Ecography

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Supplementary material

Appendix 1. Variables examined in study

Species	Invaded	Region	Location	Period	N	Years	TL	Hg	W_r
herring	0	S	Chandos Lake	historic	51	1977, 1985	35.8	0.19	71.1
	0	S	Chandos Lake	contemporary	23	2006	31.5	0.16	60.7
	1	S	Drag Lake	historic	21	1979	32.7	0.25	73.5
	1	S	Drag Lake	contemporary	32	2006	35.7	0.29	90.6
	0	S	Farrell (Farren) Lake	historic	15	1979	27.7	0.28	64.2
	0	S	Farrell (Farren) Lake	contemporary	30	2006	30.4	0.17	77.4
	0	S	Gillies Lake	historic	29	1979	24.9	0.17	79.8
	0	S	Gillies Lake	contemporary	28	2006	30.7	0.36	73.7
	1	S	Gull Lake	historic	8	1995	26.8	0.23	80.4
	1	S	Gull Lake	contemporary	30	2006	27.8	0.17	74.2
	1	S	Lake Joseph	historic	20	1988	30.7	0.13	81.1
	1	S	Lake Joseph	contemporary	47	1993, 2006	32.6	0.14	82.4
	1	S	Lake Rosseau	historic	19	1967	35.3	0.40	107.1
	1	S	Lake Rosseau	contemporary	50	1993, 2006	33.0	0.29	81.5
	1	S	Lake Simcoe	historic	84	1970, 1977, 1983, 1990	33.6	0.14	75.5
	1	S	Lake Simcoe	contemporary	30	2006	30.2	0.07	77.4
	0	S	Papineau Lake	historic	21	1983	28.9	0.24	70.2
	0	S	Papineau Lake	contemporary	38	2006	32.3	0.17	71.7
	1	S	Stony Lake	historic	12	1977	38.9	0.21	91.9
	1	S	Stony Lake	contemporary	30	2006	39.1	0.34	76.3
	0	S	Trout Lake	historic	111	1982, 1983, 1984	21.6	0.13	75.3
	0	S	Trout Lake	contemporary	29	2006	19.0	0.27	65.8
	1	S	Twelve Mile Lake	historic	11	1995	24.6	0.22	70.2
	1	S	Twelve Mile Lake	contemporary	18	2006	20.0	0.14	67.6
	1	S	Young Lake	historic	31	1995	24.0	0.29	70.9
	1	S	Young Lake	contemporary	35	2006	27.4	0.29	65.6
	1	NW	Lake Nipigon	historic	16	1976	25.4	0.11	97.1
	1	NW	Lake Nipigon	contemporary	45	1999, 2006	27.2	0.11	78.8
	1	NW	Lake Superior Black Bay	historic	9	1973	32.1	0.19	120.8
	1	NW	Lake Superior Black Bay	contemporary	20	2002	32.8	0.06	71.4
	1	NW	Lake Superior Michipicoten Island	historic	30	1973, 1978	32.6	0.31	87.8
	1	NW	Lake Superior Michipicoten Island	contemporary	20	1996	42.1	0.10	66.8

