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Supplementary Material
Modeling effects of nutrients and hypoxia on the Lake Erie's central basin foodweb

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SM1. The Ecopath with Ecosim Model (EwE)

EwE is a free ecological/ecosystem modeling software suite (https://ecopath.org/), and is designed for the construction, parameterization and analysis of mass-balance trophic models of aquatic and terrestrial ecosystems. EwE has been used widely including all five of the Laurentian Great Lakes, to study the impacts of natural and anthropogenic stressors on ecosystems (Colléter et al., 2015; Walters et al., 2008;Blukacz-Richards and Koops, 2012; Kao et al., 2014; Kao et al., 2016; Kitchell et al., 2000; Rutherford et al., 2021; Stewart and Sprules, 2011; Zhang et al., 2016).

Ecopath (the static mass-balanced portion of the package) has two governing equations:

$$B_i \cdot (\frac{P}{B})_i - \sum_{j=1}^{n} B_j \left(\frac{Q}{B}\right)_j DC_{ji} - \left(\frac{P}{B}\right)_i B_i(1 - EE_i) - Y_i - E_i - BA_i = 0 \qquad (1)$$

$$B_i (\frac{Q}{B})_i = B_i (\frac{P}{B})_i + R_i + u_i (\frac{Q}{B})_i \qquad (2)$$

where i or j is a model group, B is biomass (g m^{-2}), P/B is annual production-to-biomass ratio (yr^{-1}), Q/B is annual consumption-to-biomass ratio (yr^{-1}), DC_{ij} is diet fraction of group j in i, Y is annual fishery catch (g m^{-2}), E is net emigration (g m^{-2}), and BA is annual biomass accumulation (g m^{-2}), R is annual respiration (g m^{-2}), u is unassimilation rate. The summations estimate is the total predation by all predators j on the same group i. EE is the proportion of production that is utilized in the system, and is called ecotrophic efficiency. EE is often estimated as:

$$EE_i = \frac{Y_i + E_i + BA_i + \sum_{j=1}^{n} \quad B_j (\frac{Q}{B})_j DC_{ji}}{B_i (\frac{P}{B})_i} \qquad (3)$$

Ecopath was considered successfully constructed or balanced and ready for use in Ecosim (temporal dynamics) if all ecotrophic efficiencies were less than 1 and respiration of each model group was non-negative.

Ecosim temporally simulates the food web dynamics in response to changes in the driving (forcing) vark\iable (e.g., time series of nutrient concentration, fishery harvest, or dissolved oxygen as in this study). The Ecosim basic equation is expressed as:

$$\frac{dB_i}{dt} = g_i \sum_j \; Q_{ji} - \sum_k \; Q_{ik} - (M_i + F_i + E_i - I_i) B_i \qquad (4)$$

where dB_i/dt represents the biomass growth rate during the time interval dt of group i. g_i is the growth efficiency (production/consumption ratio), M_i is the non-predation natural mortality rate, F_i is fishing mortality rate, E_i is emigration rate, and I_i is immigration rate. The two summations estimate consumption rates with the first expressing the total consumption by group i, and the second expressing the total predation by all predators on the same group i. The consumption rates, Q, are calculated based on the 'forage arena' concept where prey are divided into vulnerable and invulnerable components (Ahrens et al., 2011; Walters et al., 1997). Parameter vulnerability defines the actual transfer rate between these two components. Higher vulnerability indicates more prey is available to predators, and vice versa.

SM2. Data, data sources and model calibration

This section provides a brief general description of the Ecopath with Ecosim model, and describes the data sources and how we derived the values for model parameters of group-specific biomass (B), production to biomass (P/B, yr^{-1}), consumption to biomass (Q/B, yr^{-1}), and diet compositions (DC) of the food web that are simulated in the central basin Lake Erie Ecopath model (Tables SM3.1- 4). We mainly used data from 1995-1998 to initiate the Ecopath.

Detritus biomass was estimated based on the concentration of particulate organic carbon measured in the central basin in 2002 (Upsdell 2005), 0.283 $g\ m^{-3}$. This value was multiplied by the average depth of the central basin (18 m), then by a factor of 2 to convert carbon to dry weight, then by 10 to get a wet biomass value of 127.5 $g\ m^{-2}$.

Phytoplankton biomass (B) was derived from the Lake Erie Plankton Abundance Study (LEPAS) database at the Ohio State University (Conroy et al. 2005). Phytoplankton biomass was the average areal biomass of all station samples in the central basin over the sampling seasons for year 1996. P/B values for algae were calculated from Munawar et al. (2008) as monthly biomass-weighted averages across the growing season.

Bacteria biomass (B) and P/B were estimated from Hwang and Heath (1997a). Bacteria Q/B values were estimated based on the P/Q ratio from Stewart and Sprules (2011).

Protozoa biomass (B) was calculated from Hwang and Heath (1997b) and Munawar et al. (2008). Protozoan P/B was calculated based on Lavrentyev et al. (2004), while Q/B was calculated based on gross growth efficiency reported by Straile (1997). Protozoan diet was from two studies (Vanderploeg 1994, Hwang and Heath 1997a).

Zooplankton biomass (B) was derived from the Lake Erie Plankton Abundance Study database at the Ohio State University (Conroy et al. 2005). P/B values were calculated based on published relationships between temperature and production (Shuter and Ing 1997, Stockwell and Johannsson 1997). Specifically, for non-predatory cladocerans, $P/B = 0.162 \cdot d^{-1}$ when temperature was >10 ˚C, and $0.042 \cdot d^{-1}$ when temperature was <10 ˚C (Stockwell and Johannsson 1997). For predatory cladocerans, P/B is a function of body weight and water temperature $log\ log\ \left(daily \frac{P}{B}\right) = -0.23\ log\ log\ \left(dry\ wt\ (\mu g)\right) - 0.73$ when mean seasonal temperature > 10 ˚C, and $log\ log\ \left(daily \frac{P}{B}\right) = -0.26\ log\ log\ \left(dry\ wt\ (\mu g)\right) - 1.36$ when mean seasonal temperature < 10 ˚C. For copepods and rotifers, P/B is calculated as $log\ log\ \left(median\ daily \frac{P}{B}\right) = A + 0.04336(median\ temperature\ (°C))$, where A = -1.844 for cyclopoids, -2.294 for calanoids, and -1.631 for rotifers (Shuter and Ing 1997). We used water temperature values provided from output of a 1-dimensional model of Lake Erie water temperature by Rucinski et al. (2010). Q/B values were calculated based on gross growth efficiency reported by Straile (1997). Diet for most zooplankton groups was obtained from Vanderploeg (1994), but for *Bythotrephes* spp was obtained from Vanderploeg et al. (1993).

Benthos biomass and production values were based on empirical data reported in Johannsson et al. (2000), except that biomass of dreissenid mussels was from Patterson et al. (2005). We divided P/B estimates by P/Q estimates (see below) to obtain Q/B values for most taxa. P/Q estimates for chironomids, sphaeriids, oligochaetes, and gastropods were reported by Lindegaard (1994); estimates for amphipods were obtained from Nilsson (1974); and estimates for mayflies, caddisflies and dragonflies were obtained from McCullogh et al. (1979). Q/B for dreissenids was obtained from Stewart and Sprules (2011). Diet was mainly detritus (Wetzel 2001). We assumed the dreissenid diet was generally proportional to algal and detritus biomass as the mussels are indiscriminate filter-feeders on most seston, except blue green algae. Dreissenid Mussels are known to selectively reject blue green algae (Vanderploeg et al. 2002), and blue green algae have higher buoyancy relative to other algae (Den Uyl et al. 2021). Thus, we set the fraction of blue-green algae in Dreissenid mussels' diet to be 0.01. We also included protozoa and rotifers in mussels' diet.

