An integrated approach to identifying ecosystem recovery targets: Application to the Bay of Quinte

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Supplement 1

This supplement provides a description of the input parameters for the Bay of Quinte (1994-2000) Lake Ontario food web (Table 1). We started with the post-dreissenid model developed by Koops et al. (2006). Here we provide a synopsis of the initial parameter values derived by Koops et al. (2006) and our modifications.

Original Model

Direct estimates of biomass, averaged across years and stations, were used for all groups. For Cormorants, Production: Biomass (P/B) and Consumption: Biomass (Q/B), ratios were estimated using values from Wesloh and Casselman (1992). Biomass estimates were summed based on functional groupings for Planktivores, Invertivores, Piscivores and Panfish. Biomass was split into life history stages for: 1) Walleye, 2) Yellow Perch, 3) White Perch, and 4) Panfish. Each multi-stanza group required additional estimates of growth rate (*K* from the von Bertalanffy growth equation) and the ratio of weight-at-maturity to asymptotic weight. Maximum length (L_∞) and *K* were estimated for each multi-stanza group by fitting a von Bertalanffy growth equation and minimizing the sum-of-squares difference between observed length-at-age (using mean total length-at-age for ages with available data) and the expected length-at-age (L_a) as estimated by the von Bertalanffy growth equation:

$$L_a = L_\infty\left(1 - e^{-K(t-t_0)}\right)$$

For all von Bertalanffy fits, *t* was equal to age and t_o was assumed to be equal to zero. P/B for Walleye was estimated from an allometric equation described by Randall and Minns (2000):

$$P/B_w = (2.64W_{mat}^{-0.35})$$

where W_{mat} is the average weight at maturity. W_{mat} was estimated separately for both male and female Walleye where age of maturity was assumed to be age-3 for males and age-4 for females (Stewart et al. 1999; Bowlby and Hoyle 2002) and these values were averaged across station-years to provide an overall P/B value for Walleye. These steps were repeated for all the remaining fish species, except for Gizzard Shad which had its P/B estimate, derived from longevity (T_{max}) from an allometric equation described by Randall and Minns (2000):

$$P/B_z = (4.22T_{max}^{-0.982}).$$

Similar steps were used for all the remaining fish species and age classes. Q/B ratios for Walleye and White Perch were derived from literature (Hurley 1986; Hurley and Minns 1986; and Hurley 1992). A simple modification of Ney's (1990) consumption equation:

$$\frac{Q}{B} = 2\left(\frac{P}{B}\right) + 3$$

where P = production, and B = biomass was used to estimate Q/B from estimates of P/B for the remaining fish species. P/B ratios for benthic invertebrates were derived from literature: 1) Other Benthos (no insects) (Johannsson et al. 2000), 2) Insects (McCullogh et al 1979 for Caddisflies, Kruger and Waters 1983 for Dragonfiles, Dermott et al. 1977 for Chaoborus, Lindegaard 1994 for Leeches, Parkyn et al 2002 for Crayfish), 3) Oligochaetes (Johnson and Brinkhurst 1971), 4) Chironomids (Johnson and Brinkhurst 1971), 5) Amphiopods (Johannsson et al. 2000), 6) Isopods (Johannsson et al. 2000), 7) Gastropods (Tudorancea et al. 1979), 8) Bivalves (Hamill et al. 1979), 9) Dreissinids (Chase and Bailey 1999). Q/B ratios for benthic invertebrates were derived from literature: 1) Other Benthos (no insects) (Nilsson 1974), 2) Insects (McCullogh et al 1979 for Caddisflies and Dragonfiles, Dermott et al. 1977 for Chaoborus, Lindegaard 1994 for Leeches, Gutierrez and Yurrita 2001 for Crayfish), 3) Oligochaetes (Lindegaard 1994), 4) Chironomids (Lindegaard 1994), 5) Amphiopods (Nilsson 1974), 6) Isopods (Nilsson 1974), 7) Gastropods (Lindegaard 1994), 8) Bivalves (Lindegaard 1994), 9) Dreissinids (Hamburger 1990). The P/B and Q/P ratios for Cercopagis were estimated from Laxson et al. (2003) where production was estimated directly. For the remaining zooplankton groups P/B ratios were derived from Stockwell and Johannsson (1997) and Q/P ratios were derived from Peters and Downing (1984). P/B ratios for Macrophytes, Epiphytes, and Periphytes were estimated from Leisti (2012 in press). Bulk phytoplankton production was measured directly using methods described by Millard et al. (1996) which served as input for P/B ratio estimates and these values were also compared to size-fractionated primary production reported by Munawar et al. (2010). Direct estimates for detritus (pelagic and sedimented) and dissolved organic carbon (DOC) were made.

