

Supplementary Material for

“An exploration of the links between parasites, trophic ecology, morphology and immunogenetics in the Lake Tanganyika cichlid radiation”

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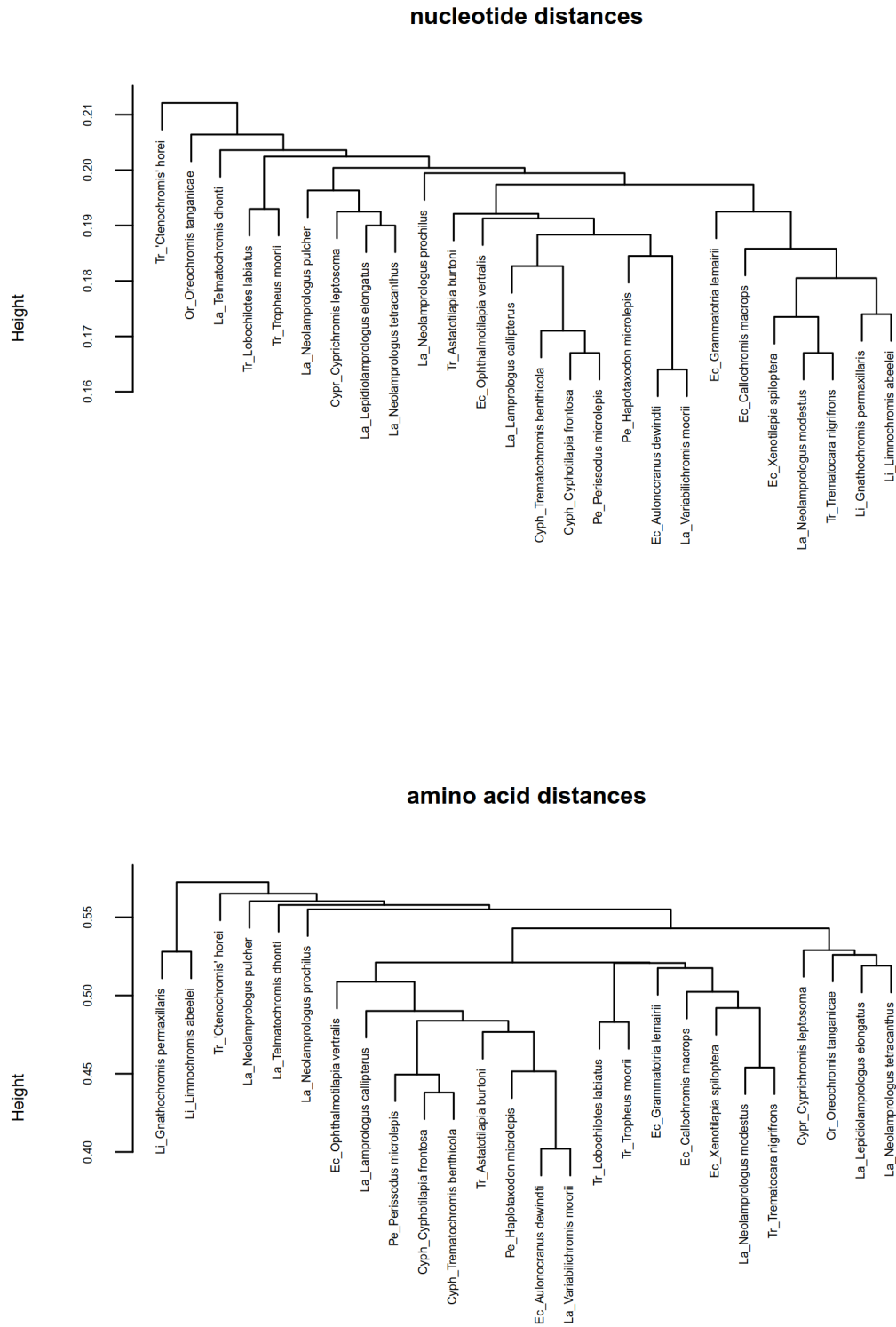
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Running header: Linking parasites, trophic ecology, morphology and immunogenetics

Keywords: parasites/macroparasites, trophic ecology, morphology, immunogenetics

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SUPPLEMENTARY FIGURE



Supplementary Figure 1. UPGMA-trees for phylogenetic distances of MHC exon 2 sequences among species at the nucleotide (top) and at the amino acid level (bottom).