Fish:

Walleye biomass was taken from the Walleye Task Group (WTG) annual report (http://www.glfc.org/lakecom/lec/WTG.htm; Kevin Kayle, ODNR, personal communication). P/B estimates for Walleye larvae and YOY stages were calculated from survival rates (Rose et al. 1999); P/B values for other age classes of Walleye were obtained from the WTG 2000 annual report (http://www.glfc.org/lakecom/lec/WTG.htm). An estimate of Q/B for age 3+ Walleye was calculated from a bioenergetics model (Hartman and Margraf 1992). Walleye diet was estimated from older sources (Hartman and Margraf 1992, Cook et al. 1997), and then updated to include round goby (FTG 2001, Ann Marie Gorman, ODNR, personal communication , Johnson et al. 2005).

Yellow Perch biomass estimates were provided by the Yellow Perch Task Group (YPTG) annual report (http://www.glfc.org/lakecom/lec/YPTG.htm; Kevin Kayle, ODNR, personal communication). The P/B value for the YOY life stage was from Herendeen (1992). The P/B value for age 1 Yellow Perch was estimated based on the survival rate of YOY Yellow Perch abundance in the late fall (interagency trawl data from yellow perch task group, http://www.glfc.org/lakecom/lec/YPTG.htm) to the beginning of age 2 (abundance estimated using ADMB model, YPTG 2013, http://www.glfc.org/lakecom/lec/YPTG.htm). The P/B value for adults was available from the YPTG 1996 annual report. Q/B was calculated using a bioenergetics model (McDermot and Rose 2000). Yellow Perch diet was adopted from Cook et al. (1997) and modified with data from ODNR (Ann Marie Gorman, ODNR, personal communication).

White Bass biomass was calculated from Ohio DNR bottom trawl data from Ohio waters of Lake Erie (Ann Marie Gorman, ODNR, personal communication) assuming a catchability coefficient of 0.42 (Kao et al. 2014). White Bass P/B was adopted from Zhang et al. (2016). The Q/B value was calculated using a bioenergetics model (McDermot and Rose 2000). Diet composition was from Cook et al. (1997).

Unidentified fish in white bass stomachs comprised 30.4% in the diet, so we distributed this percentage among fish prey species (shiner, White Perch, Freshwater Drum, and Round Gobies) found in white bass diets by ODNR (Ann Marie Gorman, unpublished data) and other studies (Bur and Klarer 1991, Hartman 1998, Madenjian et al. 2000).

White Perch biomass was also calculated from the Ohio DNR bottom trawl data from Ohio waters of Lake Erie (Ann Marie Gorman, ODNR, personal communication) assuming a catchability coefficient of 0.42 (Kao et al. 2014). White perch P/B was adopted from Zhang et al. (2016). Q/B was calculated using a bioenergetics model (McDermot and Rose 2000). White Perch diet composition was based on two studies (Bur and Klarer 1991, Cook et al. 1997).

Gizzard Shad biomass was estimated from a time series of bottom trawl data obtained from the Lake Erie Forage Task Group for the central basin (Ann Marie Gorman, ODNR, personal communication). The catchability of Gizzard Shad in bottom trawls was estimated as the ratio of biomass estimated using hydroacoustic surveys and bottom trawl data from Lake Erie's central basin in the 2005 International Field Year study of Lake Erie (IFYLE). Hydroacoustic data were processed following the standard operating procedures for fisheries acoustic surveys in the Great Lakes (Parker-Stetter et al. 2009). The acoustic estimate of fish density was partitioned among fish species that were collected using mid-water trawls at the same time and same transects. Fish density was converted into wet biomass using length-weight regressions. We assumed this biomass estimate is the true water column biomass of Gizzard Shad. The ratio between the biomass estimated from the hydroacoustic and bottom trawl data of 2005 central basin is catchability. We used this catchability ratio to estimate the biomass of Gizzard Shad from bottom trawl data as an average of 1994-1997, the period of our Ecopath model. P/B was from Zhang et al. (2016). Q/B was calculated based on the experimental equation below (Palomares and Pauly 1998).

$$log\, log\, \left(\frac{Q}{B}\right) = 7.964 - 0.204 \cdot logW_{\infty} - 1.965 \cdot T' + 0.083 \cdot A + 0.532 \cdot h + 0.398 \cdot d$$

where W_{∞} is the asymptotic weight (g), T' is an expression for the mean annual temperature of the water body, expressed using $T' = \frac{1000}{T(℃)+273.15}$, A is the aspect ratio of the caudal fin, h is a dummy variable expressing food type (1 for herbivores, and 0 for detritivores and carnivores), and d is a dummy variable (1 for detritivores, and 0 for herbivores and carnivores). Shad diet composition was based on the study of Price (1963).

Rainbow Smelt biomass was estimated as for Gizzard Shad. The P/B value was estimated from Lantry and Stewart (1993). The Q/B value was based on gross conversion efficiency of 20.4% (Lantry and Stewart 1993). Smelt diet composition was from Pothoven et al. (2009).

Freshwater Drum biomass was calculated from Ohio DNR bottom trawl data from Ohio waters of Lake Erie (Ann Marie Gorman, ODNR, personal communication) assuming a catchability coefficient of 0.32 (Kao et al. 2014). The P/B value for freshwater drum was taken from Bur (1984). Freshwater drum Q/B was calculated the same way as for Gizzard Shad. Diet composition was from Cook et al. (1997).

Shiner biomass, and values for P/B and Q/B were estimated the same way as for Gizzard Shad. Shiner diet composition was taken from Pothoven et al. (2009)

Round Goby biomass was calculated from Ohio DNR bottom trawl data from Ohio waters of Lake Erie (Ann Marie Gorman, ODNR, personal communication). We assumed that catchability was 0.42 as for Trout-perch (Kao et al. 2014). Values for Round Goby P/B and Q/B were calculated from Johnson et al.

(2005). Goby diet composition was from two studies (Johnson et al. 2005, Lederer et al. 2008) and field surveys during the IFYLE 2005 study.

Lake Whitefish biomass was calculated from Ohio DNR bottom trawl data from Ohio waters of Lake Erie (Ann Marie Gorman, ODNR, personal communication) assuming a catchability of 0.32 as for Freshwater Drum (Kao et al. 2014). Lake Whitefish diet composition was taken from Cook et al. (1997) and unpublished ODNR diet data collected in 2005 (Ann Marie Gorman, ODNR, personal communication).

Rainbow Trout (Steelhead) biomass was calculated from a study on summer diets and population dynamics of Rainbow Trout in Lake Erie (Kayle 2007). P/B value was calculated from Kayle (2007), and Q/B was from Zhang et al. (2016). Rainbow Trout diet composition was taken from two studies (Cook et al. 1997, Kayle 2007).

Other fish group included small demersal and pelagic prey fish species, such as Alewife, sunfish, minnows, Trout-perch, darter, Log Perch, etc. Other-fish biomass was adjusted to make its ecotrophic efficiency around 0.8-0.9. Values for P/B, Q/B and diet composition for "other fish" were an average of those values for Gizzard Shad, shiner and Rainbow Smelt. We assumed the "other fish" group consumes benthos and zooplankton, and excluded their consumption of detritus and algae.

Nutrient time series were represented as nutrient concentration in the EwE model. For the central basin of Lake Erie, total phosphorus (TP) concentrations were measured every spring and fall across the basin by GLNPO. In this study, we used a time series of TP concentration based on the GLNPO spring survey in the central basin of Lake Erie 1997-2017 (Figure S1).