Modified Model

The Koops et al. (2006) model was modified to allow evaluation of consistency among seven RAP targets. Specifically, some benthic groups were sub-divided to separate pollution sensitive and pollution tolerant species. Oligochaetes and chironomids were separated (originally a single group) and amphipods and isopods were separated (also originally a single group). Thus the model was modified from six benthic invertebrates groups to nine benthic groups.

Since the RAP target for phytoplankton referenced nuisance and eutrophic indicator species, the original single phytoplankton group was split into five groups. This was based on samples from composite mid-water column tows which had been enumerated to either species or genus levels in the laboratory using an inverted microscope at 600X or higher total magnification (see Nicholls et al. 2002 for details). These samples were grouped into five categories based on the U.S. EPA planktonic state indicators: 1) inedible, 2) microcystis, 3) anabena, 4) aphanixomenon, and 5) remaining edible (U.S. EPA).

Table 1. Input parameters for the Bay of Quinte Ecopath model. * groups that differ from the model developed by Koops et al. (2006).

Group name	**Biomass (t/km^2)**	**P/B**	**Q/ B (/year)**	**Unass.**	**Detr.import ($t/km^2/year$)**
Cormorants	0.0059	0.44	96.30	0.2	

Piscivores	0.2	0.41	4.90	0.2
Walleye (5+)	1.5	0.31	4.03	0.2
Walleye (4)	0.332	0.52	5.16	0.2
Walleye (3)	0.321	0.42	5.98	0.2
Walleye (2)	0.279	0.86	7.59	0.2
Walleye (1)	0.238	1.12	11.34	0.2
Walleye YOY	0.144	5.90	33.60	0.2
Smallmouth Bass	0.06	0.35	4.07	0.2
Alewife	0.65	1.20	6.75	0.2
Yellow Perch (1)	3.2	0.58	3.85	0.2
Yellow Perch YOY	0.464	7.00	19.29	0.2
White Perch (1+)	1.9	0.56	4.24	0.2
White Perch YOY	0.386	8.00	25.61	0.2
Panfish (1+)	1.2	0.44	3.73	0.2
Panfish YOY	0.476	8.91	25.84	0.2
Invertivores	3.3	0.35	2.87	0.2
Planktivores	0.12	1.65	7.76	0.2
Trout-perch	0.04	1.53	7.42	0.2
Freshwater Drum	0.51	0.25	4.08	0.2
Round Goby	0.025	1.51	5.16	0.2
Common Carp	0.33	0.11	3.45	0.2
Gizzard Shad	0.8	1.12	4.88	0.2
Other Benthos (no insects)	0.154	4.96	25.80	0.2
Insects	2.046	5.22	34.47	0.2
Oligochaetes*	2.715	10.21	63.88	0.2
Chironomids*	4.869	14.31	55.72	0.2

Amphiopods*	1.904	4.42	26.40	0.2	
Isopods*	0.782	5.18	36.33	0.2	
Gastropods	0.913	3.32	13.42	0.6	
Bivalves	0.27	4.05	23.40	0.6	
Dreissinids	225	1.33	6.83	0.6	
Cercopagis	0.013	26.52	217.04	0.2	
Predatory Cladocerans	0.027	39.73	91.66	0.2	
Copepods	0.85	46.67	125.40	0.4	
Rotifers	0.132	53.91	245.77	0.6	
Herbivorous Zooplankton	3.68	51.98	189.07	0.6	
Macrophytes	80.89	7.61	96.30		
Epiphytes	6.26	93.16			
Periphytes	2.1	20.22			
inedible*	0.15	219.99			
microcystis*	1.20	370.28			
anabena*	1.25	226.23			
aphanixomenon*	0.35	245.38			
remaining edible*	7.01	257.17			
Pelagic Detritus	22.67				1461
Sedimented Detritus	6.8				438
DOC	21.45				455