SUPPLEMENTARY TABLES

Supplementary Table 1. Overview of species included in the different data sets. Data by Muschick et al. (2012) include body shape, trophic morphology, diet and stable isotope data. N: sample size. 1/0: include (1) or not included (0).

Species	Tribe	Parasitology (N)	MHC (N)	Muschick (1/0)	Remarks
<i>Trematochromis benthicola</i>	Cyphotilapiini	0	7	1	
<i>Cyphotilapia frontosa</i>	Cyphotilapiini	0	16	1	
<i>Cyprichromis leptosoma</i>	Cyprichromini	0	11	1	
<i>Aulonocranus dewindti</i>	Ectodini	18	7	1	
<i>Callochromis macrops</i>	Ectodini	10	16	1	
<i>Cyathopharynx furcifer</i>	Ectodini	14	0	1	no genetic data
<i>Grammatotria lemairii</i>	Ectodini	0	15	1	
<i>Ophthalmotilapia ventralis</i>	Ectodini	14	16	1	
<i>Xenotilapia spiloptera</i>	Ectodini	10	16	1	
<i>Eretmodus cyanostictus</i>	Eretmodini	11	0	1	quality MHC data too low
<i>Astatotilapia burtoni</i>	Tropheini	10	8	1	parasite data incomplete; (no Gyrodactylus or fin cyst data)
<i>Ctenochromis horei</i>	Tropheini	10	15	1	
<i>Gnathochromis pfefferi</i>	Tropheini	10	0	1	quality MHC data too low
<i>Lobochilotes labiatus</i>	Tropheini	11	16	1	
<i>Simochromis diagramma</i>	Tropheini	10	0	1	no genetic data
<i>Tropheus moorii</i>	Tropheini	10	14	1	
<i>Altolamprologus compressiceps</i>	Lamprologini	11	0	1	quality MHC data too low
<i>Julidochromis ornatus</i>	Lamprologini	10	0	1	quality MHC data too low
<i>Lamprologus callipterus</i>	Lamprologini	10	14	1	
<i>Lepidiolamprologus elongatus</i>	Lamprologini	12	16	1	
<i>Neolamprologus modestus</i>	Lamprologini	10	7	1	
<i>Neolamprologus prochilus</i>	Lamprologini	0	5	1	
<i>Neolamprologus pulcher</i>	Lamprologini	10	13	1	
<i>Neolamprologus tetracanthus</i>	Lamprologini	11	8	1	
<i>Telmatochromis dhonti</i>	Lamprologini	12	14	1	no neutral genetic data
<i>Variabilichromis moorii</i>	Lamprologini	7	14	1	
<i>Gnathochromis permaxillaris</i>	Limnochromi ni	0	16	1	
<i>Limnochromis abeelei</i>	Limnochromi ni	0	7	1	
<i>Oreochromis tanganyicae</i>	Oreochromini	0	7	1	
<i>Haplotaxodon microlepis</i>	Perrissodini	10	12	1	parasite data incomplete; (no Gyrodactylus or fin cyst data)
<i>Perissodus microlepis</i>	Perrissodini	10	14	1	
<i>Trematocara nigrifrons</i>	Trematocarini	0	12	1	

Supplementary Table 2. Spearman rank correlations across cichlid species (N = 23) between infection levels of various parasite groups and morphology, trophic ecology and isotope signatures. Prevalence (A) and mean abundance (B) vs. principal components for body shape (Body1 and Body2), lower pharyngeal jaw shape (LPJ1 and LPJ2), stable isotope signatures ($\delta^{13}C$ and $\delta^{15}N$), proportional stomach and gut content (Prey1 and Prey2), and various proportional food items (m: molluscs; a: arthropods; c: crustaceans; fe: fish eggs; fs: fish scales). Correlations in bold are significant ($P < 0.05$).

