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Supporting data for the habitat-based population models developed for northern pike, smallmouth bass, largemouth bass and yellow perch

by

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ABSTRACT

C. Chu, J. E. Moore, C. N. Bakelaar, S. E. Doka and C. K. Minns. 2005. Supporting data for the habitat-based population models developed for northern pike, smallmouth bass, largemouth bass and yellow perch.

Habitat-based population models have gained popularity in fisheries science because they integrate both habitat and population processes that may act to regulate fish populations. We developed habitat-based population models to examine the impacts of water level changes on the population dynamics of northern pike (*Esox lucius*), smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides*) and yellow perch (*Perca flavescens*). This report documents the supporting data used to develop the models for these four fishes. A primary literature review was conducted to determine the habitat preferences of the different life stages of these species and their bioenergetic parameter values. The habitat-population models were developed in Visual Basic 6 and full documentation of the northern pike program code is also provided in this report. It serves as an example of the code used to model the other species. A full description of the theory and algorithms used in the models can be found in Chu *et al.*, (*In prep.*).

RÉSUMÉ

C. Chu, J. E. Moore, C. N. Bakelaar, S. E. Doka et C. K. Minns. 2005. Données utilisées dans les modèles démographiques fondés sur les habitats visant le grand brochet, l'achigan à petite bouche, l'achigan à grande bouche et la perchaude.

Dans le domaine des sciences halieutiques, les modèles démographiques fondés sur les habitats ont gagné en popularité en raison de leur capacité d'intégrer à la fois les processus dans les habitats et les processus démographiques qui peuvent régir les populations de poissons. Nous avons mis au point des modèles démographiques fondés sur les habitats pour examiner les impacts des fluctuations du niveau de l'eau sur la dynamique des populations du grand brochet (*Esox lucius*), de l'achigan à petite bouche (*Micropterus dolomieu*), de l'achigan à grande bouche (*Micropterus salmoides*) et de la perchaude (*Perca flavescens*). Le rapport présente les données qui ont servi à élaborer les modèles visant ces quatre espèces de poissons. Un examen préliminaire de la documentation a été mené en vue de déterminer les préférences en matière d'habitat des différents stades biologiques de ces espèces ainsi que les valeurs de leurs paramètres bioénergétiques. Les modèles démographiques fondés sur les habitats ont été mis au point à l'aide de Visual Basic 6. Tous les documents liés au code de programme du modèle visant le grand brochet sont également fournis dans le rapport. Ils constituent un exemple de code utilisé pour modéliser les autres espèces. Une description complète de la théorie et des algorithmes utilisés dans les modèles se trouve dans Chu *et al.*, (*en préparation*).

INTRODUCTION

On December 12, 2000, the International Joint Commission (IJC) created the International Lake Ontario - St. Lawrence River (LO-SL) Study Board. This board has a 5-year mandate to evaluate the procedures and criteria used to regulate the outflows and water levels of Lake Ontario and the St. Lawrence River up to Trois-Rivières, Quebec. This included an analysis of the impacts of different regulation plans on fishes in the LO-SL system. To examine these impacts we developed habitat-based population models for fishes in the LO-SL system. We chose northern pike (*Esox lucius*), yellow perch (*Perca flavescens*), smallmouth (*Micropterus dolomieu*) and largemouth bass (*Micropterus salmoides*) as our indicator species because they occupy the nearshore regions of the system, spawn in shallow waters, represent the warm- and cool-water thermal guilds and have different vegetation preferences.

A northern pike model developed by Minns *et al.*, (1996) provided the framework for our habitat-population models. That model assumed key population processes were controlled by a saturation function of habitat supply. Simulations with varied habitat supply indicated that fry and juvenile-adult habitat maybe more limiting than spawning habitat. Our models differ from its predecessor because a bioenergetic component has been added. This allows for detailed estimates of growth for each life stage. Fecundity, young-of-year (YOY) survival, biomass estimates and population density are consequently affected (Figure 1). Models were developed for northern pike, smallmouth bass, largemouth bass and yellow perch.

This report documents the supporting data used to develop the habitat-population models. This includes summaries of a primary literature review to determine the habitat preferences of the four species, summaries of the bioenergetic parameter values used for each species, and documentation of the program code used in the model. The theory and algorithms used in the population models can be found in Chu *et al.*, (*In prep.*). We also ran the northern pike model in a selected area on Lake Ontario to demonstrate the model input requirements and output.

