and are thus impossible for others to apply.

One step regression formulas for perch total length and fork length were developed using methods outlined in Leach et al. (1997) and using SPSS version 14.0. The 'curve estimation' feature in SPSS was used to assess various regression curves (linear, logarithmic, power, etc.) to paired sets of dimensions (for example, cleithrum length to total length for all specimens), and the curve that produced the highest correlation coefficient was selected. Power curves consistently provided the strongest correlations. In total, 17 element dimensions were used to develop formulas for estimating total length and fork length (Fig. 3; Table 3, Appendix A). In addition, we developed both one step and two step regression formulas for estimating perch weight (Appendices B and C). The one-step formulas allow element dimensions to be entered directly into formulas that produce an estimation of weight. In the two step formulas, length is first estimated from an element dimension using the one step formulas, and this length estimate is entered into a second formula to provide a weight estimate. While we primarily use only the total length equations (a widely used dimension in fisheries biology), all formulas are provided in the appendices.

Table 3 shows statistics for the total length equations. To calculate total length based on an element dimension (here the angular 1 measurement), one applies the constant and slope values in the following manner: total length = 3.867 × (angular 1 dimension in cm)$^{0.932}$. The correlation coefficients (R values) in Table 3 are reasonably high for each element dimension and formula, and the standard errors of estimate are all less than 0.07 cm. As such, we believe the resulting formulas provide reasonably accurate estimates for total length, particularly for perch within the size range of our comparative sample.

For the Ityrkhei assemblage, all perch elements for which regression formulas were developed were measured and total length estimations made. This approach potentially produces multiple length estimations for individual elements and more size estimations than individual fish as assessed through

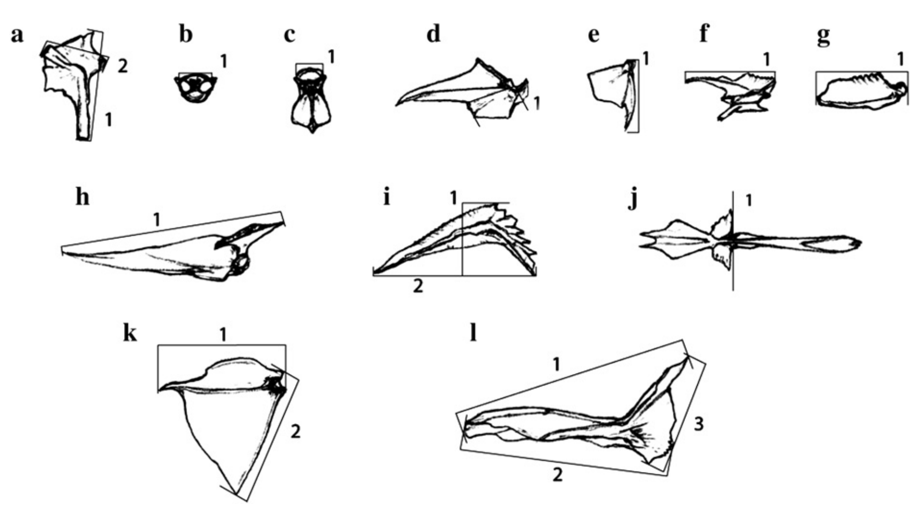

Fig. 3. Perch element dimensions utilized in this study: (a) hyomandibular 1 and 2, (b) atlas 1, (c) basioccipital 1, (d) angular 1, (e) quadrate 1, (f) posttemporal 1, (g) supracleithrum 1, (h) basipterygium 1, (i) preopercle 1 and 2, (j) parasphenoid 1, (k) opercle 1 and 2, (l) cleithrum 1, 2, and 3.