(A)	Body1	Body2	LPJ 1	LPJ2	$\delta^{13}c$	$\delta^{15}n$	Prey1	Prey2	sand	aufwuchs	plants	m	a	c	fish	fe	fs
Acanthocephala	-0.3	-0.05	0.45	-0.09	0.39	-0.39	-0.23	-0.1	0.41	0.44	0.26	0.27	-0.01	-0.35	0	0.05	-0.27
Nematoda	0.1	-0.35	-0.16	0.24	-0.23	0.34	-0.04	-0.02	-0.31	0.07	-0.03	-0.4	-0.04	0.07	-0.17	-0.36	0.02
<i>Urogyrus</i> sp.	-0.24	-0.14	0.2	0.09	0.04	0.05	0.15	0.15	0.02	0.53	-0.2	0.19	0.05	0.32	0.1	0.02	0.01
<i>Enterogyrus</i> sp.	0.11	0.36	-0.42	0	-0.1	0.14	0.36	0.13	-0.29	-0.32	-0.28	0.09	0.2	0.23	0.45	0.3	0.02
Digenea	0.38	-0.28	0.13	0	-0.07	-0.05	-0.17	0.2	0.03	-0.22	0.06	0.23	-0.31	-0.27	-0.25	-0.01	0.13
Gill cysts	0.13	-0.13	0.11	0.01	0.15	-0.06	-0.21	-0.12	-0.09	-0.41	0.17	-0.07	0.03	0.11	-0.46	-0.2	-0.1
Fin cysts	0.07	0.45	0.07	-0.23	0.13	-0.32	-0.11	-0.11	-0.05	-0.02	0.15	0.17	0.1	-0.04	-0.35	-0.1	0.4
<i>Gyrodactylus</i> sp.	-0.23	0.15	-0.17	0.07	-0.32	0.08	0.32	-0.25	0	0.17	-0.11	0.1	0.31	0.03	0.38	0.02	0
<i>Cichlidogyrus</i> sp.	-0.09	-0.48	0.12	0.33	-0.11	0.11	0.15	0.29	0.36	0.14	-0.21	0.37	-0.04	0.3	-0.02	0.35	-0.22
<i>Ergasilus</i> sp.	-0.33	0.2	0.18	-0.03	0.19	-0.11	0.28	-0.11	-0.02	0.12	-0.13	0.32	0.39	0.15	0.08	0.03	-0.09
(B)	Body1	Body2	LPJ 1	LPJ2	$\delta^{13}c$	$\delta^{15}n$	Prey1	Prey2	sand	aufwuchs	plants	m	a	c	fish	fe	fs
Acanthocephala	-0.37	-0.25	0.46	0.03	0.32	-0.2	-0.22	-0.16	0.22	0.49	0.28	0.14	-0.01	-0.28	-0.01	0	-0.36
Nematoda	0.09	-0.36	-0.14	0.24	-0.22	0.35	-0.05	-0.02	-0.3	0.1	-0.02	-0.39	-0.04	0.08	-0.19	-0.36	-0.01
<i>Urogyrus</i> sp.	-0.23	-0.14	0.19	0.11	0.02	0.05	0.16	0.16	0.05	0.52	-0.21	0.22	0.05	0.3	0.1	0.02	0.02
<i>Enterogyrus</i> sp.	0.06	0.38	-0.44	0.05	-0.12	0.17	0.38	0.09	-0.29	-0.33	-0.28	0.1	0.22	0.19	0.48	0.29	-0.02
Digenea	0.37	-0.26	0.13	-0.02	-0.05	-0.05	-0.16	0.19	0.01	-0.21	0.07	0.25	-0.29	-0.26	-0.26	-0.01	0.16
Gill cysts	0.19	-0.06	0.03	0.05	0.06	-0.1	-0.15	-0.06	0.01	-0.37	0.11	0.06	0.05	0.1	-0.46	-0.14	0.02
Fin cysts	0.11	0.42	0.05	-0.21	0.1	-0.31	-0.09	-0.06	-0.03	-0.01	0.13	0.22	0.1	-0.03	-0.34	-0.12	0.42
<i>Gyrodactylus</i> sp.	-0.16	0.14	-0.17	0.01	-0.32	0.05	0.27	-0.23	0.03	0.19	-0.09	0.11	0.29	0.02	0.33	0	0.03
<i>Cichlidogyrus</i> sp.	-0.16	-0.58	0.17	0.41	-0.16	0.02	0.11	0.25	0.34	0.25	-0.15	0.27	-0.04	0.4	0.04	0.33	-0.29
<i>Ergasilus</i> sp.	-0.33	0.12	0.09	0.1	0.12	-0.04	0.44	-0.08	-0.01	0.11	-0.28	0.3	0.48	0.29	0.12	0.12	-0.08