METHODS

A literature review was conducted to determine the habitat preferences for spawning, fry YOY, juvenile and adult northern pike, smallmouth and largemouth bass, and yellow perch. The program Fish Bioenergetics 3.0 (Hanson *et al.*, 1997) and studies in the primary literature provided the bioenergetic parameter data.

Habitat preferences were incorporated into the habitat supply database (Bakelaar *et al.*, *In prep.*). This database is designed to estimate changes in habitat with fluctuating water levels by calculating the weighted suitable area (WSA) available for each life stage of each species in a selected site (Bakelaar *et al.*, *In prep.*). The bioenergetic data were incorporated into the population models to calculate growth of the YOY, juveniles and adults of each species. The population models were programmed in Visual Basic 6 and the program code for the northern pike model is summarized and annotated in Appendix A. Code for the other species models follows a similar format except that species-specific parameter values, e.g. the bioenergetic parameters, differ among species.

The northern pike model is demonstrated using a study area along the southern shore of Lake Ontario. This area consists of a 1 km stretch of shoreline with a total area of 123 ha (area from 0 – 20 m deep) including a small wetland of 2.65 ha (Figure 2). The habitat data for this study area and daily water levels for a 100-year period (1900-2000) were entered into the habitat database and the WSAs were calculated for each life stage of northern pike in the study area. The WSAs were then entered into the population model to determine how fluctuating water levels influence northern pike in this study area.

RESULTS

The habitat preferences of the four species are summarized in Tables 1-4. The different habitat combinations were assigned suitability values of 1, 0.5 and 0.25 based on what the primary literature defined as the most suitable habitat. Northern pike, largemouth bass and yellow perch prefer varying percentages of vegetative cover while substrate, particularly rocky substrates are more important to smallmouth bass. Northern pike were the shallowest spawners preferring depths of 0-0.5 m while smallmouth bass, largemouth bass and yellow perch prefer depths of 0-2.5 m, 0.2-1 m and 1-4 m, respectively, for spawning (Table 1-4). The juveniles of all four species could be found in depths shallower than 10 m while adults could be found up to 20 m deep. The habitat preferences were incorporated into the habitat database and provided a framework for calculating the amount of suitable habitat available for any life stage of the four fishes anywhere in the LO-SL system.

The bioenergetic data were incorporated into the population models to calculate growth of the YOY, juveniles and adults of each species. Daily temperatures and density estimates were also calculated in the population model to provide estimates of growth throughout each ice free season as a function of temperature and density (Figure 1).

The habitat database results indicated that higher water levels in the later part of the century reduced the suitable area available for spawning in the study area (Figure 3). More habitat was available for the fry than the YOY but both increased or decreased with concomitant increases or decreases in the water levels. The juvenile and adult WSAs were not sensitive to the water level changes (Figure 3). Higher water levels in the later part of the century reduced both the YOY and total fish (age one and older) densities of the northern pike population in the study area (Figure 4).

DISCUSSION

The literature reviews produced an extensive database of the habitat preferences and bioenergetic data for the different life stages of each species. YOY densities were higher than total fish densities in some years because the total fish densities included fish age one and older. This produced a one year lag between increases in YOY densities and increases in the population. The decrease in northern pike YOY and total fish densities with increased water levels during the later part of the century can be attributed to the decline in suitable spawning habitat in the study area. There was no suitable spawning habitat available in 1976, 1978, 1985-1987, 1991 and 1997. In the population model, eggs are not deposited unless suitable spawning habitat is available therefore these years resulted in zero recruitment and the population densities declined. Our results suggest that a regulation plan that maintains water levels closer to those recorded in the earlier part of the century (74.4-74.9 m) would positively impact northern pike in our example study area.

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Table 1: Northern pike habitat suitability in Lake Ontario-St. Lawrence system as determined by depth and vegetation.

Life stage	**Depth (m)**	**Vegetation** Where emergents (E) exist, submergents (S) = 1-E	**Suitability**
Spawn	0-0.5	E ≥ 75% cover E ≥ 50% cover S ≥ 50% cover	1 0.5 0.25
	0.5-2	E ≥ 75% cover E ≥ 50% cover S ≥ 75% cover	0.5 0.25 0.25
	2-5	S ≥ 75% cover	0.25
Fry (swim-up)	0-2	E ≥ 50% E < 50% > 0% S ≥ 50%	1 0.5 0.25
	2-5	S ≥ 50%	0.25
YOY (post 50 mm)	0-2	E > 90% E ≤ 90% ≥ 40% E < 40% > 0% S ≥ 40%	0.5 1 0.25 0.25
	2-5	S ≥ 50%	0.25
Juvenile	0.5-5	E > 80% any combination E, S and open water open water	0.5 1 0.5
	5-10	E > 80% Any combination of E, S and open water open water	0.5 1 1
	10-20	Any combination E, S and open water Open water	0.5 0.25
Adult	0.5-5	E > 80% any combination E, S and open water open water	0.25 0.5 0.5
	5-10	E > 80% Any combination of E, S and open water Open water	0.25 1 1
	10-20	Any combination E,S and open water Open water	1 0.5

Table 2: Smallmouth bass habitat suitability in Lake Ontario-St. Lawrence system as determined by depth and substrate.