herring	0	NW	Separation Lake	historic	46	1974, 1975, 1976, 1985	33.1	0.37	115.9
	0	NW	Separation Lake	contemporary	7	2003	34.4	0.16	98.1
	1	NE	Lake Temagami	historic	9	1976	23.2	0.04	73.7
	1	NE	Lake Temagami	contemporary	30	2005	32.1	0.14	76.2
	0	NE	Net Lake	historic	13	1983	24.2	0.26	115.4
	0	NE	Net Lake	contemporary	32	2006	30.3	0.30	78.9
	1	NE	Red Cedar Lake	historic	19	1976, 1977	35.1	0.25	103.0
	1	NE	Red Cedar Lake	contemporary	30	2006	29.5	0.14	92.9
	0	NE	Round Lake	historic	12	1994	46.1	0.23	104.1
	0	NE	Round Lake	contemporary	20	2001	43.2	0.17	90.9
whitefish	1	S	Boshkung Lake	historic	25	2001	39.5	0.14	92.5
	1	S	Boshkung Lake	contemporary	45	2006	47.3	0.23	83.2
	1	S	Georgian Bay Cape Rich	historic	45	1981, 1982	46.7	0.07	82.4
	1	S	Georgian Bay Cape Rich	contemporary	119	1986, 1989, 1992, 2001, 2003	46.8	0.06	87.7
	0	S	Lake Clear	historic	20	1982	48.9	0.16	99.1
	0	S	Lake Clear	contemporary	25	1998, 2001	54.6	0.21	99.5
	1	S	Lake Huron Grand Bend	historic	37	1978, 1981	43.2	0.05	107.9
	1	S	Lake Huron Grand Bend	contemporary	88	1986, 1989, 1994, 2003	45.3	0.05	91.6
	1	S	Lake Joseph	historic	19	1976, 1988	59.8	0.10	90.2
	1	S	Lake Joseph	contemporary	28	1993, 2005, 2006	66.6	0.09	106.5
	1	S	Lake Ontario Bay of Quinte	historic	27	1982	49.8	0.07	98.9
	1	S	Lake Ontario Bay of Quinte	contemporary	50	1993, 1994, 2000	45.2	0.05	81.7
	0	S	Lake Opeongo	historic	40	1981, 1982	33.5	0.16	85.3
	0	S	Lake Opeongo	contemporary	50	2000, 2005	32.6	0.11	84.7
	1	S	Lake Simcoe	historic	102	1970, 1971, 1975, 1977, 1983, 1990	50.7	0.05	86.2
	1	S	Lake Simcoe	contemporary	113	1995, 1999, 2000, 2002, 2005	54.9	0.07	89.6
	1	S	Round Lake	historic	44	1978, 1982, 1998	55.4	0.31	83.6
	1	S	Round Lake	contemporary	22	2006	58.4	0.28	81.1
	0	S	Smoke Lake	historic	50	1976, 1981, 1982	32.1	0.13	86.1
	0	S	Smoke Lake	contemporary	46	2001, 2005	26.5	0.10	90.1
	1	S	Twelve Mile Lake	historic	21	2000, 2001	41.9	0.14	85.7
	1	S	Twelve Mile Lake	contemporary	42	2005, 2006	48.8	0.20	97.7
	0	NW	Abamasagi Lake	historic	19	1984	45.3	0.10	103.1
	0	NW	Abamasagi Lake	contemporary	13	2002	41.9	0.08	85.4
	0	NW	Big Trout Lake	historic	42	1988	46.8	0.06	88.2
	0	NW	Big Trout Lake	contemporary	26	1999, 2000	48.7	0.10	84.0
	0	NW	Dogtooth Lake	historic	28	1985, 1993	42.8	0.09	97.0
	0	NW	Dogtooth Lake	contemporary	30	1998, 2003	40.4	0.09	81.7
	0	NW	Eagle Lake	historic	93	1975, 1982, 1985	43.7	0.08	119.4