Supplementary Table 3. Spearman rank correlations across cichlid species (N = 26) between dimensions of MHC divergence (MHC dimension 1 and MHC dimension 2) and morphology, trophic ecology and isotope signatures. MHC divergence at the amino acid level (A) and exon 2 level (B) vs. principal components for body shape (Body1 and Body2), lower pharyngeal jaw shape (LPJ1 and LPJ2), stable isotope signatures ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$), proportional stomach and gut content (Prey1 and Prey2), and various proportional food items (m: molluscs; a: arthropods; c: crustaceans; fe: fish eggs; fs: fish scales). Correlations in bold are significant ($P < 0.05$).

(A)	Body 1	Body2	LPJ 1	LPJ2	$\delta^{13}\text{c}$	$\delta^{15}\text{n}$	Prey1	Prey2	sand	aufwuch s	plants	m	a	c	fish	fe	fs
MHC dimensi on 1	-0.14	0.22	-0.18	-0.07	-0.07	0.12	0.31	-0.15	0.17	0.02	-0.21	0.27	0.32	0.05	-0.19	-0.28	-0.03
MHC dimensi on 2	0.14	0.04	0.09	-0.19	0.31	0.14	-0.02	-0.16	-0.43	-0.04	0.07	-0.39	0.16	0.02	-0.3	-0.18	0.11
(B)	Body 1	Body2	LPJ 1	LPJ2	d13c	d15n	Prey1	Prey2	sand	aufwuch s	plants	m	a	c	fish	fe	fs
MHC dimensi on 1	-0.18	0.11	-0.04	0.04	-0.12	0.02	0.29	-0.13	0.3	0.02	-0.2	0.5	0.19	0.06	-0.03	-0.12	-0.05
MHC dimensi on 2	-0.06	0.11	-0.04	-0.02	0.08	0.29	0.06	-0.03	-0.25	-0.15	-0.05	-0.16	0.16	0.06	-0.29	-0.47	0.07

Supplementary Table 4. Spearman rank correlations across cichlid species (N = 17) between dimensions of MHC divergence (MHC dimension 1 and MHC dimension 2) and infection levels. MHC divergence at the amino acid level vs. prevalence (A) and mean abundance (B), and MHC divergence at the exon 2 level vs. prevalence (C) and mean abundance (D). Correlations in bold are significant (P < 0.05).

(A)	Acanthocephala	Nematoda	<i>Urogyrus</i> sp.	<i>Enterogyrus</i> sp.	Digenea	Gill cysts	Fin cysts	<i>Gyrodactylus</i> sp.	<i>Cichlidogyrus</i> sp.	<i>Ergasilus</i> sp.
MHC dimension 1	0.31	0.09	0.06	-0.35	0.09	0.32	0.23	-0.21	0.22	0.34
MHC dimension 2	-0.18	0.73	0.05	-0.13	-0.27	0.44	0.22	-0.34	0.07	0.14
(B)	Acanthocephala	Nematoda	<i>Urogyrus</i> sp.	<i>Enterogyrus</i> sp.	Digenea	Gill cysts	Fin cysts	<i>Gyrodactylus</i> sp.	<i>Cichlidogyrus</i> sp.	<i>Ergasilus</i> sp.
MHC dimension 1	0.25	0.08	0.11	-0.37	0.12	0.38	0.31	-0.21	0.12	0.42
MHC dimension 2	0.08	0.75	-0.01	-0.15	-0.27	0.36	0.16	-0.34	0.07	0.17
(C)	Acanthocephala	Nematoda	<i>Urogyrus</i> sp.	<i>Enterogyrus</i> sp.	Digenea	Gill cysts	Fin cysts	<i>Gyrodactylus</i> sp.	<i>Cichlidogyrus</i> sp.	<i>Ergasilus</i> sp.
MHC dimension 1	0.51	-0.34	0.01	-0.30	0.20	0.10	0.19	0.07	0.28	0.35
MHC dimension 2	-0.29	0.71	-0.07	-0.29	-0.10	0.55	0.29	-0.50	-0.03	0.01
(D)	Acanthocephala	Nematoda	<i>Urogyrus</i> sp.	<i>Enterogyrus</i> sp.	Digenea	Gill cysts	Fin cysts	<i>Gyrodactylus</i> sp.	<i>Cichlidogyrus</i> sp.	<i>Ergasilus</i> sp.
MHC dimension 1	0.34	-0.36	0.15	-0.32	0.23	0.21	0.28	0.067	0.17	0.43
MHC dimension 2	-0.11	0.71	-0.10	-0.30	-0.10	0.49	0.23	-0.50	-0.01	0.04