Table 3
Statistics for perch total length estimation developed in this study

Element dimension	Cases	Constant	Slope	Standard error of estimate	Standard error of R	R value	R^2
Angular 1	101	3.867	0.932	0.055	0.216	0.950	0.902
Atlas 1	50	4.374	0.953	0.038	0.217	0.977	0.954
Basioccipital 1	51	8.911	0.917	0.052	0.342	0.954	0.911
Basipterygium 1	50	1.004	0.915	0.053	0.138	0.954	0.910
Cleithrum 1	101	0.981	0.902	0.039	0.069	0.974	0.950
Cleithrum 2	101	0.985	0.937	0.028	0.050	0.987	0.974
Cleithrum 3	102	1.995	0.868	0.034	0.093	0.981	0.962
Hyomandibular 1	102	1.289	1.063	0.031	0.066	0.984	0.967
Hyomandibular 2	102	3.136	0.934	0.030	0.103	0.985	0.971
Opercle 1	99	1.776	0.898	0.042	0.119	0.966	0.933
Opercle 2	101	1.757	0.895	0.031	0.086	0.981	0.963
Parasphenoid 1	51	13.944	0.726	0.065	0.339	0.928	0.861
Posttemporal 1	94	2.308	0.897	0.031	0.113	0.978	0.957
Preopercle 1	101	1.921	1.050	0.042	0.115	0.970	0.941
Preopercle 2	102	0.998	1.006	0.035	0.062	0.980	0.960
Quadrate 1	96	2.370	0.960	0.041	0.141	0.967	0.934
Supracleithrum 1	94	2.197	0.881	0.036	0.130	0.970	0.941

minimum number of individuals. Nonetheless, this approach is often followed because using only one element dimension would result in too few length estimations to be meaningful. Also, it is often clear that some fish are represented by very few elements, and using only one or two element dimensions would often result in excluding these poorly represented individuals. Using this approach, 485 total length estimations were made for the Ityrkhei perch.

As with most zooarchaeological assessments, fish size studies are affected by recovery methods employed in excavation and the manner in which data are aggregated. For example, the average total length and weight of perch recovered in the 1970s samples are larger than those recovered in 2005 (total length difference of 3.3 cm, t-test of significance <0.001; weight difference of 46.7 g, t-test of significance <0.001); Table 4). This suggests that not only the recovery rate was affected by the use of sieves, but that the use of sieves resulted in more consistent recovery of smaller specimens. Another interesting pattern appears when comparing total length mean and standard deviations by layer for the two sets of excavations (Figs. 4 and 5). The 1970s samples suggest a slight increase in mean perch length over time, while the 2005 sample demonstrates no clear trend. Neither provides support for decreasing perch size due to fishing pressure or environmental changes. Integrating the two samples also failed to produce any clear trends in perch size.

Table 4
Total length and weight means for the perch size estimations for the 1970s and 2005 Ityrkhei samples

Sample	No. of cases	Weight mean (g)	Error of mean	SD	Total length mean	Error of mean	SD
1970s	145	272.90	16.28	196.00	27.98	0.31	5.48
2005	340	226.16	8.38	154.62	24.66	0.29	3.96

5. Harvest technologies and selectivity

The selectivity of fishing gear is often examined through size frequency diagrams. However, some interpretive problems exist in using such diagrams for inferring harvest technology. One is that in most archaeological situations, sets of size estimations for a fish taxon often do not represent discrete fishing events (as is the case with most biological observations) but instead were produced through multiple fishing events, perhaps over many days, seasons, and years. A second issue is that archaeological samples, especially those accumulated over long periods, potentially were harvested with multiple technologies, each with their own selectivity. Compounding these issues is differential treatment of fish by those

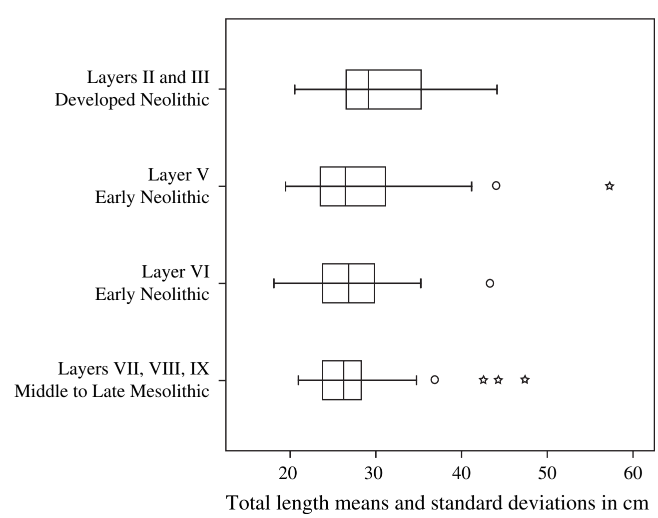

Fig. 4. Means and standard deviations for perch total length estimations by layer for the 1970s Ityrkhei samples. Statistical outliers indicated. Note that layer I is not shown here because only two size estimations were available. Layers II and III and layers VII, VIII, and IX were combined to increase sample size.