whitefish	0	NW	Eagle Lake	contemporary	17	2001	44.3	0.11	89.8
	0	NW	Favel Lake	historic	50	1975	38.6	0.17	126.1
	0	NW	Favel Lake	contemporary	11	1999	44.9	0.16	88.5
	0	NW	Hawley Lake	historic	15	1978	50.7	0.15	121.2
	0	NW	Hawley Lake	contemporary	20	2001	51.5	0.15	101.9
	0	NW	Kenogamisis Lake	historic	50	1986, 1987	46.4	0.12	105.2
	0	NW	Kenogamisis Lake	contemporary	19	1997	31.6	0.12	95.3
	1	NW	Lake Nipigon	historic	25	1976, 1988	49.6	0.12	105.5
	1	NW	Lake Nipigon	contemporary	30	2006	41.7	0.08	90.4
	0	NW	Lake of the Woods Whitefish Bay	historic	20	1986	42.9	0.05	95.3
	0	NW	Lake of the Woods Whitefish Bay	contemporary	30	2005	42.3	0.06	90.4
	1	NW	Lake Superior Whitefish Bay	historic	19	1973, 1975	47.4	0.12	102.9
	1	NW	Lake Superior Whitefish Bay	contemporary	183	1987, 1992, 1993, 1997, 2000, 2001, 2002, 2003, 2004	48.0	0.07	83.9
	0	NW	Long Lake	historic	10	1984	42.2	0.33	139.4
	0	NW	Long Lake	contemporary	17	2002	40.7	0.12	86.0
	0	NW	Sandybeach Lake	historic	10	1982	47.2	0.09	95.0
	0	NW	Sandybeach Lake	contemporary	12	2000	49.7	0.13	95.9
	0	NW	Separation Lake	historic	315	1974, 1975, 1976, 1979, 1981, 1982, 1983, 1984, 1985, 1987, 1988, 1989, 1990, 1991, 1993, 1995	44.5	0.28	122.8
	0	NW	Separation Lake	contemporary	32	1997, 2000, 2003	43.3	0.17	102.9
	0	NW	Wabigoon Lake	historic	13	1976, 1990	43.8	0.05	123.2
	0	NW	Wabigoon Lake	contemporary	17	2001	48.8	0.06	107.6
	0	NE	Lake Abitibi	historic	12	1982	43.1	0.20	127.7
	0	NE	Lake Abitibi	contemporary	20	2001	39.4	0.15	123.2
	1	NE	Lake Temagami	historic	11	1976	41.3	0.04	62.8
	1	NE	Lake Temagami	contemporary	30	2005	36.0	0.08	89.2
	0	NE	Lake Wakami	historic	35	1979, 1992	42.7	0.07	107.2
	0	NE	Lake Wakami	contemporary	32	1998, 2001	46.4	0.07	101.7
	0	NE	Larder Lake	historic	10	1976	37.8	0.16	91.0
	0	NE	Larder Lake	contemporary	21	1997	37.5	0.18	84.4
	0	NE	Opeepeesway Lake	historic	15	1980	41.4	0.20	86.7
	0	NE	Opeepeesway Lake	contemporary	20	1998	43.4	0.29	108.2

Species invasion codes are 0 = uninvaded, 1 = invaded; regions are south (S), northwest (NW) and northeast (NE), as defined in text. N = number of observations used in estimation of mean values for each time period (contemporary or historic, as defined in text). Years = years of data included in estimation of historic or contemporary means; TL = mean total length of fish (cm); Hg = mean mercury concentration of fish (μg g^{-1} wet weight); W_r = mean relative weight of fish, estimated from species-specific standard weight (W_s) equations as described in text and expressed as a percentage of W_s.

Appendix 2. Application of a multivariate approach to determine effects of *Bythotrephes* invasion and geography on coregonid [Hg]

Following methods described in Somers and Jackson (1993), we collected eight univariate summary statistics, describing the mean, standard deviation (SD), minimum and maximum for fish [Hg] and total length for LW and LH, within historic and contemporary time periods in each population. Regressions of $\log_{10}$[Hg] against fish total length for each species were used to provide bivariate summary statistics (slope, intercept, R^2). These 11 univariate and bivariate summary statistics were range-standardized and a Euclidean distance matrix was created. The distance matrix was double-centred, and used to perform a principal coordinates analysis (PCoA). Ordination plots and Spearman correlations among Principal Coordinate axes were examined, as were correlations with the original variables. We then examined the effects of *Bythotrephes* invasion on the paired differences among the 11 summary statistics and principal component scores on the first 5 axes using multivariate analyses of variance (MANOVAs), with INVASION as the factor of interest (invaded, reference). MANOVAs were also performed to determine effects of geographical region (northwest, northeast, southern). Distance measures and ordinations were estimated using NT-SYSpc 2.02, and MANOVAs were carried out using the car package in R, employing type III sums of squares as described in the methods section of the text.

