

**SEX-LINKAGE OF ISOCITRATE DEHYDROGENASE AND GENETIC LINKAGE  
OF MANNOSE PHOSPHATE ISOMERASE AND GLUCOSEPHOSPHATE  
ISOMERASE IN ICTALURID CATFISH**

Q Liu, Ecological Research Center  
Division of Ecology and Organismal Biology  
Department of Biology, The University of Memphis, Memphis, TN 38152  
(901) 678-2594, (901) 327-8001

C A Goudie, Catfish Genetics Research Unit  
US Department of Agriculture, Agricultural Research Service  
PO Box 38, Stoneville, MS 38776  
(601) 686-5460, (601) 686-3004, cgoudie@ag.gov

B A Simco, Ecological Research Center  
Division of Ecology and Organismal Biology  
Department of Biology, The University of Memphis, Memphis, TN 38152  
(901) 678-2594, (901) 327-8001, simcoba@cc.memphis.edu

K B Davis, Ecological Research Center  
Division of Ecology and Organismal Biology  
Department of Biology, The University of Memphis, Memphis, TN 38152  
(901) 678-2594, (901) 327-8001, daviskb@cc.memphis.edu

**Abstract**

Sex-linkage of isocitrate dehydrogenase (*IDH-m*) and genetic linkage of mannose phosphate isomerase (*MPI*) and glucosephosphate isomerase-A (*GPI-A*) were observed in two experimental matings between channel catfish *Ictalurus punctatus* females and hybrid males (channel catfish female × blue catfish *I. furcatus* male) with recombination rates of 13.0% and 5.9%, respectively. Evolutionary relationships of these gene arrangements were compared among teleost species.

**Introduction**

The construction of linkage maps has proven to be a powerful tool in genetic studies of animal genomes (Morizot, 1993). The availability of detailed linkage maps allows identification and location of genes controlling simple and complex traits, and the provides information on the origin and evolution of gene arrangements in a variety of taxa. Gene mapping studies have been conducted for a large number of isozyme loci in salmonid and poeciliid fishes. Comparison of linkage maps revealed numerous cases of probable homologous gene arrangements among these fishes, and several examples of conservation of fish and mammalian linkage arrangements (Morizot et al., 1991). By contrast, construction of gene maps in ictalurids is in its infancy: linkage of *glutathione reductase* and *phosphoglucomutase* (Morizot et al., 1994) and sex-linkage of *glucosephosphate isomerase-B* (Liu et al., 1996) are the only groups that have been assigned in channel catfish.

The information presented here represents a partial contribution toward assembly of gene maps and sex-linkage in ictalurid catfish. Study of genetic mapping and linkage arrangements provides evidence for testing theoretical models for the conservation of gene arrangement, and has possible implications for improving production in this important aquaculture group.

**Materials and Methods**

Sperm was obtained from hybrids of channel catfish females and blue catfish *I. furcatus* males, and was used in two experimental matings to fertilize eggs of channel catfish. Offspring from each cross were maintained in separate aquaria. At 10 month of age, sex was determined by gross examination of gonads, and muscle and liver were dissected for protein electrophoretic analyses. Tissue preparation and horizontal starch gel electrophoresis followed those previously described by Liu et al. (1996).

Genetic distances between loci were reflected in the proportion of recombinant offspring. Theoretically, linked loci would result in greater than 50% parental phenotypes due to the absence of independent assortment. Joint segregation was examined by the log-likelihood ratio G-test. Enzyme nomenclature of GPI and IDH were assigned according to Champion and Whitt (1976) and Shaklee et al. (1990), respectively.

**Results and Discussion**

Analysis of joint segregation of *IDH-m* and *SDG* in two experimental matings are presented in Table 1. The progeny consisted of 45.6% heterozygous males, 41.4% homozygous females and 13.0% recombinants. Disproportionate ratios of parental (87.0%) and recombinant (13.0%)

Table 1. Recombination rates ( $\gamma$ ) and tests for joint segregation of *IDH* and sex in two matings of channel catfish female  $\times$  hybrid male (channel catfish  $\times$  blue catfish).

Family	Sex	Parental Genotype	Progeny Genotype		$\gamma$ (%)	$G^*$
			100/100	100/50		
HBCH95B	Male	100/50	3	21	13.8	28.41
	Female	100/100	29	5		
HBCH95D	Male	100/50	5	56	11.8	32.38
	Female	100/100	41	8		
Overall	Male	100/50	8	77	13.0	54.67
	Female	100/100	70	14		

\* The value of log-likelihood ratio test to demonstrate joint segregation of parental and recombinant progeny genotypes (Sokal and Rohlf, 1981); significant if  $G > \chi^2_{[0.05; d.f.=3]} = 7.81$ .

phenotypes indicated that the allele *IDH-m\*50* was linked with *SDG* in the heterozygous male hybrids used in this study. In previous studies of channel catfish and blue catfish, the presence of two loci for *IDH* was demonstrated in a tissue-specific manner (Carmichael et al., 1992; Liu et al., 1992). *IDH-m* was strongly expressed in muscle, and exhibited a fixed difference between channel catfish and blue catfish. Because the hybrid males were produced from matings between channel catfish females and blue catfish males, the *IDH-m\*50* allele originated from a blue catfish. Therefore, *IDH-m\*50* served as a marker of the Y-chromosome from blue catfish, and represents an initial contribution toward assembly of a sex-linkage map in blue catfish.