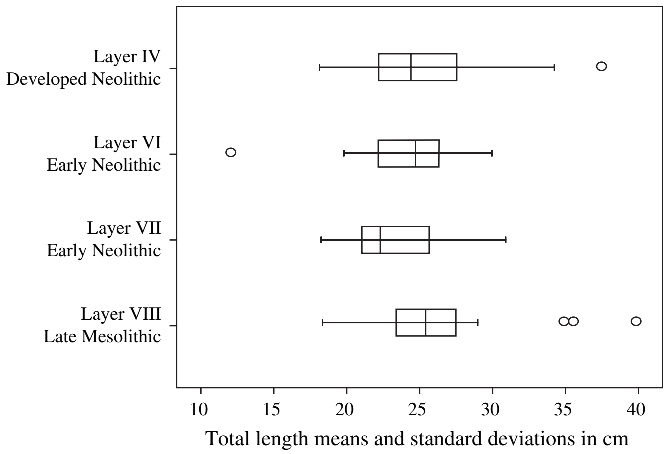

Fig. 5. Means and standard deviations for perch total length estimations by layer for the 2005 Ityrkhei samples. Statistical outliers indicated.

processing, eating, and discarding them, and various post-depositional processes that potentially result in selective survival of specimens.

Individual harvesting technologies like hooks and spears could be used to take most of the Ityrkhei fishes, but spearing seems an inefficient and unlikely way of taking perch. Perch are quick, darting fish and their relatively narrow profile when viewed from above would make them difficult to strike. However, if a wide size range of perch were available, we suggest that spearing would produce a size frequency distribution favoring the largest fish.

Angling probably was a suitable perch harvest method. Experiments with modern angling equipment demonstrate that hooks of a given size select for fish of an optimal size, but often take fish somewhat smaller and larger than this optimum, resulting in a bell shaped selection curve (Cortez-Zaragoza et al., 1989; Ralston, 1982, 1990; Løkkeborg and Bjordal, 1992; Miranda and Dorr, 2000; Otway and Craig, 1993). Larger hooks tend to take broader size ranges of fish than do smaller ones (Cortez-Zaragoza et al., 1989). Similar selectivity trends presumably occur with ancient hooks, although this is yet to be demonstrated. No comprehensive metric study has been made of Baikal fish hooks, but a wide size range was clearly used (Okladnikov, 1950, 1955; Medvedev, 1971; Svinin, 1976). As such, it is possible that Lake Baikal archaeological hooks would produce size frequency distributions that include very small to very large fish.

Mass harvest technologies also can be selective. Unbaited traps have been successfully used in some Eurasian lakes to harvest perch, and these have proven selective for size (Craig, 1974, 1975; Allen, 1953; Worthington, 1950; Bagenal, 1972; Le Cren et al., 1977). For example, Craig (1974) found that traps with 1.28 cm mesh failed to catch perch below about 9.5 cm total length. Large perch also were often excluded from traps because the trap opening was too small for them to enter (Le Cren et al., 1977:286). At Lake Windermere, in the UK, perch traps used in the spring spawning season captured over three times as many males as females (Le Cren et al., 1977:289). However, we are unaware of any selectivity curves specifically derived for perch traps.

Very small gauge nets, sometimes termed seines, have to be pulled through areas inhabited by fish to be effective in most lake settings. Their mesh size allows very small fish to be harvested, while larger fish stand better chances at escape as they are more capable of successfully moving out of the net path. Very large seines, in ideal circumstances, could harvest all but the very smallest individuals. However, large seine nets would have been very costly to make and were probably extremely rare in antiquity. Smaller seines would be most effective in shallow waters with dense concentrations of fish. Such waters in Lake Baikal would likely contain mostly juvenile fish, including perch. As such, we speculate that the resulting selectivity curves would have the bulk of their distribution centering on juvenile fishes.