A principal coordinates analysis (PCoA) on the 11 summary statistics explained 96.3% of the variation in LH fish size and Hg on the first five PCoA axes; similarly, 95.6% of the variation in lake whitefish size and Hg was explained on the first five PCoA axes. Spearman correlation matrices among variables revealed only weak associations between mean length and [Hg] for LH (r= 0.171) and LW (r=–0.02; Table S1). Furthermore, axes with which Hg was strongly correlated were not also strongly correlated with fish length, and vice versa for both species of coregonids. Statistics regarding fish [Hg] were strongly correlated with the first axis for both species, representing 34% percent of the total variation for both LH and LW. Statistics regarding length were most strongly correlated with the 3rd axis for LH and 4th axis for LW, representing only 18% and 14% percent of the total variation respectively, approximately ½ that captured by the first axes. This suggested that patterns in mean fish [Hg] were not strongly influenced by fish size in these populations, and that conclusions from this multivariate approach would not provide additional insights compared with more straightforward examinations of patterns in mean Hg and length alone.

MANOVA on the paired distances (contemporary minus historic) among the 11 univariate and bivariate summary statistics for LH showed no significant effect of *Bythotrephes* invasion (all measures of significance, p= 0.16) or region (Roy's greatest root= 1.81, p= 0.28; all other measures of multivariate significance reported higher p-values). MANOVA on paired differences among the fist five PCoA axes revealed non-significant effects of invasion (all, p= 0.057), and region (Roy's greatest root= 0.91, p= 0.059; all others reported higher p-values). MANOVA on paired differences among univariate and bivariate summary statistics for LW showed no significant effect of *Bythotrephes* invasion (all, p= 0.31) or region (Roy's greatest root= 0.84, p= 0.26, all others reported higher p-values). MANOVA on paired differences among the fist five PCoA axes also revealed no significant effects of invasion (all, p= 0.46) or region (Roy's greatest root= 0.4, p= 0.13, all others reported higher p-values).

Table S1. Spearman correlation matrix among univariate and bivariate summary statistics of fish [Hg], length and first five axes of principal coordinates analysis.

Species	Statistic	Hg (mean)	Length (mean)	Slope	Intercept	R^2	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Lake herring											
Coregonus artedi	slope	0.221	–0.045	–	–0.916	0.759	0.715	0.566	–0.125	0.281	0.150
	intercept	0.050	–0.079	–0.916	–	–0.761	–0.534	–0.726	–0.088	–0.311	–0.188
	R^2	0.007	–0.057	0.759	–0.761	–	0.595	0.763	0.024	0.046	–0.331
	length (mean)	0.171	–	–0.045	–0.079	–0.057	0.164	–0.211	0.879	0.262	0.063
	length (SD)	–0.042	0.400	–0.069	–0.012	0.278	0.233	0.170	0.657	–0.602	–0.090
	length (min)	0.091	0.542	–0.039	–0.028	–0.180	–0.123	–0.282	0.306	0.868	–0.070
	length (max)	0.080	0.845	–0.082	–0.079	0.050	0.206	–0.083	0.935	–0.126	0.059
	Hg (mean)	–	0.171	0.221	0.050	0.007	0.724	–0.553	–0.130	0.053	–0.081
	Hg (SD)	0.831	0.197	0.460	–0.224	0.277	0.895	–0.243	0.026	–0.154	0.130
	Hg (min)	0.631	–0.036	0.023	0.192	–0.085	0.268	–0.494	–0.378	0.440	–0.435
	Hg (max	0.918	0.140	0.385	–0.128	0.139	0.833	–0.403	–0.110	–0.020	0.066
Lake whitefish											
Coregonus clupeaformis	slope	0.127	0.090	–	–0.799	0.571	–0.044	0.092	–0.872	0.342	0.152
	intercept	0.407	–0.298	–0.799	–	–0.504	0.493	–0.187	0.687	0.062	–0.178
	R^2	–0.067	–0.122	0.571	–0.504	–	–0.393	–0.492	–0.559	0.360	–0.375
	length (mean)	–0.019	–	0.090	–0.298	–0.122	0.078	0.125	–0.384	–0.756	0.037
	length (SD)	–0.359	0.024	–0.259	0.040	0.369	–0.530	–0.802	0.142	–0.331	–0.093
	length (min)	0.266	0.483	0.260	–0.195	–0.204	0.443	0.636	–0.447	–0.196	–0.220
	length (max)	–0.316	0.659	–0.136	–0.184	0.100	–0.316	–0.360	–0.137	–0.800	–0.012
	Hg (mean)	–	–0.019	0.127	0.407	–0.067	0.889	–0.136	–0.251	0.374	–0.084
	Hg (SD)	0.718	0.194	0.339	0.039	0.041	0.620	–0.279	–0.445	0.094	0.342
	Hg (min)	0.826	–0.087	–0.029	0.467	–0.025	0.812	–0.111	–0.146	0.343	–0.404
	Hg (max	0.669	0.160	0.149	0.185	–0.074	0.617	–0.285	–0.258	0.027	0.365