Time series of fishery harvest: Total fishery harvest included commercial and recreational harvest. Fishery harvests in the U.S. water were provided by the Ohio Department of Natural Resources (ODNR) (Brian Schmidt and Ann Marie Gorman at ODNR, personal communication). Commercial harvests in Canadian waters were available from Andy Cook at the Lake Erie Management Unit of Ontario Ministry of Natural Resources and Forestry (personal communication). Recreational harvests in Canadian waters were surveyed in 1998 (Sztramko 2000) and 2004 (MacDougall et al. 2005). We used recreational harvest values from 1998 to represent harvest for the 1996-2003 period, and from 2004 to represent harvest for the 2004-2020 period. We used the average harvest of 2016-2020 for long-term scenario simulations.

Time series of biomass: Ecosim was calibrated to biomass time series for 23 model groups. Biomass time series of zooplankton and benthic groups were calculated from U.S. EPA's GLNPO monitoring program. Fish biomass estimates were based on bottom trawl data from Ohio DNR, and then were scaled to the biomass estimates in Ecopath.

Ecopath balance

The balanced central basin Lake Erie Ecopath model (Table SM3.1) had four trophic levels containing 14.6 g m^{-2} of fish biomass and 265 g m^{-2} of lower trophic level biomass which was dominated by Dreissenid Mussel biomass of 212 g m^{-2}.

Ecosim calibration

We calibrated Ecosim with 23 observed biomass time series of model groups using a built-in fitting process to tune the vulnerabilities and achieve the minimum error sum of squares between simulated biomass and observed biomass. When simulated biomass is markedly different to observations, some processes may be missing in the model structure, which could be incorporated into the model using mediation functions or forcing functions (e.g., the hypoxia function mentioned above). A second approach was to force the biomass of some groups in Ecosim to see if simulations of other groups were improved. For example, during calibration we found that simulated biomass of adult Yellow Perch was consistently lower than observations. We forced biomass of chironomids without further calibrating the model, and the simulation of Yellow Perch was improved, as were some of the other modeled fish groups.

Here, we reported our calibration and comparisons with and without forced chironomid biomass (Figure SM3.4-SM3.5, dash lines). For all simulation scenarios mentioned below, chironomids were simulated, not forced. Simulated biomass showed similar temporal trends to observed biomass trends for some model groups, e.g., blue green algae, amphipods, calanoid copepods, and adult Walleye (Walleye 3+). Most of the calibrated model groups showed similar biomass means and coefficients of variation between modeled and observed biomass, while simulated biomass of some model groups (such as chironomids, shiners *Notropis* spp., White Perch *Morone americana*, White Bass *M. chrysops*, Freshwater Drum *Aplodinotus grunniens*, and adult Yellow Perch (Yellow Perch 2+)) was much lower than observed (Table SM3.5). Simulations of lower trophic levels were largely unaffected by the forced chironomid biomass, except Amphipoda (Figure SM3.4). Fish that fed on chironomids were positively affected using the forced chironomid biomass, and the simulations of White Perch, White Bass, Freshwater Drum and Yellow Perch 2+ were improved and agreed well with the temporal trends shown in observations (Figure SM3.5).

SM3. Tables and Figures

Table SM3.1. The balanced Ecopath model for Lake Erie's central basin showing model groups and parameter values (B - biomass, P/B - production to biomass, Q/B - consumption to biomass, EE - ecotrophic efficiency, and TL - trophic level). Bolded code names indicate multi-stanza groups.

Code	Group name	B	P/B	Q/B	EE	TL
WAE	Walleye *Sander vitreus*					
WAE Y	Young-of-year	0.12	4.77	7.9	0.06	3.9
WAE 1	Age 1	0.24	0.32	2.8	0.33	4.0
WAE 2	Age 2	0.54	0.42	2.0	0.03	4.0
WAE 3+	Age 3 and older	1.84	0.66	1.4	0.20	4.0
YPH	Yellow Perch *Perca flavescens*					
YPH Y	Yong-of-year	0.03	3.96	19.6	0.29	3.2
YPH 1	Age 1	0.08	0.76	7.8	0.60	3.3
YPH 2+	Age 2 and older	0.55	0.73	3.9	0.44	3.5
RBT	Rainbow Trout *Oncorhynchus mykiss*					
RBT-st	Stocked	-	-	-	-	-
RBT 1+	Age 1 and older	0.05	1.18	2.6	0.07	4.1
WHB	White Bass *Morone chrysops*	0.18	0.48	4.8	0.62	4.1
WHP	White Perch *M. americana*	0.86	0.63	10.8	0.75	3.5
GIZ	Gizzard Shad *Dorosoma cepedianum*	1.58	2.15	10.2	0.55	2.4
RBS	Rainbow Smelt *Osmerus mordax*	3.53	1.54	7.5	0.95	3.2
FWD	Freshwater Drum *Aplodinotus grunniens*	2.17	0.66	4.8	0.17	3.1
SHR	Shiners	0.62	1.37	13.2	0.59	3.3
RDG	Round Goby *Neogobius melanostomus*	0.25	1.69	9.7	0.92	3.1
LWF	Lake Whitefish *Coregonus clupeaformis*	0.19	0.39	2.1	0.43	3.1
OTH_F	Other fish	1.75	1.20	12.5	0.90	3.2
DREI	*Dreissena* mussels	212.0	2.54	16.8	0.02	2.0
AMPH	Amphipoda	0.40	2.44	12.9	0.92	2.0
SPHA	Sphaeriidae	0.88	2.52	16.2	0.34	2.0
CHIR	Chironomidae	9.35	2.21	10.5	0.87	2.0
OLIG	Oligochaete	5.28	4.89	40.1	0.03	2.0
OTH_B	Other benthos	0.47	2.92	16.3	0.42	2.0
PRED	Predaceous cladocerans	0.37	25.50	94.4	0.50	3.2
CLAD5	Herbivorous cladocerans	4.77	54.14	200.5	0.38	2.2
CYCL	Cyclopoid copepods	2.20	17.09	65.7	0.46	2.5
CALA	Calanoid copepods	1.43	8.48	32.6	0.79	2.2
ROTI	Rotifers	4.83	56.70	236.3	0.03	2.4
PROT	Protozoa	3.08	138.60	462.0	0.61	2.5
BACT	Bacteria	3.40	343.83	621.0	0.86	2.0
BLUE	Blue-green algae	1.81	285.00	-	0.21	1.0
OTH_A	Non-blue green algae	14.63	202.44	-	0.85	1.0
DET	Detritus	127.5	-	-	0.81	1.0

Table SM3.2. Diets (% of wet weight of the total diet) of piscivorous fish (in columns) in the balanced Ecopath model. See Table SM3.1 for full description of species group names.

Predator/ Prey	WAE Y	WAE 1	WAE 2	WAE 3+	YPH 1	YPH 2+	RBT 1+	WHB
WAE Y		1.30	2.00					0.62
WAE 1				1.00				
YPH Y	3.29	1.00						
YPH 1			0.10	0.5			5.80	1.62
WHB				1.00			0.32	
WHP	5.00	4.00		3.50		3.30	4.79	6.71
GIZ	51.10	36.80	37.20	21.00				3.00
RBS	16.30	39.06	43.40	29.80	10.01	12.20	41.82	45.50
FWD	2.08	0.00	1.00	4.20			3.00	7.23
SHR	11.25	10.69	2.9	2.50		3.00	16.81	6.00
RDG		0.08	0.6	3.00	2.00	9.40	1.05	1.26
LWF								3.00
Oth_F	10.98	6.99	9.8		3.00	2.60	7.50	13.62
DREI					3.00	2.80		
AMPH					3.50	5.70		
CHIR					30.61	29.60	11.31	10.00
PRED					5.20	5.18	7.58	1.43
CLAD					37.81	26.00		
CYCL					1.60	0.10		
CALA					3.26	0.10		

Table SM3.3. Diets (% of wet weight of the total diet) of planktivorous and omnivorous fish (in columns) in the balanced Ecopath model. See Table SM3.1 for full description of species group names.