Cytosolic IDH and GPI were reported to be in the same syntenic linkage group in salmonid fishes (May and Johnson, 1990) and *Xiphophorus* (Morizot et al., 1993). In a previous study, GPI-B, a muscle form of GPI, was observed to be sex-linked in channel catfish. However, the genetic relationship of IDH and GPI has not been established for either channel catfish or blue catfish. Although the comparison of linkage maps reveals few or no instances of gene arrangement divergence in fishes (Morizot et al., 1993), the tissue-specific expression of IDH and GPI in salmonid and poeciliid fishes indicates a possible differentiation of gene arrangement in ictalurids. Confirmation of this hypothesis awaits further investigation of sex-linkage groups in interspecific crosses of ictalurid catfishes.

Significant deviations from independent assortment expectations were observed for GPI-A and MPI (Table 2). Tight linkage of GPI-A and MPI was confirmed with a recombination fraction of 5.9%.

Table 2. Recombination rates ( $\gamma$ ) and tests for joint segregation of GPI-A and MPI in two matings of channel catfish female  $\times$  hybrid (channel catfish  $\times$  blue catfish) male.

Family	Locus	Parental Phenotypes		Progeny Phenotypes				$\gamma$ (%)	G
		Female	Male	AA	AA'	AA	AA'		
HYCH95B	GPI-A	AA	AA'	46	53	2	4	0.057	24.31
	MPI	BB	BB'						
HYCH95D	GPI-A	AA	AA'	29	31	2	2	0.063	27.64
	MPI	BB	BB'						
OVERALL				75	84	4	6	0.059	39.50

\* The value of log-likelihood ratio test to demonstrate joint segregation of parental and recombinant progeny genotypes (Sokal and Rohlf, 1981); significant if  $G > \chi^2_{[0.05; d.f.=3]} = 7.81$ .

GPI-A was expressed in most tissues and inherited in an autosomal manner in channel catfish (Liu et al., 1996). The linkage of GPI and MPI was also demonstrated in *Xiphophorus* (Morizot et al., 1993) and salmonids (May and Johnson, 1990). However, the GPI isozyme in the study of *Xiphophorus* was muscle specific, and GPI-3 was the sex-linked isozyme in salmonids (May et al.,

1989). Again, the differentiation of genetic association of GPI-A and MPI in catfish indicates the divergence of the original linkage group in fishes. Further study on tissue specificity and other properties of isozymes will provide valuable evidence to confirm the conservation of gene arrangements among fishes.

## References

- Carmichael, GJ, ME Schmidt and DC Morizot 1992 Genetic markers in channel and blue catfish and identification with electrophoresis of low-risk tissues. Transactions of the American Fisheries Society 121:26-35.
- Champion, MJ, and GS Whitt 1976 Synchronous allelic expression at the glucosephosphate isomerase A and B loci in interspecific sunfish hybrids. Biochemical Genetics 14:723-737.
- Liu, Q, CA Goudie, BA Simco, KB Davis, and DC Morizot 1992 Gene-centromere mapping of six enzyme loci in gynogenetic channel catfish. Journal of Heredity 83:245-248.
- Liu, Q, CA Goudie, BA Simco, and KB Davis 1996 Sex-linkage of glucosephosphate isomerase-B and mapping of the sex-determining gene in channel catfish. Cytogenetics and Cell Genetics (in press).
- May, B, KR Johnson, and JE Wright, Jr 1989 Sex linkage in salmonids: evidence from a hybridized genome of brook trout and arctic charr. Biochemical Genetics 27:291-301.
- May, B, and KR Johnson 1990 Composite linkage map of salmonid fishes (*Salvelinus*, *Salmo*, *Oncorhynchus*). In Genetic Maps of Complex Genomes Book 4 Nonhuman Vertebrates. SJ O'Brien (ed). Cold Spring Harbor Laboratories, Cold Spring Harbor, N.Y.
- Morizot, DC, SA Slaughaupt, KD Kallman, and A Chakravarti 1991 Genetic linkage map of fishes of the genus *Xiphophorus* (Teleostei: Poeciliidae). Genetics 127:399-410.
- Morizot, DC, J Harless, RS Nairn, KD Kallman, and RB Walter 1993 Linkage maps of non-salmonid fishes. In Genetic Maps of Complex Genomes Book 6. SJ O'Brien (ed). Cold Spring Harbor Laboratories, Cold Spring Harbor, N.Y.
- Morizot, DC, ME Schmidt, and GJ Carmichael 1994 Joint segregation of allozymes in catfish genetic crosses: designation of *Ictalurus punctatus* linkage group I. Transactions of the American Fisheries Society 123:22-27.
- Shaklee, JB, FW Allendorf, DC Morizot, and GS Whitt 1990 Genetic nomenclature for protein-coding loci in fish: proposed guidelines. Transactions of the American Fisheries Society 118:218-227.
- Sokal, RR, and FJ Rohlf 1981 Biometry. WH Freeman, San Francisco, California