Life stage	Depth (m)	Substrate	Suitability
Spawn and Fry	0-2.5	If any combination of cobble+ rubble+ gravel+ boulder+ sand >50% If any combination of cobble+ rubble+ gravel+ boulder+ sand >25<50% If any combination of cobble+ rubble+ gravel+ boulder+ sand <25%	1 0.5 0.25
	2.5-5	If any combination of cobble+ rubble+ gravel+ boulder+ sand >50% If any combination of cobble+ rubble+ gravel+ boulder+ sand >25<50%	0.5 0.25
YOY	0-5	If any combination of cobble+ rubble+ gravel+ boulder+ sand >50% If any combination of cobble+ rubble+ gravel+ boulder+ sand >25<50% If any combination of cobble+ rubble+ gravel+ boulder+ sand <25%	1 0.5 0.25
	>5	If any combination of cobble+ rubble+ gravel+ boulder+ sand >50% If any combination of cobble+ rubble+ gravel+ boulder+ sand >25<50%	0.5 0.25
Juvenile	0-5	If any combination of cobble+ rubble+ gravel+ boulder+ sand >50% If any combination of cobble+ rubble+ gravel+ boulder+ sand >25<50% If any combination of cobble+ rubble+ gravel+ boulder+ sand <25%	1 0.5 0.5
	5-10	If any combination of cobble+ rubble+ gravel+ boulder+ sand >50% If any combination of cobble+ rubble+ gravel+ boulder+ sand >25<50% If any combination of cobble+ rubble+ gravel+ boulder+ sand <25%	1 0.5 0.25
	10-20	If any combination of cobble+ rubble+ gravel+ boulder+ sand >50% If any combination of cobble+ rubble+ gravel+ boulder+ sand >25<50%	0.5 0.25
Adult	0-10	If any combination of cobble+ rubble+ gravel+ boulder+ sand >25%	1
	10-20	If any combination of cobble+ rubble+ gravel+ boulder+ sand >25%	0.5

Table 3: Largemouth bass habitat suitability habitat suitability in Lake Ontario-St. Lawrence system as determined by depth and vegetation.

Life stage	**Depth (m)**	**Vegetation** Where emergents (E) exist, submergents (S) = 1-E	**Suitability**
Spawn and Fry	0.2-1	E and/or S >50% cover	1
	1-1.5	E and/or S >50% cover	0.5
	1.5-3	E and/or S >50% cover	0.25
YOY	0-2	E and/or S >25% cover	1
	2-4	E and/or S >25% cover	0.25
Juvenile	0-2	E and/or S >10% cover <10% cover	1 0.5
	2-5	E and/or S >10% cover <10% cover	0.5 0.25
	5-20	E and/or S >10% cover	0.25
Adult	0-2	E and/or S >10% cover <10% cover	1 0.5
	2-5	E and/or S >10% cover <10% cover	0.5 0.25
	5-20	E and/or S >10% cover	0.25

Table 4: Yellow perch habitat suitability in the Lake Ontario-St. Lawrence system as determined by depth, vegetation and substrate.