Predator/ Prey	YPH Y	WHP	GIZ	RBS	FWD	SHR	RDG	LWF	Oth_F
GIZ		1.30							
RBS		13.49			10.67				
SHR		0.85							
RDG		0.10						1.00	
Oth_F		11.00		1.40				5.00	
DREI		2.52			35.69		49.10	54.70	
AMPH	4.04	7.00					1.20	11.80	
SPHA	1.01	0.40			6.15		1.20	5.00	
CHIR	10.20	19.80		18.00	44.59	10.30	18.30	22.50	19.30
OLIG		5.46			1.01		5.00		
Oth_B			3.00				4.00		
PRED	5.07	10.90	2.00	1.80	1.31	15.70	1.20		5.70
CLAD	54.52	11.20	14.01	43.19		57.40	10.00		55.40
CYCL	5.05	6.00	2.00	27.28		10.20	5.00		10.20
CALA	10.10	5.00	2.90	8.33		1.40	5.00		7.40
ROTI	10.00	5.00	10.01			5.00			2.00
Oth_A			26.03						
Detritus			40.04		0.59				

Table SM3.4. Diets (% of wet weight of the total diet) of lower trophic level consumers (in columns) in the balanced Ecopath model. Note that the diets composition of benthic groups SPHA, CHIR, OLIG, Oth_B and bacteria BACT are all detritus. See Table SM3.1 for full description of species group names.

Predator/ Prey	DREI	AMPH	PRED	CLAD	CYCL	CALA	ROTI	PROT
CLAD			79.42		16.66			
CYCL			7.92		2.22			
CALA					3.11			
ROTI	0.01		12.67		1.00			
PROT	1.00			10.00	12.60	10.00	9.37	
BACT							25.65	50.00
BLUE	1.00							5.00
Oth_A	9.00	5.00		80.00	64.41	80.00	64.98	40.00
Detritus	88.99	95.00		10.00		10.00		5.00

Table SM3.5. Comparison of mean observed biomass and Ecosim-generated biomass (Coefficient of Variation) for model groups in the central basin of Lake Erie for the calibration period of 1996-2020. 'Simulated' refers to chironomids being dynamically simulated for the model calibration, while 'Forced' refers to the model run with forced chironomid biomass.

Model group	Observation	Simulated	Forced
Walleye 2	0.57 (1.28)	0.73 (0.38)	0.79 (0.31)
Walleye 3+	2.30 (0.39)	2.36 (0.29)	2.64 (0.23)
Yellow Perch 2+	1.24 (0.35)	0.55 (0.44)	0.95 (0.47)
Rainbow Trout 1+	0.06 (0.06)	0.08 (0.32)	0.09 (0.32)
White Bass	0.25 (0.56)	0.16 (0.34)	0.24 (0.40)
White Perch	2.52 (0.54)	1.63 (0.41)	3.30 (0.55)
Lake Whitefish	0.18 (0.90)	0.15 (0.32)	0.22 (0.37)
Gizzard Shad	2.37 (1.53)	2.32 (0.29)	2.27 (0.31)
Rainbow Smelt	3.30 (0.68)	4.05 (0.20)	4.81 (0.26)
Freshwater Drum	4.53 (0.59)	1.92 (0.31)	3.56 (0.58)
Shiners	3.26 (0.87)	1.49 (0.68)	1.66 (0.54)
Round Goby	0.27 (0.82)	0.30 (0.32)	0.38 (0.35)
Dreissenid Mussels	292.70 (1.11)	272.86 (0.33)	269.49 (0.35)
Amphipoda	0.20 (1.29)	0.30 (0.51)	0.20 (0.91)
Sphaeriidae	0.82 (0.39)	1.12 (0.40)	1.09 (0.43)
Oligochaetes	5.87 (0.43)	7.37 (0.30)	7.26 (0.32)
Chironomids	21.08 (0.81)	11.58 (0.28)	21.08 (0.81)
Predaceous cladocerans	0.41 (0.60)	0.47 (0.25)	0.44 (0.31)
Herbivorous cladocerans	4.50 (0.62)	6.14 (0.22)	6.11 (0.24)
Cyclopoid copepods	2.12 (0.31)	2.84 (0.23)	2.82 (0.24)
Calanoid copepods	1.44 (0.39)	1.87 (0.24)	1.85 (0.25)
Blue green algae	1.92 (1.01)	2.15 (0.68)	2.11 (0.71)
Non-blue green algae	20.54 (0.65)	19.26 (0.25)	19.2 (0.26)

Table SM3.6. Nutrient and hypoxia functions in Ecosim.

	Description	Effects	Directly affected groups
Nutrient	Time series of TP concentration	nutrient limiting	blue green algae, other algae
Hypoxia function *f1*	Volumetric ratio of normoxic water to the whole central basin	Hypoxia separates zooplankters from zooplanktivores, so decreases the search rate of zooplanktivores for zooplankton	herbivorous cladocerans, calanoid and cyclopoid copepods
Hypoxia function *f2*	1 plus the volumetric ratio of hypoxic water to the whole central basin plus 1	Aggregates cool-water fish Rainbow Smelt in the metalimnion and increases the search rate of predators for Rainbow Smelt	Rainbow Smelt
Hypoxia function *f3*	1 plus the areal ratio of hypoxic water to the whole central basin	Aggregates Round Goby in normoxic waters, so increase search rates of its predators	Round Goby
Hypoxia function *f4*	Instantaneous hypoxia-induced mortality based on the areal ratio of hypoxic water to the whole central basin	Causes mortality of immobile or less mobile benthic invertebrates	*Dreissena* spp., amphipods, Sphaeriidae, chironomids, oligochaetes, other benthos

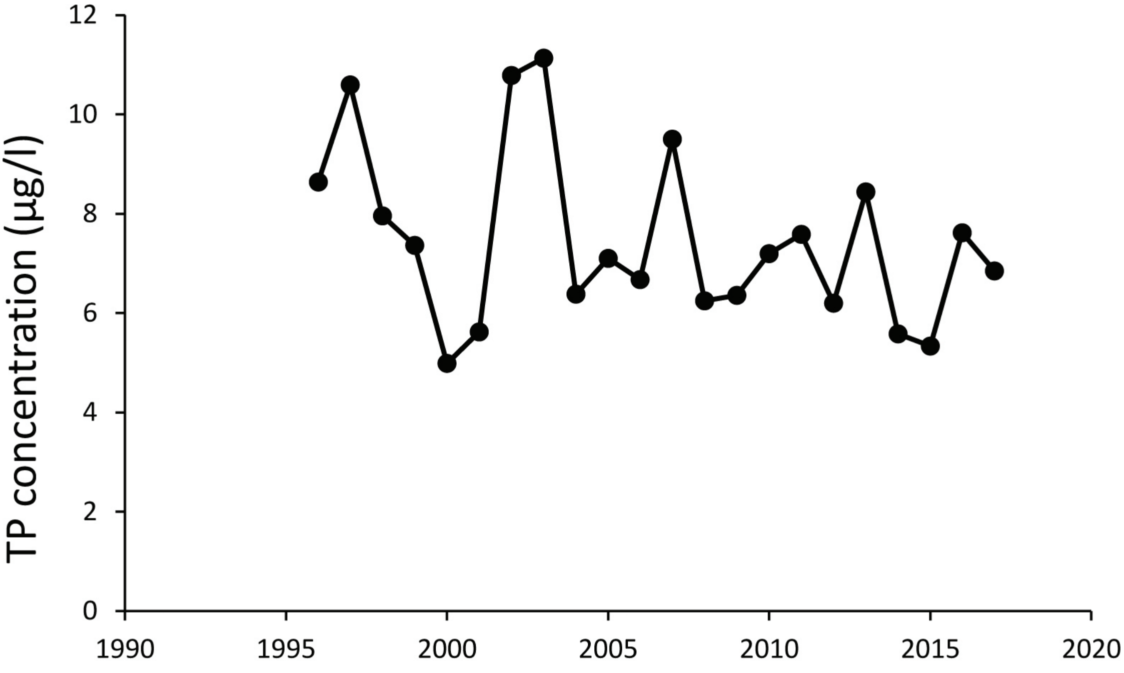

Figure SM3.1. Total phosphorus (TP) concentration (µg l^{-1}) in the central basin of Lake Erie, based on spring monitoring data by U.S. EPA Great Lakes National Program Office survey. Data from 1996 were not available, so the estimate for that year was an average of data from 1997-1999.