The diet matrix for the Bay of Quinte, Lake Ontario Ecopath model is presented below where the diet proportions are shown for each species. Age classes for some of the fishes are indicated in parentheses. Phytoplankton is broken down into five groups: 1) inedible, 2) microcystis, 3) anabena, 4) aphanixomenon, and 5) remaining edible. Diets for cormorants were based on Wesloh and Casselman (1992). The diets for fish were based on information from FishBase (http://www.fishbase.org/search.php) and Scott and Crossman (1998). For benthic invertebrates, the diets were based on several sources: 1) other benthos (Nilson, 1974), 2) insects (McCullogh et al., 1979; Lindegaard, 1994; Gutierrez and Yurrita, 2001), 3) oligochaetes and chironomids (Lindegaard, 1992), 4) amphiopods and isopods (Nilson, 1974), 5) gastropods and bivalves (Lindegaard 1992), and 6) dreissinids (Hamburger et al., 1990). For zooplankton, were also based on several sources: 1) cercopagis (Pichlová-Ptáčníková and Vanderploeg, 2009), 2) predatory cladocerans (Yurista and Schulz, 1995), 3) copepods (Sprules, 1984), 4) rotifers, and 5) herbivorous zooplankton (Sprules, 1984).

	Predator -group							
Prey-group	**Cormorants**	**Piscivores**	**Walleye (5+)**	**Walleye (4)**	**Walleye (3)**	**Walleye (2)**	**Walleye (1)**	**Walleye YOY**
Cormorants								
Piscivores	0.005	0.012	0.00099	0.007	0.006	0.005	0.005	0.001
Walleye (2)	0.027							
Walleye (1)	0.108	0.012	0.00099					
Walleye YOY		0.012	0.00099	0.028	0.025	0.019	0.038	0.035
Smallmouth Bass	0.007	0.005	0.0005	0.001	0.00099	0.00095	0.00091	0.00097
Alewife	0.007	0.058	0.01	0.01	0.01	0.01	0.01	0.011
Yellow Perch (1)	0.462	0.208	0.00099	0.233	0.22	0.211		
Yellow Perch YOY		0.117	0.00099	0.15	0.246	0.205	0.375	0.1
White Perch (1+)	0.009	0.058	0.00099	0.15	0.119	0.103		
White Perch (1+)		0.058	0.00099	0.15	0.119	0.205	0.335	0.1
Panfish (1+)	0.308	0.156	0.00099	0.015	0.015	0.01	0.01	0.011
Panfish YOY		0.081	0.00099					0.02
Invertivores	0.009	0.058	0.00099					0.03
Planktivores	0.02	0.012	0.00099	0.01	0.01	0.01	0.01	0.011
Trout-perch		0.011		0.001	0.001	0.001	0.001	
Freshwater Drum	0.016	0.012						
Round Goby	0.001	0.001	0.000099	0.002	0.001	0.001	0.001	0.001

Common Carp		0.012						
Gizzard Shad	0.02	0.058	0.01	0.091	0.075	0.063	0.059	0.057
Other Benthods (no insects)		0.004	0.003	0.006	0.005	0.006	0.005	0.004
Insects		0.054	0.046	0.085	0.071	0.074	0.072	0.053
Oligochaetes			0.007	0.022	0.027	0.027	0.021	0.041
Chironomids			0.012	0.039	0.048	0.049	0.038	0.073
Amphiopods								0.038
Isopods								0.016
Predatory Cladocerans								0.054
Copepods								0.171
Rotifers								
Herbivorous Zooplankton								0.171

	Predator -group							
Prey-group	**Smallmouth Bass**	**Alewife**	**Yellow Perch (1)**	**YOY Yellow Perch**	**White Perch (1+)**	**White Perch YOY**	**Panfish (1+)**	**Panfish YOY**
Walleye YOY	0.011	0.01	0.01		0.005		0.003	
Smallmouth Bass	0.001							
Alewife	0.05		0.01					
Yellow Perch (1)	0.101							
Yellow Perch YOY	0.164		0.01				0.003	
White Perch (1+)	0.055		0.01					
White Perch YOY	0.055		0.01				0.003	
Panfish (1+)	0.01		0.01					