Life stage	Depth (m)	Vegetation Where emergents (E) exist, submergents (S) = 1-E	Substrate	Suitability
Spawn	0-1	E and/or S 10-25% cover and 50-70%	>10% gravel, sand, silt	0.25
		E and/or S >25<50% cover	>10% gravel, sand, silt	0.5
		E and/or S 0-10% and >70-100%	>10% gravel, sand, silt	0.25
	1-4	E and/or S 10-25% cover and 50-70%	>10% gravel, sand, silt	0.5
		E and/or S >25<50% cover	>10% gravel, sand, silt	1
		E and/or S 0-10% and >70-100%	>10% gravel, sand, silt	0.5
	4-8	E and/or S 10-25% cover and 50-70%	>10% gravel, sand, silt	0.25
		E and/or S >25<50% cover	>10% gravel, sand, silt	0.5
		E and/or S 0-10% and >70-100%	>10% gravel, sand, silt	0.25
Fry (pelagic stage)	0-2, 3.5-6	E and/or S >25<50% cover	>10% rubble, gravel, sand and silt	0.5
		E and/or S 0-25 and 50-70% cover	>10% rubble, gravel, sand and silt	0.25
	2-3.5	E and/or S >25<50% cover	>10% rubble, gravel, sand and silt	1
		E and/or S 0-25 and 50-70% cover	>10% rubble, gravel, sand and silt	0.5
YOY	0-6	E and/or S 10-25% cover and 50-70%	>10% rubble, gravel, sand and silt	0.5
		E and/or S >25<50% cover	>10% rubble, gravel, sand and silt	1
			>10% rubble, gravel, sand and silt	0.25
	6-9	E and/or S 10-25% cover and 50-70%	>10% rubble, gravel, sand and silt	0.25
		E and/or S >25<50% cover	>10% rubble, gravel, sand and silt	0.5
	9-20	E and/or S >25<50% cover	>10% rubble, gravel, sand and silt	0.25
Juvenile	0-4, 7-10	E and/or S 10-25% cover and 50-70%	>10% sand and silt	0.25
		E and/or S >25<50% cover	>10% sand and silt	0.5
		E and/or S 0-10% and >70-100%	>10% sand and silt	0.25
	4-7	E and/or S 10-25% cover and 50-70%	>10% sand and silt	0.5
		E and/or S >25<50% cover	>10% sand and silt	1
		E and/or S 0-10% and >70-100%	>10% sand and silt	0.5
	10-20	E and/or S >25<50% cover	>10% sand and silt	0.25
Adult	0-2, 8-10	E and/or S 10-25% cover and 50-70%	>10% sand and silt	0.25

		E and/or S >25<50% cover E and/or S 0-10% and >70-100%	>10% sand and silt >10% sand and silt	0.5 0.25
	2-8	E and/or S 10-25% cover and 50-70% E and/or S >25<50% cover E and/or S 0-10% and >70-100%	>10% sand and silt >10% sand and silt >10% sand and silt	0.5 1 0.5
	10-20	E and/or S >25<50% cover	>10% sand and silt	0.25

Table 5: Bioenergetic parameters* used to estimate growth of the young-of-year, juvenile and adult northern pike, smallmouth bass, largemouth bass and yellow perch.

Parameter	Definition of bioenergetic parameters	Northern pike		Smallmouth bass		Largemouth bass		Yellow perch	
		YOY	Age one+	YOY	Age one+	YOY	Age one+	YOY	Age 1+
CA	intercept of mass dependent function ($g \cdot g^{-1} \cdot d^{-1}$)	0.228	0.205	0.25	0.339	0.33	0.33	0.51	0.25
CB	slope of mass dependent function	-0.355	-0.18	-0.31	-0.305	-0.325	-0.325	-0.42	-0.27
CQ	approximates Q_{10} – the rate at which the function increases over relatively low water temperatures	2.391	2.59	3.8	4.2	2.65	2.65	29	23
CTO	optimum temperature (°C)	26.35	24	29	22	27.5	27.5	32	28
CTM	temperature at which consumption ceases (°C)	34	34	36	37	37	37	2.3	2.3
RA	number of grams of oxygen consumed by a 1 gram fish at the optimum temperature ($g \cdot g^{-1} \cdot d^{-1}$)	0.002	.003	0.009	0.244	0.087	0.116	0.035	0.035
RB	slope of the allometric mass function for standard metabolism	-0.031	-0.18	-0.21	-0.756	-0.355	-0.355	-0.2	-0.2
RQ	approximates Q_{10} – the rate at which the function increases over relatively low water temperatures	2.1	2.1	3.3	1.8	0.0811	0.081	32	28
RTO	optimum temperature for respiration (°C)	28	27	30	30	0.0196	0.0196	35	33
RTM	maximum lethal temperature (°C)	29	29	37	37	0	0	2.1	2.1
RK1	Intercept for swimming speed above the cutoff temperature ($cm \cdot s^{-1}$)					1	1		
RK4	mass dependent coefficient for swimming speed at all water temperatures					0	0		
BACT	water temperature dependence coefficient of swimming speed					0	0		
ACT	activity multiplier	1.04	1	2	1	1	1.0198	4.4	1
SDA	specific dynamic action	0.14	0.14	0.16	0.16	0.163	0.163	0.15	0.15
FA	egestion ($g \cdot g^{-1} \cdot d^{-1}$)	0.13	0.2	0.104	0.104	0.104	0.104	0.15	0.158
UA	excretion ($g \cdot g^{-1} \cdot d^{-1}$)	0.07	0.07	0.068	0.068	0.068	0.068	0.15	0.58

*The equations for the bioenergetic models are documented in Fish Bioenergetics 3.0 (Hanson *et al.*, 1997) and Appendix A.