Gill or entanglement nets depend on the movement of fish to be effective, and their selectivity has been well established (Hamley, 1975, 1980; Holst et al., 1998; Jensen, 1986, 1990). Critical factors include mesh size, visibility, flexibility, how tightly or loosely they are strung, and where and how they are utilized. Nets of a given size also can have selectivity specific to species. Selectivity of gillnet harvest of perch and roach, which commonly overlap in habitat (and are common at Ityrkhei), has been extensively studied (Albert, 2004; Kurkilahti and Rask, 1996; Hamley, 1980; Psuty-Lipska et al., 2006). Perch have a much greater chance of becoming entangled in gillnets of a given size compared to roach because they are much spinier, and thus have more potential entangling points (Hamley, 1980; Albert, 2004). Nets of a given size therefore can be less selective for perch than roach, as the majority of roach taken will be wedged into the net (and the ability of nets to wedge fish is largely controlled by fish size), while the perch taken will be both wedged and entangled. A loosely stretched net, which would be more effective at entangling than a tightly strung net, would harvest a wider size range of perch but not a wider size range of roach. This entanglement ability can result in selectivity curves that are skewed to the right (Albert, 2004:10). Nonetheless, nets of a given mesh size are most effective at taking perch of a limited size range, and most fish below a certain threshold are excluded (Albert, 2004; Psuty-Lipska et al., 2006).

6. Perch size at Itrykhei

Figs. 6 and 7 show perch size (total length) frequency distributions for the 1970s and 2005 excavations, respectively. Despite the different recovery methods and sample sizes, both distributions are centered on the 20–30 cm range, and both are skewed to the right. With only a single exception from layer VI (2005 sample), no perch less than about 17 cm is represented. Somewhat similar size frequency distributions are produced when individual layers are analyzed, although they tend to be less broad, largely due to fewer larger specimens being present (Figs. 8 and 9). Given that modern Lake Baikal perch reach adulthood at around 15–20 cm, all curves suggest only adult perch were being taken (Evtyuchova-Rekstin, 1962).

While individual layer frequency distributions probably represent multiple fish harvests, and several fishing technologies

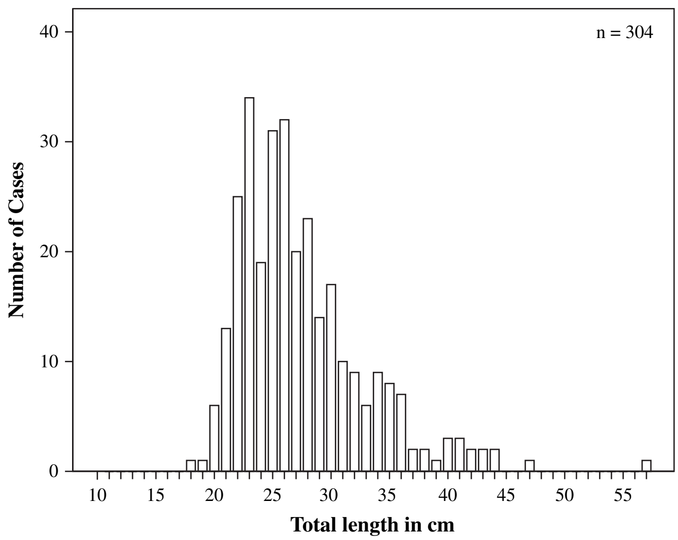

Fig. 6. Total length frequency distribution for perch recovered in 1970s excavations of Ityrkhei, all layers combined. Number of cases indicated.

could have contributed to each, we nonetheless believe some inferences about harvesting technology can be made. In those layers where fish were relatively abundant, the focus was on harvesting perch in the 20–30 cm range. In nearly all cases some larger fish were harvested, but almost none less than about 17 cm were taken. One explanation could be that this pattern relates to the differential preservation of fish elements by size. However, it seems difficult to explain why elements from 20 cm long perch would survive while those from perch 3–4 cm shorter would not. Elements from our comparative sample fish in this lower size range appear fairly robust, despite their size. In addition, the consistent presence of relatively delicate bone features in the Ityrkhei sample, such as projections on perch cleithra, suggests preservation conditions were conducive to fish bone preservation. Another possible explanation would be that small perch were processed differently than larger ones, resulting in their destruction or deposition in an