Supplementary Table 5. Prevalence of parasites in 23 species of Lake Tanganyika cichlids, collected along the Zambian shore of Lake Tanganyika in 2011-2013.

Species	tribe	Acanthocephala	Nematoda	Urogyrus sp.	Enterogyrus sp.	Digenea	Gill cysts	Fin cysts	Gyrodactylus sp.	Cichlidogyrus sp.	Ergasilus sp.
<i>Altalamprologus compressiceps</i>	Lamprologini	0.000	0.000	0.000	0.200	0.000	0.000	0.000	0.200	0.455	1.000
<i>Astatotilapia burtoni</i>	Tropheini	0.500	0.600	0.000	0.000	0.000	0.000			0.800	0.700
<i>Aulonocranus dewindti</i>	Ectodini	0.182	0.909	0.000	0.000	0.000	0.176	0.000	0.000	0.706	0.647
<i>Callochromis macrops</i>	Ectodini	0.600	0.000	0.000	0.000	0.400	0.000	0.000	0.000	0.900	0.900
<i>Ctenochromis horei</i>	Tropheini	0.200	0.200	0.100	0.000	0.000	0.100	0.000	0.000	1.000	0.500
<i>Cyathopharynx furcifer</i>	Ectodini	0.200	0.200	0.000	0.000	0.800	0.000	0.000	0.000	0.929	0.714
<i>Eretmodus cyanostictus</i>	Eretmodini	0.600	0.000	0.000	0.000	0.000	0.182	0.100	0.000	0.091	1.000
<i>Gnathochromis pfefferi</i>	Tropheini	0.200	0.300	0.300	0.000	0.000	0.000	0.000	0.100	0.700	1.000
<i>Haplotaxodon microlepis</i>	Perissodini	0.100	0.400	0.000	0.000	0.000	0.000			0.111	0.000
<i>Julidochromis ornatus</i>	Lamprologini	0.900	0.100	0.000	0.000	0.100	0.000	0.000	0.125	0.200	0.600
<i>Lamprologus callipterus</i>	Lamprologini	0.200	0.100	0.000	0.000	0.000	0.100	0.100	0.000	1.000	0.600
<i>Lepidolamprologus elongatus</i>	Lamprologini	0.000	0.000	0.000	0.300	0.300	0.000	0.000	0.000	0.500	0.500
<i>Lobochilotes labiatus</i>	Tropheini	0.800	0.000	0.200	0.000	0.000	0.000	0.000	0.200	1.000	1.000
<i>Neolamprologus modestus</i>	Lamprologini	0.300	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.900	1.000
<i>Neolamprologus pulcher</i>	Lamprologini	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.100	0.400	0.000
<i>Neolamprologus tetracanthus</i>	Lamprologini	0.111	0.000	0.000	0.111	0.000	0.000	0.000	0.000	0.636	0.455
<i>Ophthalmotilapia ventralis</i>	Ectodini	0.300	0.000	0.000	0.000	0.600	0.143	0.000	0.000	0.786	0.357
<i>Perissodus microlepis</i>	Perissodini	0.000	0.250	0.000	0.000	0.500	0.100	0.000	0.000	0.700	0.500
<i>Simochromis diagramma</i>	Tropheini	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.400	0.300
<i>Telmatochromis dhonti</i>	Lamprologini	0.100	0.000	0.000	0.300	0.100	0.083	0.100	0.000	0.250	1.000
<i>Tropheus moorii</i>	Tropheini	0.600	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.600	0.300
<i>Variabilichromis moorii</i>	Lamprologini	0.000	0.429	0.143	0.000	0.000	0.000	0.143	0.000	0.000	1.000
<i>Xenotilapia spiloptera</i>	Ectodini	0.600	0.000	0.100	0.000	0.500	0.100	0.100	0.000	0.700	0.500