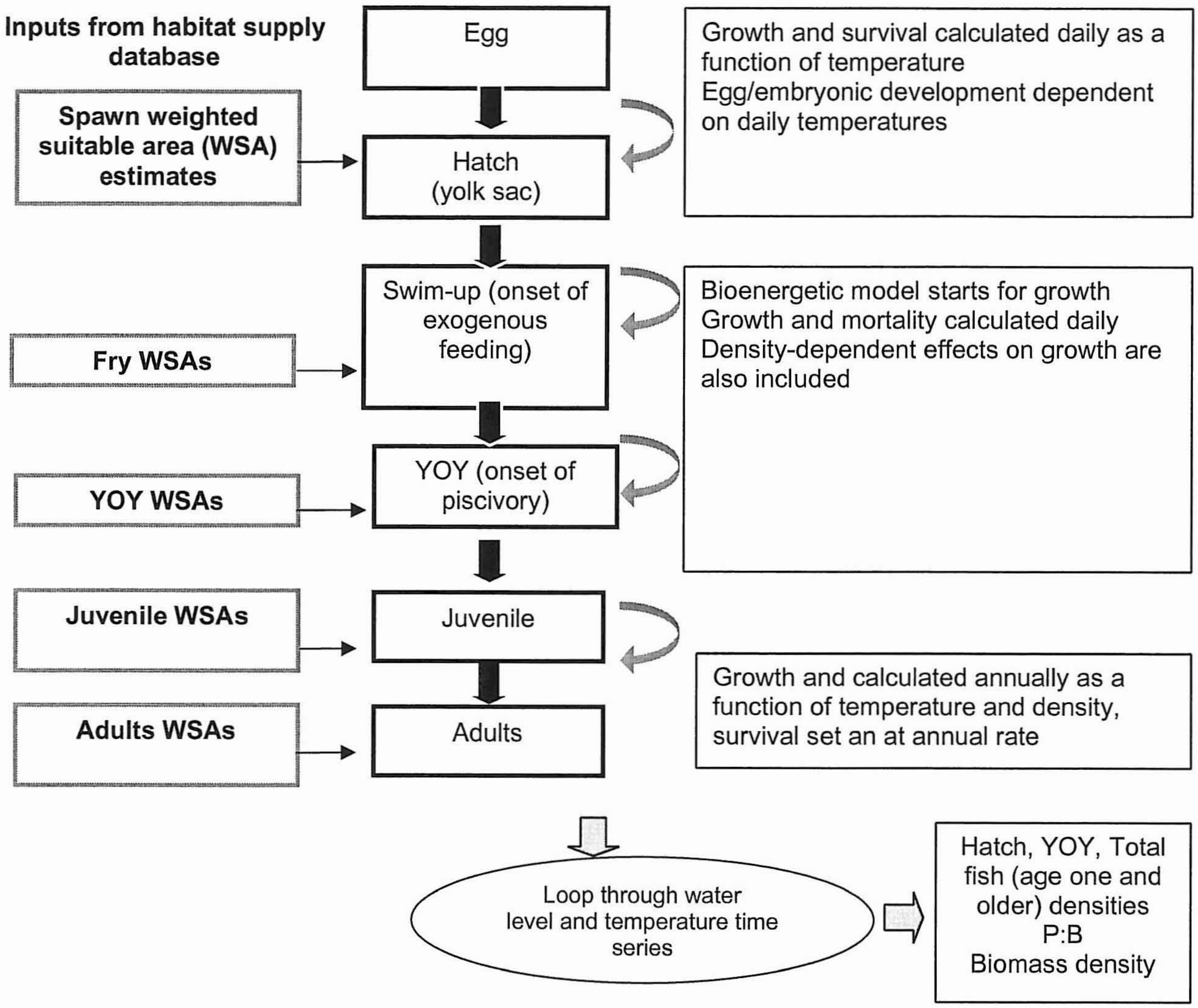

Figure 1: Framework of habitat-based population model for fishes in the Lake Ontario-St. Lawrence system.