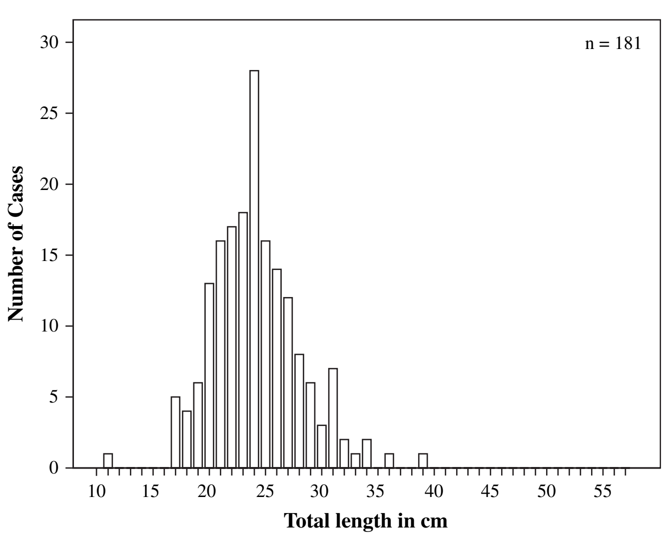

Fig. 7. Total length frequency distribution for perch recovered in 2005 excavation of Ityrkhei, all layers combined. Number of cases indicated.

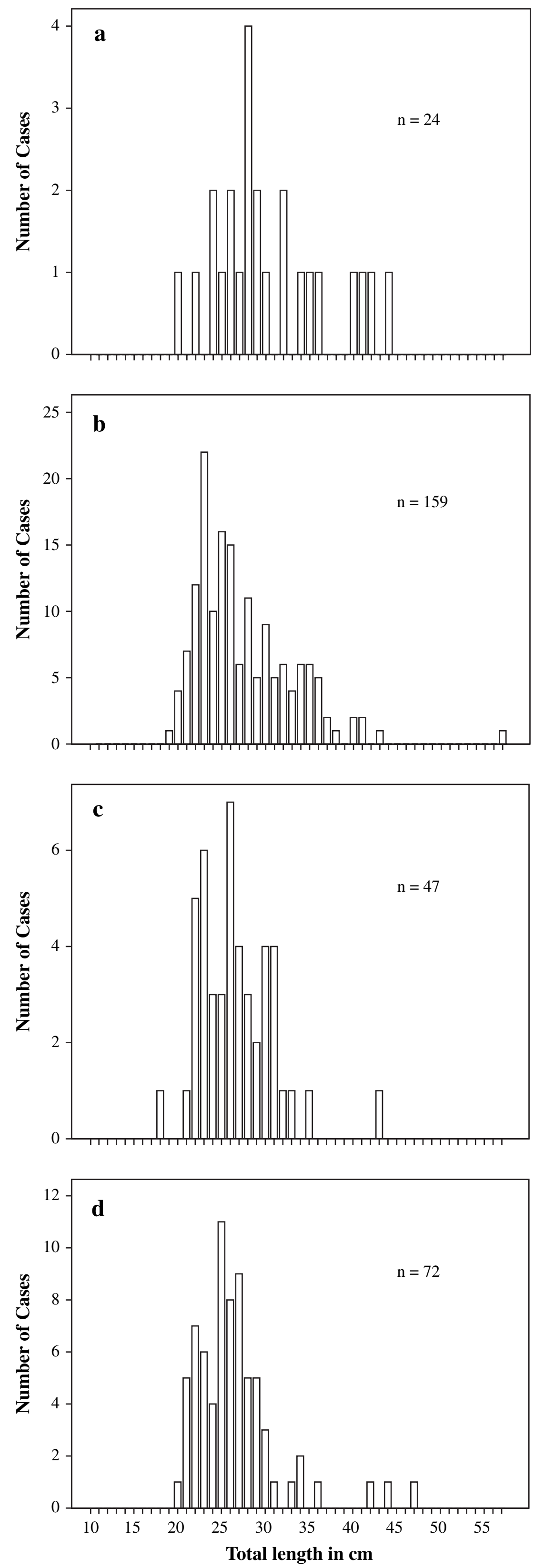

Fig. 8. Total length frequency distributions for perch recovered in the 1970s excavations of Ityrkhei: (a) layers II and III, (b) layer V, (c) layer VI, (d) layers VII, VIII, and IX. Number of cases indicated.