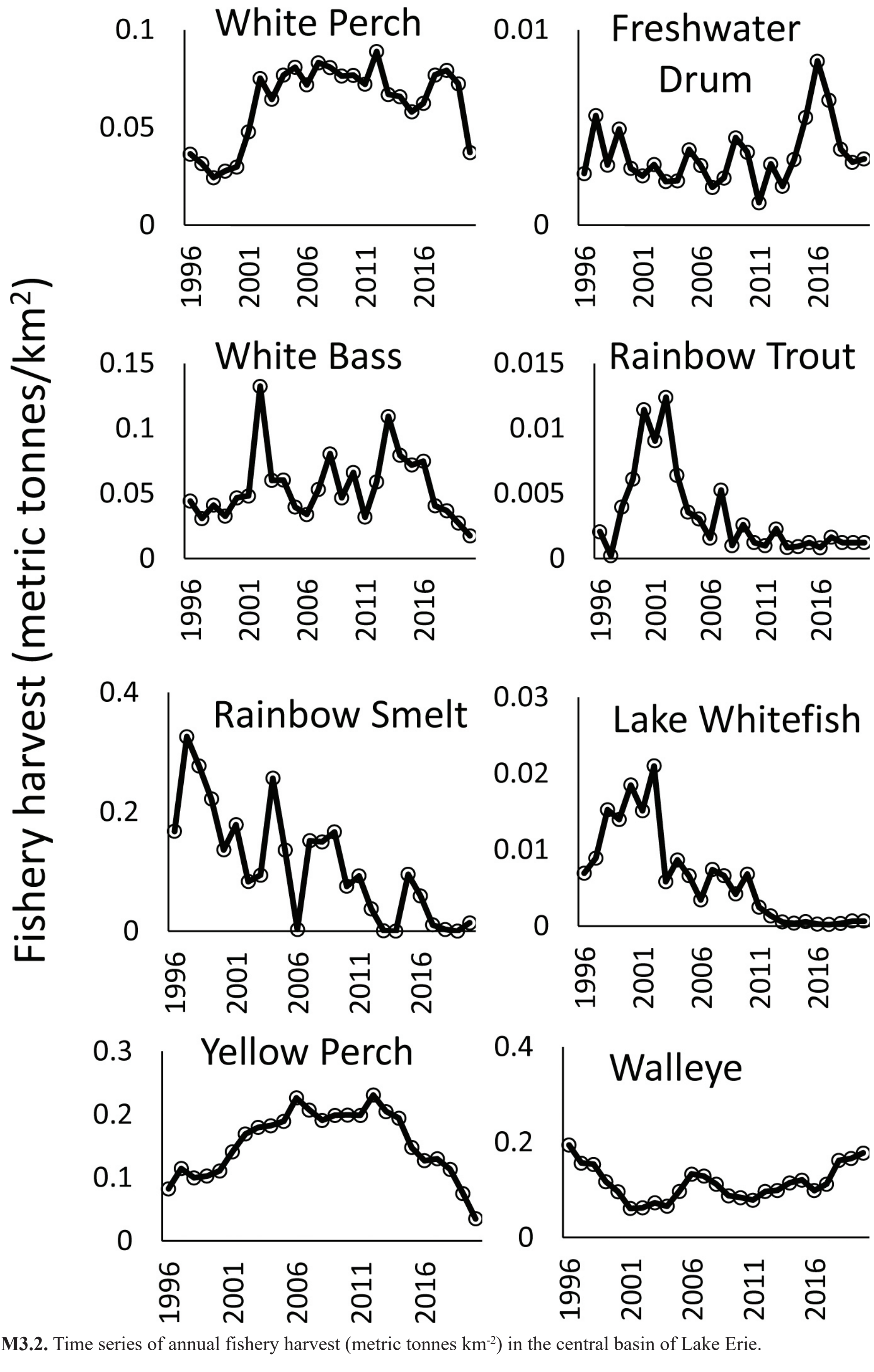

Figure SM3.2. Time series of annual fishery harvest (metric tonnes km^{-2}) in the central basin of Lake Erie.

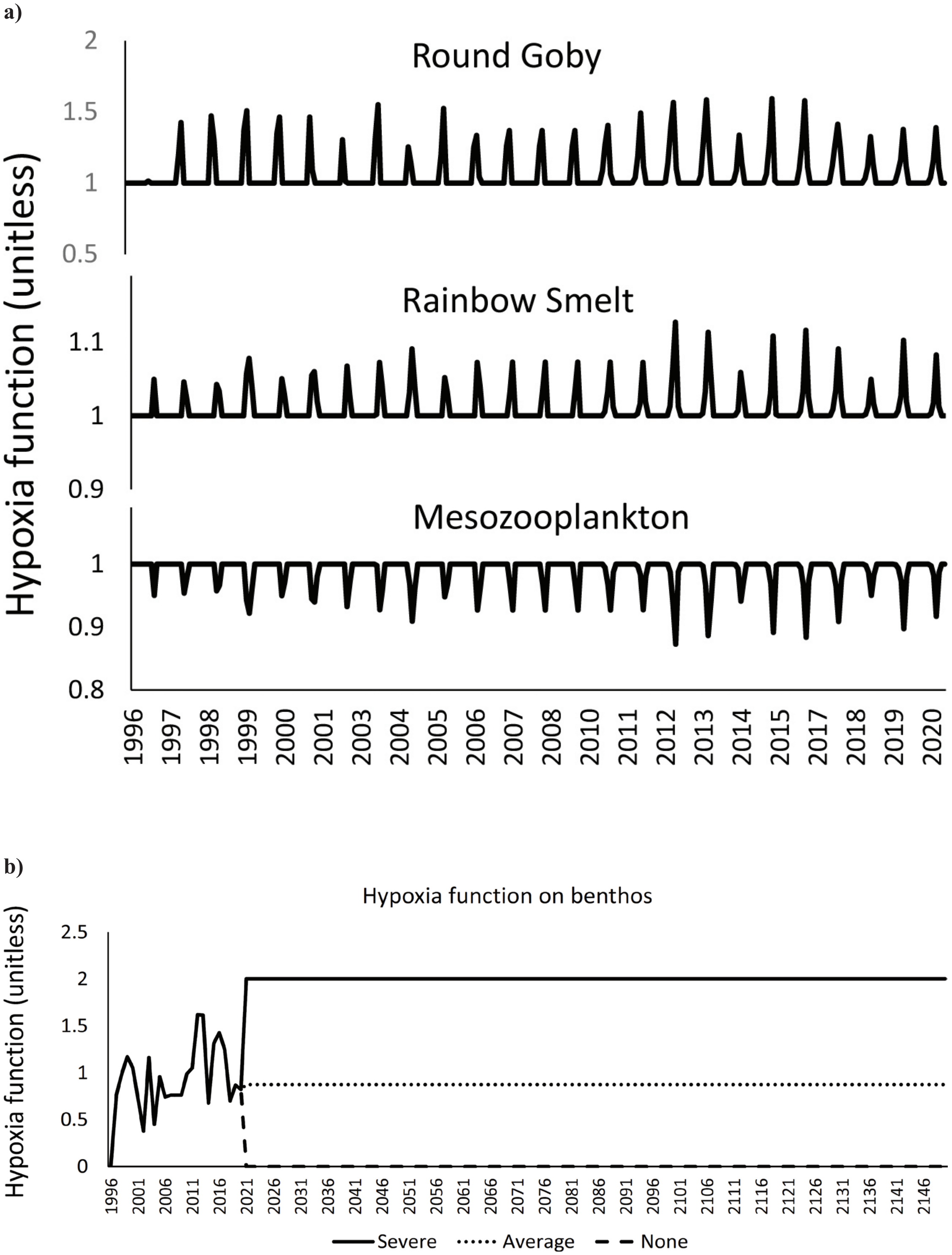

Figure SM3.3. Hypoxia functions as modifier for vulnerabilities (A) and as hypoxia-induced mortality (B). Note A only showed time series over calibration period 1996-2020, while B showed both calibration period and scenario period.