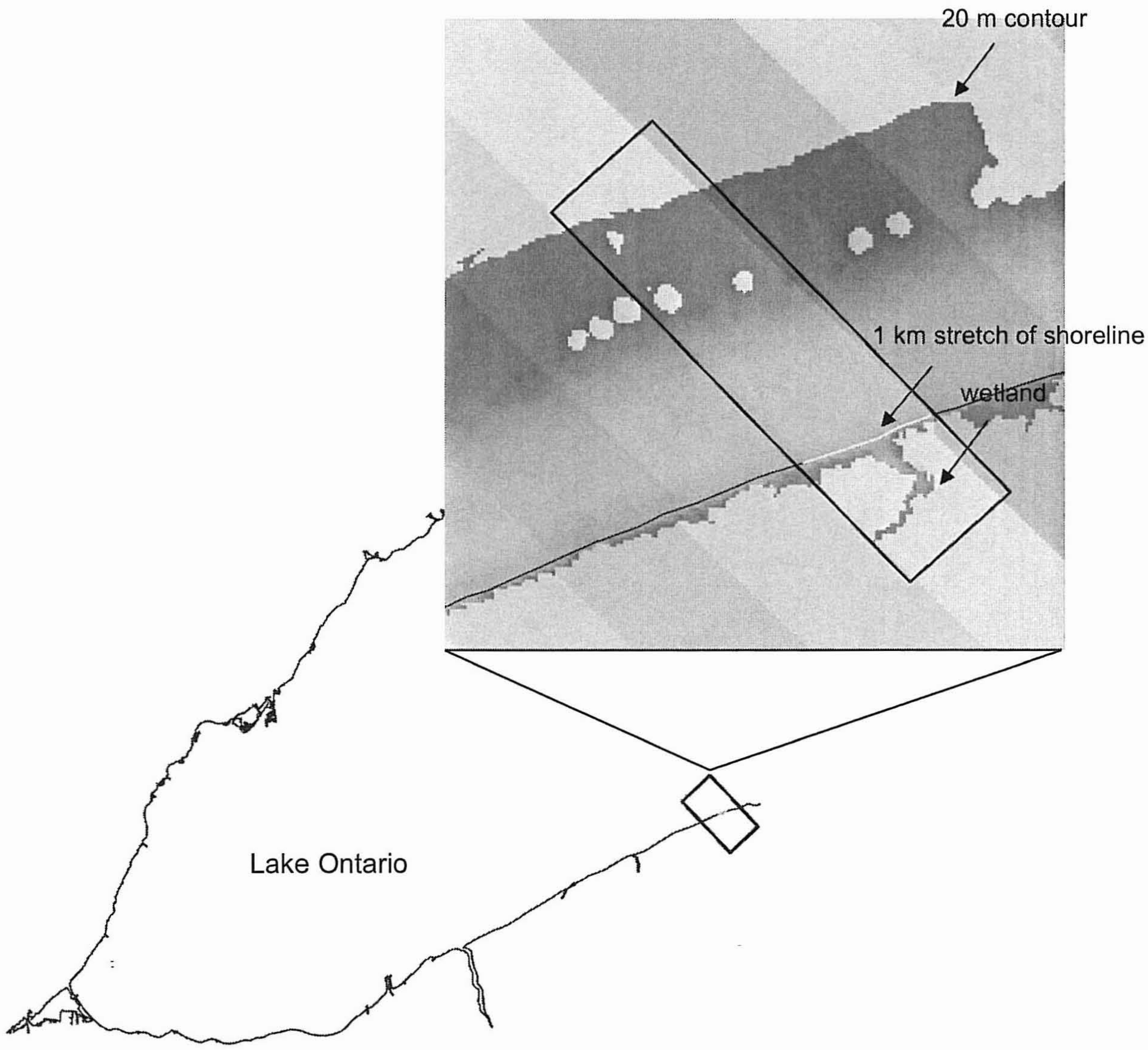

Figure 2: Study area used for demonstration of the northern pike population model. The rectangle defines the study area.