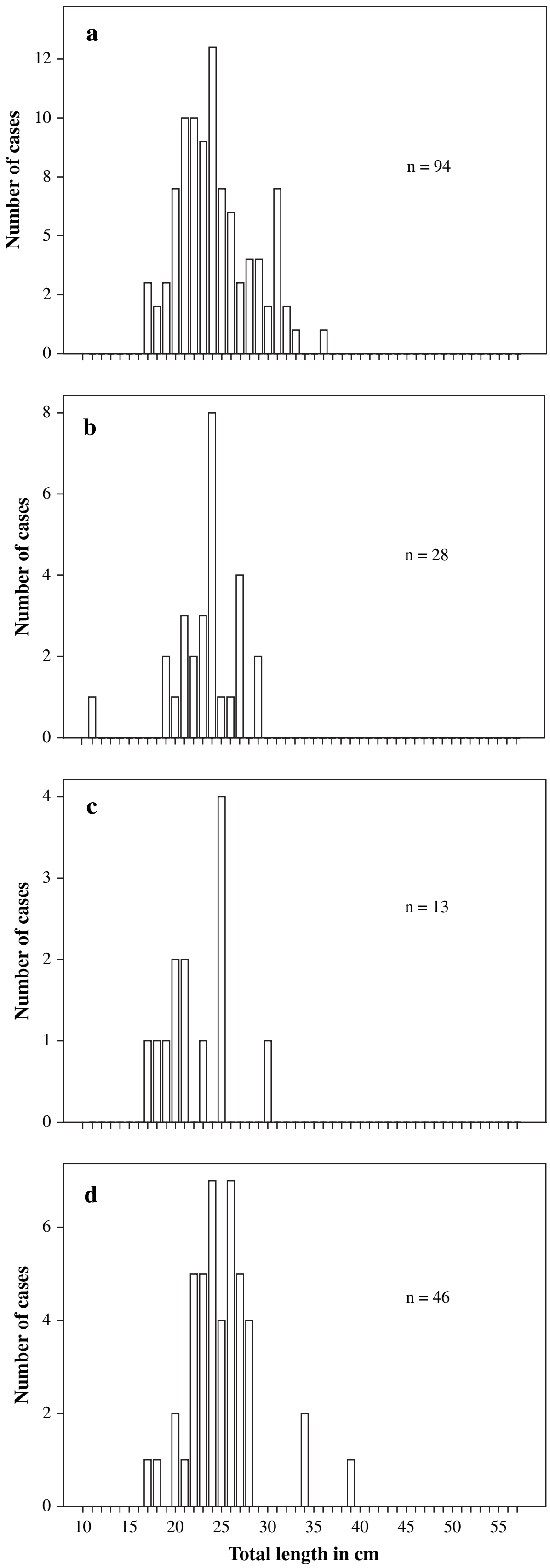

Fig. 9. Total length frequency distribution for perch recovered in the 2005 excavation of Ityrkhei: (a) layer IV, (b) layer VI, (c) layer VII, (d) layer VIII. Number of cases indicated.

unexcavated area. Such practices undoubtedly occurred, but it seems unlikely that they were consistent over thousands of years of site use. In short, we suspect this pattern is the result of selective harvest.

Smaller fish would be expected if small gauge nets or traps were employed, particularly if used in shallow areas where juvenile fish congregate. We also expect small fish would be present if people were angling from shore with hooks during periods of open water. These practices probably were very rarely undertaken at Ityrkhei. Angling with fairly large hooks through the ice or from watercraft during open water periods might produce the size frequency distributions seen in these curves, but the lack of smaller perch is still unexpected, given that quite small perch can be taken with relatively large hooks. The distributions also appear fairly consistent with the use of relatively large gauge nets or traps. Such equipment would be most effective at taking perch of a relatively limited size range, but also would take some larger fish while excluding smaller individuals. Such technologies would likely have been most effective when perch were concentrated, most notably during the spring spawning period.