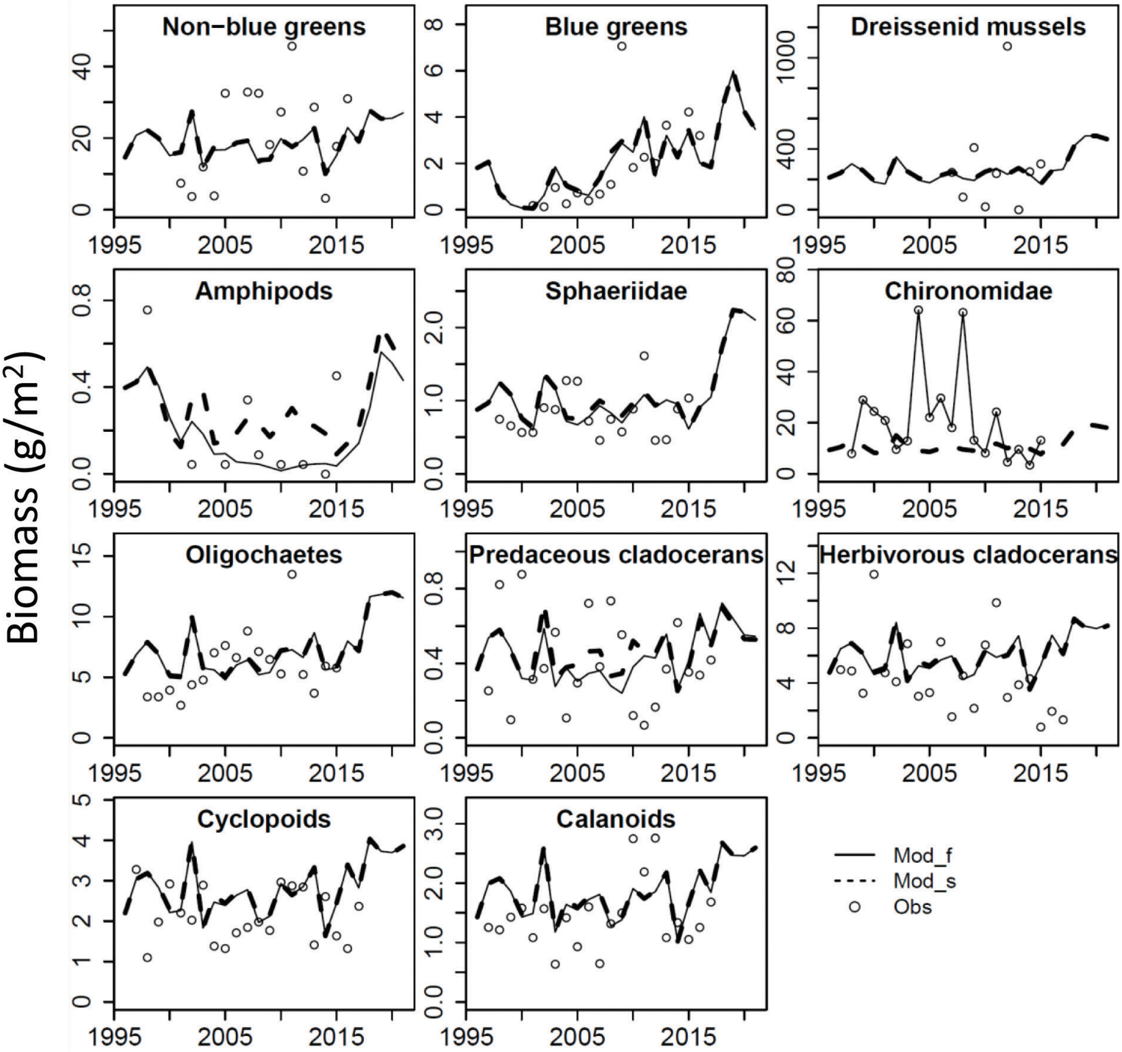

Figure SM3.4. Calibration of observed biomass (open circles) and model-generated biomass of lower trophic level groups with forced chironomid biomass (solid lines, “Mod_f”) and without forced chironomid biomass (dashed lines, “Mod_s”).