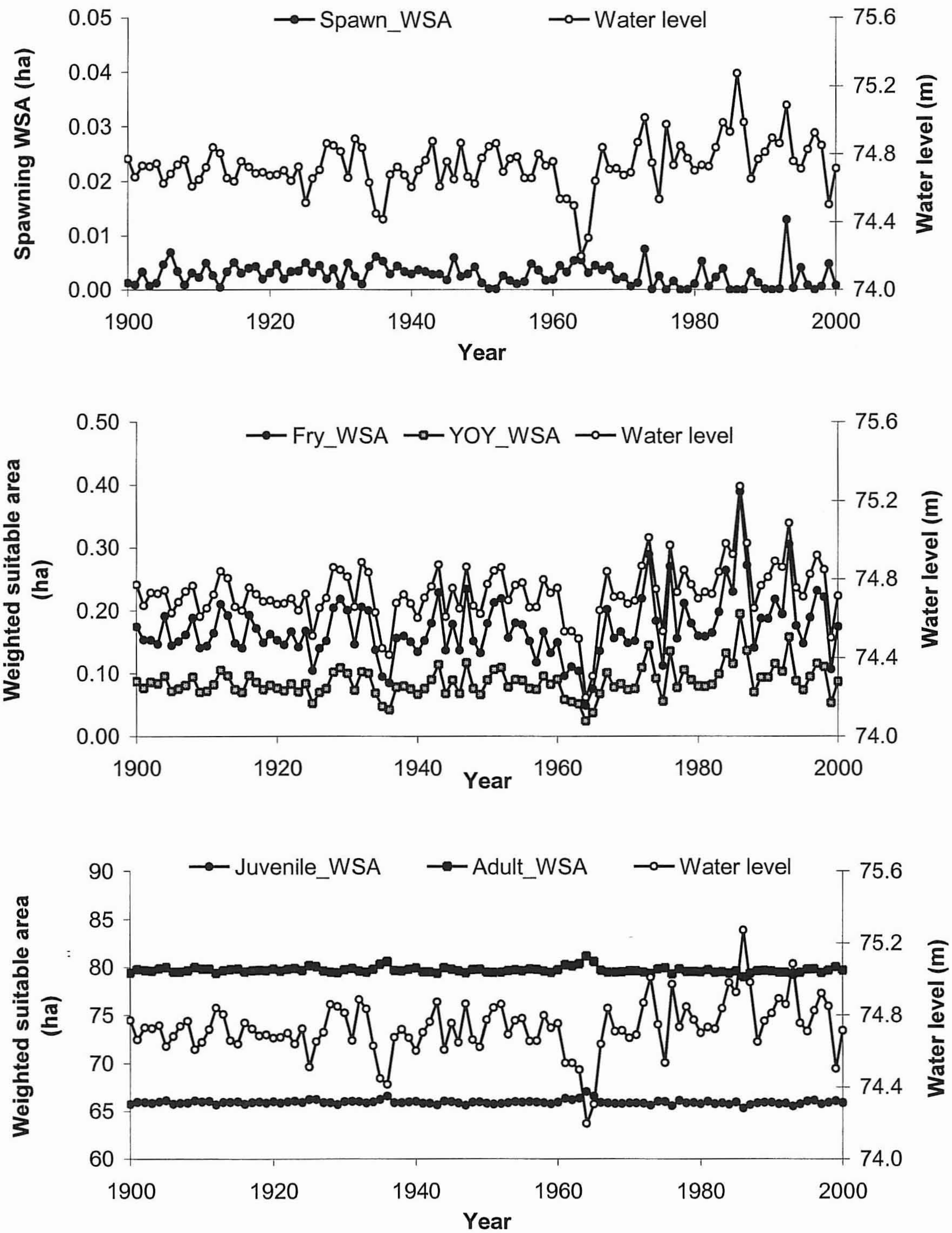

Figure 3: Suitable habitat available for the different life stages of northern pike in a 123 ha study area along the northeastern shore of Lake Ontario.