The 2005 specimens from layers IV and VIII, derived from concentrations of fish remains, provide more discrete samples (Fig. 9a and d, respectively). Among the 2896 fish specimens from the layer IV feature, at least 449 are perch (MNI = 15), 144 are Cyprinidae (MNI = 7 roach), and 6 are Coregonidae (MNI = 1), the remainder being unidentified. Here 94 total length estimations were made, and perch ranged in length between 17 and 36 cm, but most were in the 20–31 cm range. Again, perch less than about 17 cm are absent. This is a somewhat narrower range than in other layers, raising the possibility that a single harvest technology was used. Assuming all fishes were harvested at the same time (and this may not be a valid assumption), the presence of at least one whitefish or omul', which are quite difficult to take with a hook, suggests to us that a net or trap was utilized. An alternative harvest strategy would be hook and line fishing in an area where no juvenile fish were present. In the Layer VIII feature, 4803 fish remains were found, and at least 428 are perch (MNI = 8), 371 are Cyprinidae (MNI = 14), 5 are pike (MNI = 1), and 3 are Coregonidae (MNI = 1), the remainder being unidentified. The three largest perch shown in Fig. 9d are represented by remains not found in the concentration. As such, the size frequency distribution for this feature is quite narrow, with all perch being between 17 and 28 cm. If a single technology took all fishes in this concentration, perhaps a large gauge trap or net was employed. Large hooks, however, cannot be ruled out.

7. Discussion

While reconstruction of harvested perch at Ityrkhei did not produce unequivocal evidence for use of a specific fishing technology, we believe these data provide some support for the use of mass harvesting equipment such as nets or traps. Intensive fishing for littoral species at Ityrkhei began sometime during the Late Mesolithic, at which time people were apparently harvesting perch no smaller than about 17 cm. This suggests some selectivity, and to us, more selectivity than would be expected through the use of hooks alone. The minor presence of whitefish or omul' also may indirectly provide support for the use of nets or traps. This interpretation is consistent with paucity of fish hooks recovered from the site, and lends credibility to the notion that the notched stones recovered here were used as net weights. Regardless of the specific technology used, much of the fishing at Itrykhei appears to have been done through the ice or from watercraft away from shallow waters where juvenile perch were abundant.

Our data appear to support earlier notions about the use of nets on Lake Baikal that were based largely on the presence of supposed net sinkers and other possible net-related technology in sites. Given that such technology may have been used at Ityrkhei since the Mesolithic, this study suggests that nets or traps, and perhaps boats, may have been used several thousand years earlier than previously assumed. There is little evidence at Ityrkhei, however, for the use of omul', the fish often inferred to be most important to the lake's foragers. However, given that Ityrkhei is located on a shallow cove not regularly frequented by omul', and the need for very small hooks or small gauge nets to harvest these often deepwater fish, their absence is not unexpected.

To us, the possible net or trap use at Ityrkhei also is not unexpected, as nets were used in Eurasia since the Upper Paleolithic (Adovasio et al., 1996), and small fauna such as hare (*Lepus* spp.), which are most efficiently harvested with nets, snares, or traps, were being regularly taken in southern Siberia since the Upper Paleolithic (Goebel, 2002:126). Net impressions are also commonly seen on Baikal pottery throughout the Holocene (Weber, 1995). Nets and traps can be expensive technologies, but are probably more efficient means of harvesting large numbers of many Lake Baikal fishes than are spearing or angling. During the Holocene, Lake Baikal was home to substantial human populations (Weber, 1994, 1995; Weber and McKenzie, 2003), and stable isotope data clearly indicate that fish were being consumed on a regular basis. Extensive use of fish mass harvest technology and watercraft could have been significant elements of the subsistence economies of these foragers.