Panfish YOY	0.055		0.01				0.003	
Invertivores	0.108		0.051					
Planktivores	0.01		0.001					
Trout-perch	0.011							
Round Goby	0.001		0.00052					
Gizzard Shad	0.011		0.01					
Other Benthods (no insects)	0.021		0.005		0.003		0.009	
Insects	0.282		0.071		0.039		0.115	
Oligochaetes	0.02	0.004	0.154	0.118	0.26	0.132	0.041	0.035
Chironomids	0.035	0.006	0.276	0.212	0.466	0.236	0.074	0.063
Amphiopods		0.007	0.076		0.073		0.194	
Isopods		0.003	0.031		0.03		0.08	
Gastropods			0.01				0.137	
Bivalves			0.01					
Dreissinids			0.107				0.189	
Cercopagis		0.01	0.01		0.01	0.01	0.01	0.011
Predatory Cladocerans		0.01	0.01	0.01	0.01	0.01	0.01	0.01
Copepods		0.31	0.053	0.11	0.052	0.244	0.022	0.44
Rotifers								
Herbivorous Zooplankton		0.64	0.053	0.55	0.052	0.368	0.107	0.44

	Predator -group								
Prey-group	**Panfish (1+)**	**Panfish YOY**	**Invertivores**	**Planktivores**	**Trout-perch**	**Freshwater Drum**	**Round Goby**	**Common Carp**	**Gizzard Shad**
Walleye (1)	0.003								
Smallmouth Bass			0.011			0.01			
Yellow Perch (1)	0.003								
White Perch (1+)	0.003								

Panfish (1+)	0.003								
Panfish YOY			0.01						
Invertivores						0.011			
Freshwater Drum			0.0005			0.001			
Common Carp						0.078			
Gizzard Shad	0.009		0.015		0.014	0.00077	0.0007	0.0007	
Other Benthods (no insects)	0.115		0.204		0.186	0.01	0.009	0.009	
Insects	0.041	0.035	0.158	0.107	0.143	0.04	0.036	0.036	
Oligochaetes	0.074	0.063	0.283	0.193	0.257	0.071	0.064	0.064	
Chironomids	0.194		0.203		0.284	0.079	0.071	0.071	
Amphiopods	0.08		0.083		0.116	0.032	0.029	0.029	
Isopods	0.137		0.011			0.111	0.08	0.1	
Gastropods			0.011			0.111	0.01	0.07	
Bivalves	0.189		0.011			0.444	0.6	0.2	
Dreissinids	0.01	0.011		0.01					
Cercopagis	0.01	0.01		0.1					0.053
Predatory Cladocerans	0.022	0.44		0.09			0.05		0.105
Copepods									
Rotifers	0.107	0.44		0.5			0.05		0.105
Herbivorous Zooplankton								0.3	
Macrophytes								0.3	
Epiphytes								0.1	0.105
Periphytes								0.01	0.105
inedible									0.009
microcystis									0.034
anabena									0.039
aphanixomenon									0.005
remaining edible									0.44
Sedimented								0.01	

Detritus

	Predator -group								
Prey-group	**Other Benthods (no insects)**	**Insects**	**Oligochaetes**	**Chironomids**	**Amphiopods**	**Isopods**	**Gastropods**	**Bivalves**	**Dreissinids**
Other Benthods (no insects)	0.03								
Insects	0.398								
Oligochaetes	0.165								
Chironomids	0.296								
Amphiopods	0.079				0.0275	0.0275	0.037		
Isopods	0.032				0.0275	0.0275	0.015		
Macrophytes					0.308	0.308	0.19		
Epiphytes							0.284		
Periphytes					0.208	0.208	0.284		
microcystis	0.000041	0.07	0.07	0.07				0.023	0.027
anabena	0.000046	0.078	0.078	0.078				0.026	0.031
aphanixomenon	0.0000085	0.014	0.014	0.014				0.005	0.006
remaining edible	0.00049	0.838	0.838	0.838				0.279	0.33
Pelagic Detritus									0.346
Sedimented Detritus					0.43	0.43	0.19	0.573	
DOC								0.093	0.26

	Predator -group				
Prey-group	**Cercopagis**	**Predatory Cladocerans**	**Copepods**	**Rotifers**	**Herbivorous Zooplankton**
Copepods	0.2	0.2	0.14		
Rotifers			0.047		
Herbivorous	0.8	0.8	0.279		

Zooplankton			
microcystis	0.037	0.031	0.033
anabena	0.042	0.035	0.037
aphanixomenon	0.008	0.006	0.007
remaining edible	0.448	0.372	0.397
Pelagic Detritus		0.556	0.526

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