Supplementary Table 6. Mean abundance of parasites in 23 species of Lake Tanganyika cichlids, collected along the Zambian shore of Lake Tanganyika in 2011-2013

Species	tribe	Acanthocephala	Nematoda	Urogyrus sp.	Enterogyrus sp.	Digenea	Gill cysts	Fin cysts	Gyrodactylus sp.	Cichlidogyrus sp.	Ergasilus sp.
<i>Altolamprologus compressiceps</i>	Lamprologini	0.000	0.000	0.000	0.200	0.000	0.000	0.000	0.200	0.455	1000
<i>Astatotilapia burtoni</i>	Tropheini	0.500	0.600	0.000	0.000	0.000	0.000			0.800	0.700
<i>Aulonocranus dewindti</i>	Ectodini	0.182	0.909	0.000	0.000	0.000	0.176	0.000	0.000	0.706	0.647
<i>Calochromis macrops</i>	Ectodini	0.600	0.000	0.000	0.000	0.400	0.000	0.000	0.000	0.900	0.900
<i>Ctenochromis horei</i>	Tropheini	0.200	0.200	0.100	0.000	0.000	0.100	0.000	0.000	1000	0.500
<i>Cyathopharynx furcifer</i>	Ectodini	0.200	0.200	0.000	0.000	0.800	0.000	0.000	0.000	0.929	0.714
<i>Eretmodus cyanostictus</i>	Eretmodini	0.600	0.000	0.000	0.000	0.000	0.182	0.100	0.000	0.091	1000
<i>Gnathochromis pfefferi</i>	Tropheini	0.200	0.300	0.300	0.000	0.000	0.000	0.000	0.100	0.700	1000
<i>Haplotaxodon microlepis</i>	Perissodini	0.100	0.400	0.000	0.000	0.000	0.000			0.111	0.000
<i>Julidochromis ornatus</i>	Lamprologini	0.900	0.100	0.000	0.000	0.100	0.000	0.000	0.125	0.200	0.600
<i>Lamprologus callipterus</i>	Lamprologini	0.200	0.100	0.000	0.000	0.000	0.100	0.100	0.000	1000	0.600
<i>Lepidolamprologus elongatus</i>	Lamprologini	0.000	0.000	0.000	0.300	0.300	0.000	0.000	0.000	0.500	0.500
<i>Lobochilotes labiatus</i>	Tropheini	0.800	0.000	0.200	0.000	0.000	0.000	0.000	0.200	1000	1000
<i>Neolamprologus modestus</i>	Lamprologini	0.300	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.900	1000
<i>Neolamprologus pulcher</i>	Lamprologini	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.100	0.400	0.000
<i>Neolamprologus tetracanthus</i>	Lamprologini	0.111	0.000	0.000	0.111	0.000	0.000	0.000	0.000	0.636	0.455
<i>Ophthalmotilapia ventralis</i>	Ectodini	0.300	0.000	0.000	0.000	0.600	0.143	0.000	0.000	0.786	0.357
<i>Perissodus microlepis</i>	Perissodini	0.000	0.250	0.000	0.000	0.500	0.100	0.000	0.000	0.700	0.500
<i>Simochromis diagramma</i>	Tropheini	1000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.400	0.300
<i>Telmatochromis dhonti</i>	Lamprologini	0.100	0.000	0.000	0.300	0.100	0.083	0.100	0.000	0.250	1000
<i>Tropheus moorii</i>	Tropheini	0.600	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.600	0.300
<i>Variabilichromis moorii</i>	Lamprologini	0.000	0.429	0.143	0.000	0.000	0.000	0.143	0.000	0.000	1000