Obviously, additional empirical support for these notions would be ideal. A next step would be to reconstruct sizes of other fishes at Ityrkhei (particularly the Cyprinidae) and those at other Baikal area sites. Application of the formulas developed here to other samples of Baikal archaeological perch samples should provide further insight on fishing technologies used in the area. Additional modeling of the size selectivity of various fishing technologies is needed, as is some experimental testing of such models. A detailed metric study of existing fishing technology, including fishhooks and sinkers, could also prove useful, and identification of Coregonidae elements to species could be revealing. Other evidence for the use of boats, particularly the occupation of far offshore islands during open water periods, would also be helpful. Ultimately, detailed faunal analyses of multiple Lake Baikal sites from an array of time periods and geographic settings likely will prove most informative about fish and fishing in the economies of the lake's ancient inhabitants.

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Appendix A

Statistics for perch fork length equations

Element dimension	Cases	Constant	Slope	Standard error of estimate	Standard error of *R*	*R* value	R^2
Angular 1	101	3.477	0.961	0.060	0.214	0.943	0.889
Atlas 1	50	3.953	0.982	0.045	0.232	0.969	0.940
Basioccipital 1	51	8.216	0.843	0.058	0.348	0.948	0.899
Basipterygium 1	50	0.852	0.948	0.056	0.123	0.953	0.908
Cleithrum 1	101	0.827	0.973	0.041	0.610	0.974	0.949
Cleithrum 2	101	0.840	0.969	0.033	0.500	0.983	0.966
Cleithrum 3	102	1.763	0.900	0.037	0.088	0.979	0.958
Hyomandibular 1	102	1.104	1.102	0.034	0.062	0.982	0.964
Hyomandibular 2	102	2.782	0.966	0.034	0.106	0.982	0.964
Opercle 1	99	1.544	0.929	0.044	0.108	0.965	0.931
Opercle 2	102	0.845	1.043	0.037	0.056	0.979	0.958
Parasphenoid 1	51	13.011	0.754	0.068	0.330	0.927	0.859
Posttemporal 1	94	2.044	0.924	0.034	0.109	0.976	0.952
Preopercle 1	101	1.660	1.091	0.044	0.102	0.971	0.942
Preopercle 2	102	0.845	1.043	0.037	0.056	0.979	0.958
Quadrate 1	96	2.037	1.003	0.041	0.124	0.968	0.937
Supracleithrum 1	94	1.911	0.914	0.039	0.125	0.966	0.933

Appendix B

Statistics for one step perch weight equations

Element dimension	Cases	Constant	Slope	Standard error of estimate	Standard error of *R*	*R* value	R^2
Angular 1	101	0.536	2.891	0.187	0.102	0.940	0.883
Atlas 1	50	0.765	2.969	0.121	0.120	0.976	0.952
Basioccipital 1	51	6.901	2.564	0.161	0.814	0.956	0.914
Basipterygium 1	50	0.007	2.887	0.157	0.003	0.959	0.920
Cleithrum 1	101	0.007	2.840	0.111	0.001	0.979	0.959
Cleithrum 2	101	0.007	2.940	0.082	0.001	0.989	0.978
Cleithrum 3	102	0.064	2.717	0.110	0.010	0.979	0.959
Hyomandibular 1	102	0.017	3.323	0.105	0.003	0.981	0.963
Hyomandibular 2	102	0.263	2.927	0.094	0.027	0.985	0.970
Opercle 1	99	0.043	2.821	0.115	0.008	0.974	0.948
Opercle 2	101	0.043	2.803	0.083	0.006	0.986	0.973
Parasphenoid 1	51	28.055	2.286	0.200	2.082	0.932	0.868
Posttemporal 1	94	0.113	2.764	0.101	0.018	0.977	0.954
Preopercle 1	101	0.056	3.294	0.130	0.010	0.972	0.944
Preopercle 2	102	0.007	3.158	0.103	0.001	0.982	0.964
Quadrate 1	96	0.109	3.008	0.123	0.020	0.968	0.938
Supracleithrum 1	94	0.078	2.800	0.086	0.011	0.982	0.965

Appendix C

Statistics for two step perch weight equations

	Cases	Curve	Constant	Slope	Standard error of estimate	Standard error of R	R value	R^2
Total length to weight (g)	51	Power	0.008	3.098	0.082	0.002	0.989	0.978
Fork length to weight (g)	51	Power	0.014	2.979	0.088	0.003	0.987	0.974

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