Appendix 3. Decadal declines in lake herring abundance in the Great Lakes and Lake Simcoe

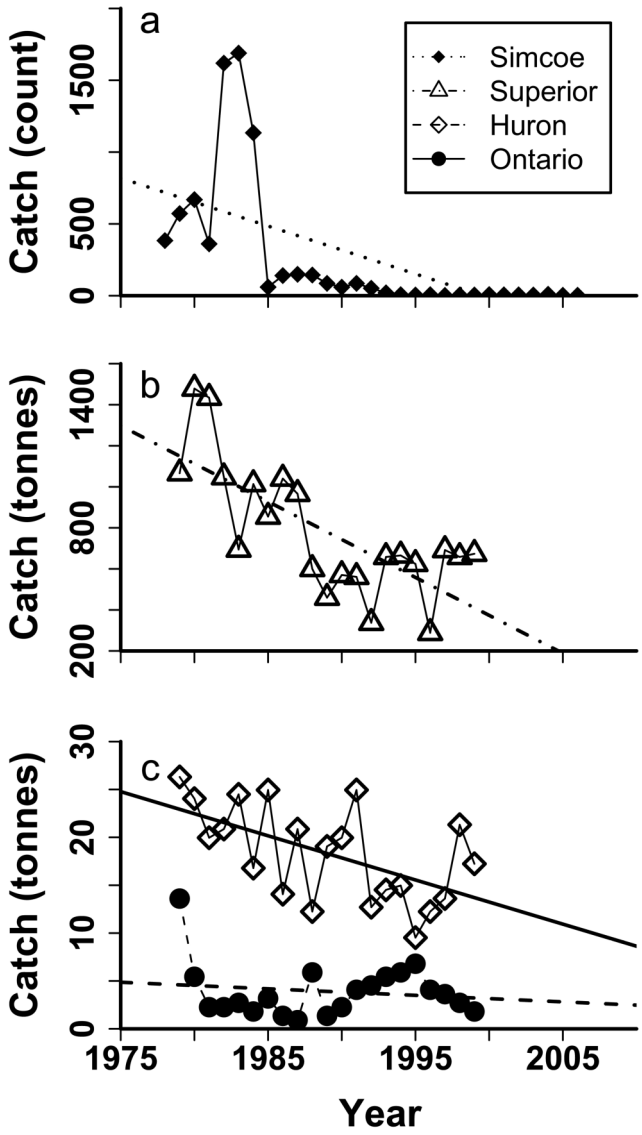

Figure S1. Reported catch of lake herring in Lake Simcoe (a) and the Laurentian Great Lakes (b, c), 1979-present. Lake Simcoe data are total catch from standardized fall trap-netting surveys, 1978–2006, courtesy Lake Simcoe Fisheries Assessment Unit, Sutton West, Ontario. Lake Superior, Huron and Ontario commercial catch data reported by the Great Lakes Fishery Commission (1979–2000) available online (Baldwin et al. 2002). Data for lakes Michigan and Erie were unavailable or insufficiently represented in reported catch, as herring are minor components of catch on these lakes. Note differences in scale and units among panels.

References

Baldwin, N. A. et al. 2002. Commercial fish production in the Great Lakes 1867–2000. – <http://www.glfc.org/databases/commercial/commerc.php>, accessed 22 February 2008].