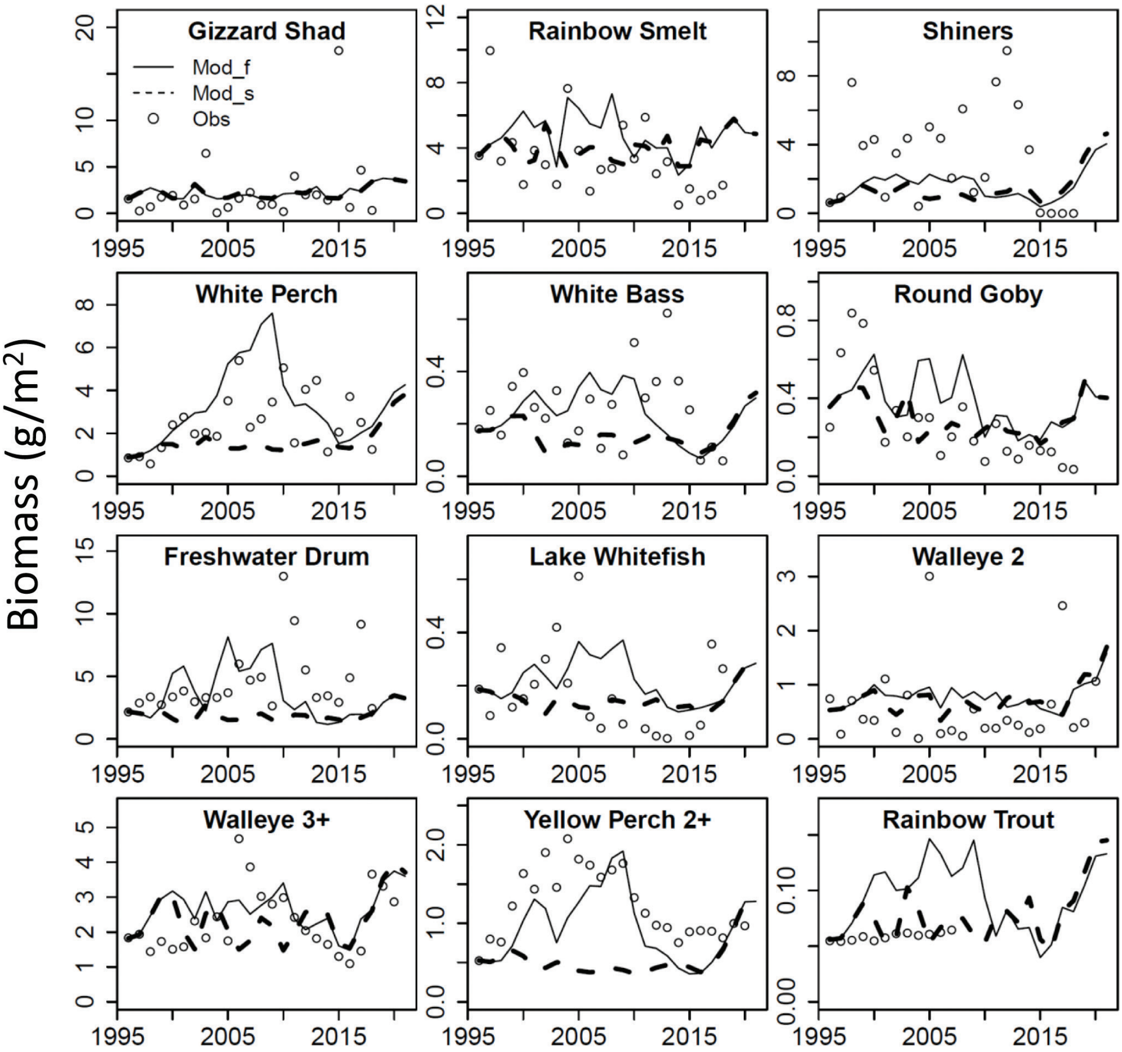

Figure SM3.5. Calibration of observed biomass (open circles) and model-generated biomass of fish with forced chironomid biomass (solid lines, “Mod_f”) and without forced chironomid biomass (dashed lines, “Mod_s”).

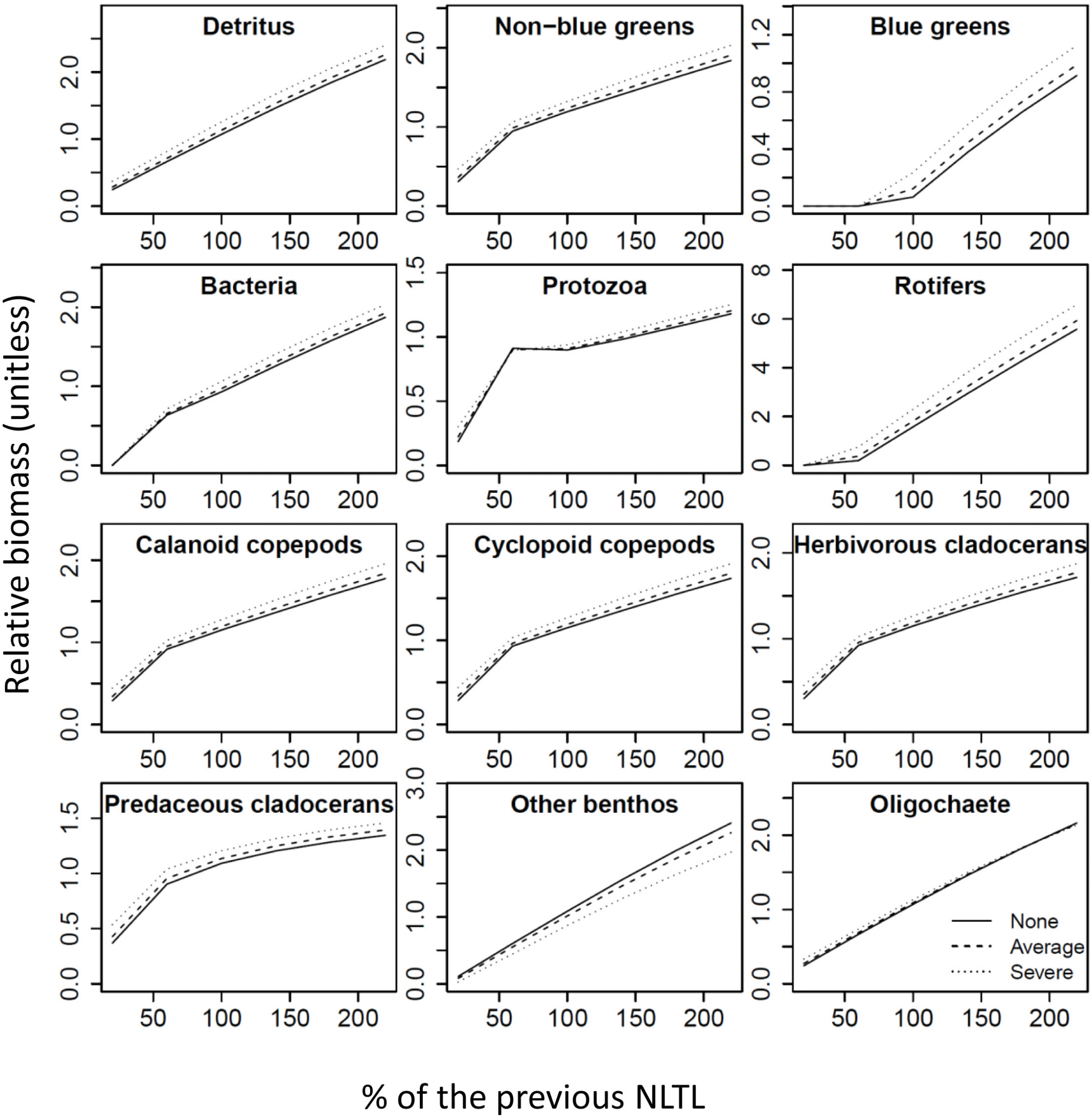
Detritus
Non−blue greens
Blue greens
Bacteria
Protozoa
Rotifers
Calanoid copepods
Cyclopoid copepods
Herbivorous cladocerans
Predaceous cladocerans
Other benthos
Oligochaete
None
Average
Severe
Relative biomass (unitless)
% of the previous NLTL
50
100
150
200

Figure SM3.6

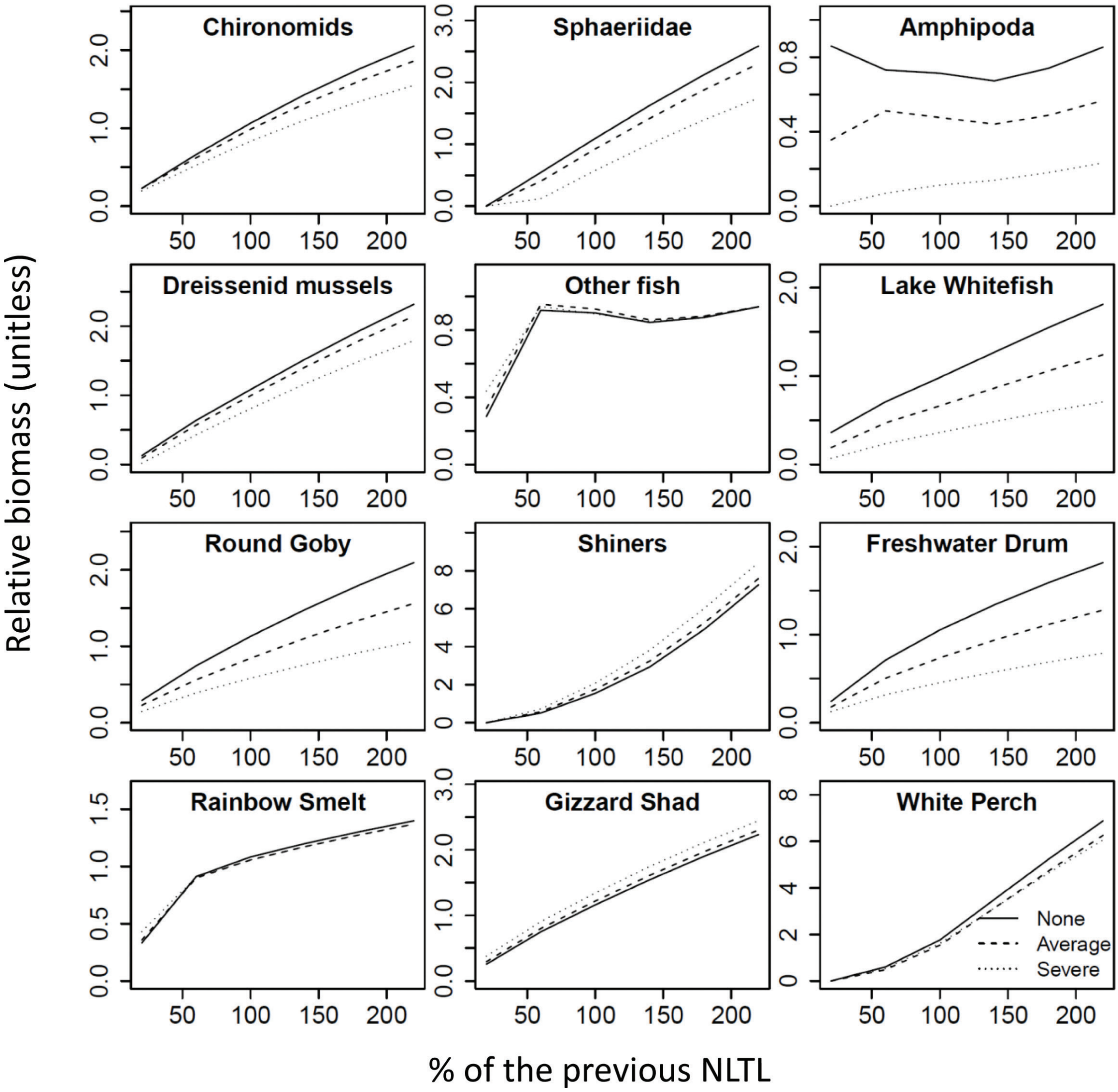

Figure SM3.6 cont.

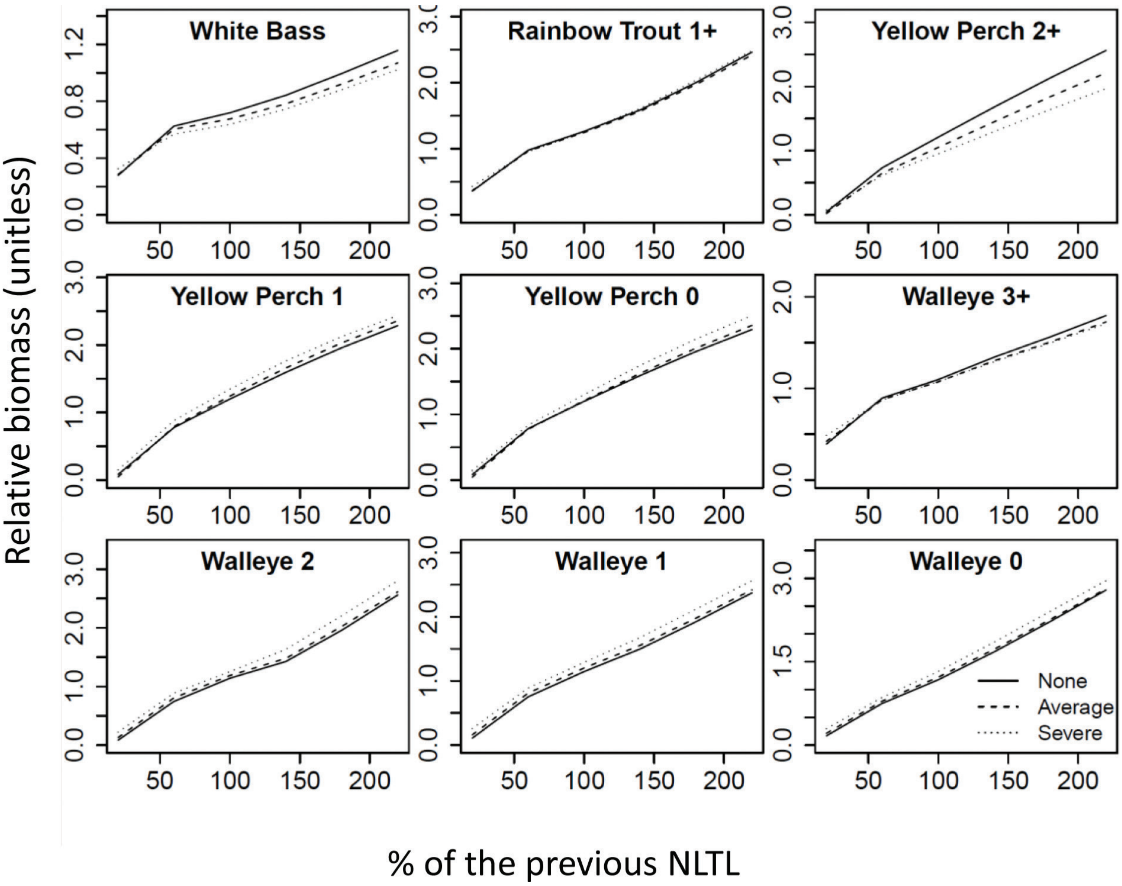

Figure SM3.6. Changes in relative biomass of model groups under combination scenarios of TP levels and hypoxia conditions. Relative biomass refers to biomass relative to the initial biomass in Ecopath. Average hypoxia reflects the average of monthly hypoxia values from 1996 to 2020. Severe hypoxia reflects the highest monthly hypoxia value from 1996 to 2020.

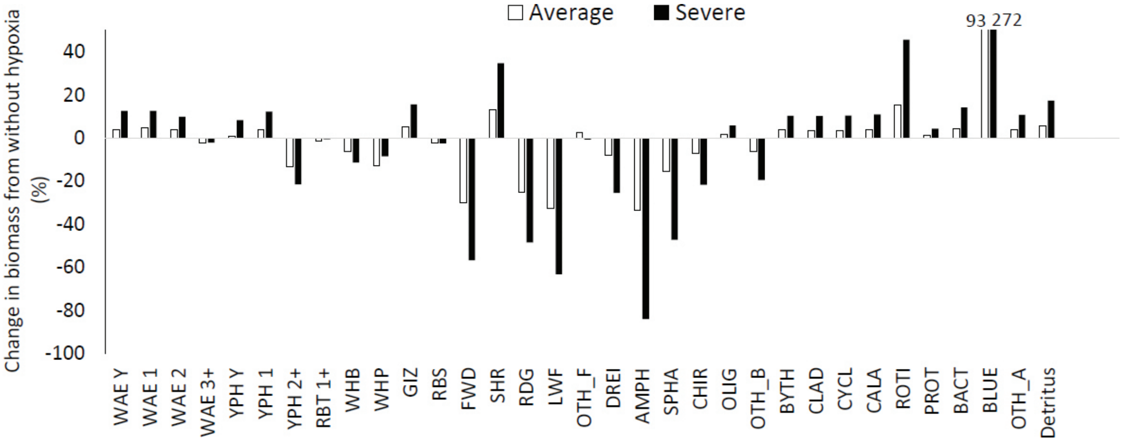

Figure SM3.7. Percent change in biomass of central basin Lake Erie food web groups (see Table SM3.1 for explanation) caused by average hypoxia (white bars) or severe hypoxia (black bars) relative to a no-hypoxia scenario. All hypoxia scenarios were run under the 100% of the previous NLTL scenario. Note the numbers on the bars for the blue green algae (BLUE) indicate the % change in biomass from average hypoxia (93%) and severe hypoxia (272%) relative to the no hypoxia scenario.

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