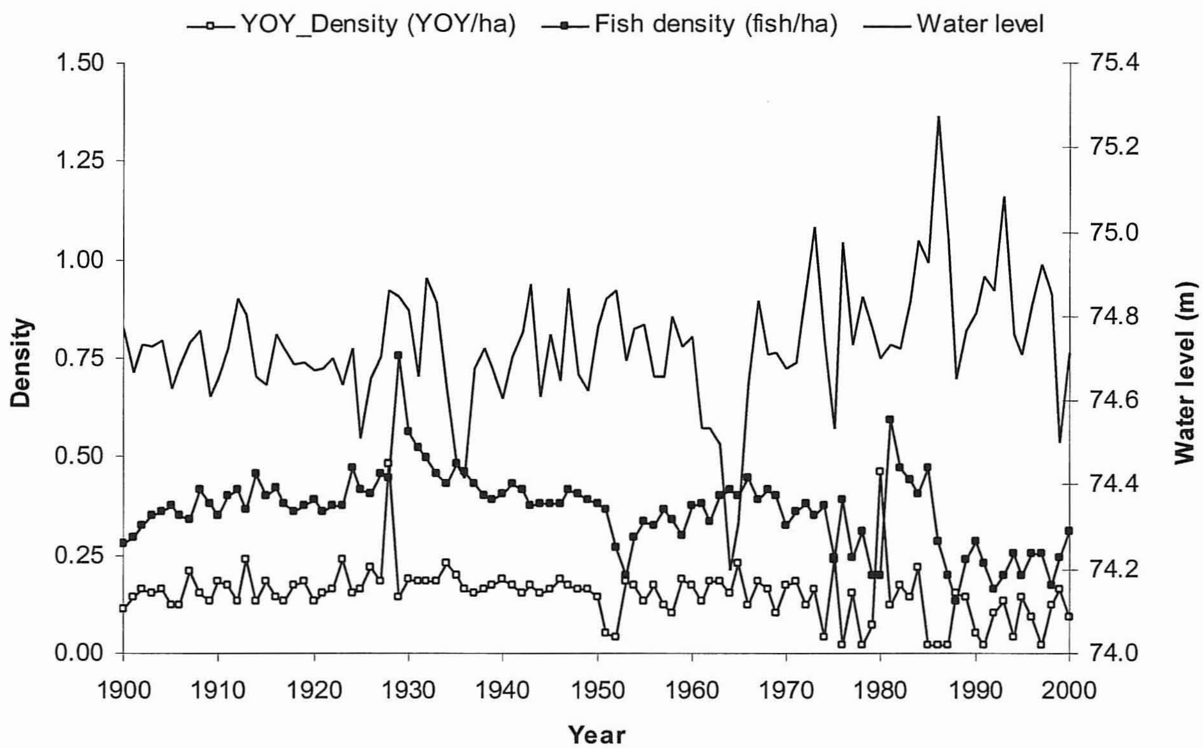

Figure 4: Water levels (m), young-of-year (YOY·ha^{-1}), total fish densities (fish age one and older·ha^{-1}) of northern pike in a 123 ha study area along the southern shore of Lake Ontario.

APPENDIX A

Northern pike habitat-population model code in Visual Basic 6.0 (Microsoft Corp© 1987-1998):

Variable	Definition	Variable	Definition
temp	temperature	JAHR	total home range area required by all juveniles
currstrand	water level change	AHR	total home range area required by all adults
LakeArea	total lake area	CA	Table 5
SPACT	spawn WSA	CQ	Table 5
FFACT	fry WSA	CTO	Table 5
YACT	YOY WSA	CTM	Table 5
JACT	juvenile WSA	RA	Table 5
AACT	adult WSA	RB	Table 5
AreaACT	variable that can represent juvenile and adult WSA	CB	Table 5
STF	average suitability	RQ	Table 5
TotalEggs	total number of eggs available for deposition from all mature females	RTO	Table 5
EDPD(i)	eggs deposited per day of spawning season on day i	RTM	Table 5
Eggsdeposited	number of eggs available for individual females	ACT	Table 5
Eh	eggs surviving each day of the egg development period	SDA	Table 5
SpawnDays	number of days throughout the spawning season	fa	Table 5
Spawned	eggs deposited per day of spawning season	UA	Table 5
Hatchlings	hatchlings surviving each day of the yolk-sac stage	p	proportion of food consumed/maximum consumption
Fry	number of fry surviving each day of fry stage	w	weight
FDEN	fry density	CON-V, -W, -X, -Y	Kitchell *et al.*, 1977 calculations for consumption
swim	number of fry surviving each day of the swim up stage	RESP-V, -W, -X, -Y	Kitchell *et al.*, 1977 calculations for respiration
swimsize	size each day	CONS	consumption
YOY1	number of YOY at end of swim up stage	F	egestion
YOY2	number of YOY surviving to the end of the first season	RESP	respiration
length	length in mm	sda1	SDA*(consumption-egestion)

Fishage	age class	EXC	excretion
MalePop	number of males	ARESP	activity*respiration
FemalePop	number of females	GOACT	actual juvenile/adult growth per day given density
MLength	male length	ACTG	actual YOY growth per day given density
FLength	female length	GRL	potential YOY/juvenile/adult growth given abundant prey, temperature and no density dependent effects
SPArea	area required if each female had an optimal spawning area	HRF	home range required by all YOY
JAArea	area required if there were no overlaps among juvenile home ranges by a single juvenile	Growth	daily growth converted from weight to length
AAHR	area required if there were no overlaps among adult home ranges by a single adult		

```
Sub Main()
 Call FishPopulationSim(1, "BQ”, "NPike")                    ‘call up scenario data
End Sub

Sub FishPopulationSim(RegPlanID As Integer, ReachGroupID As String, SpeciesID As String)
'==================================================================
'= Dimension Variables & Pointers:
'==================================================================
 Const MDB_Fish As String = "IERM_LO_Fish"
 Dim pMDBWS As DAO.Workspace
 Set pMDBWS = DAO.Workspaces(0)

 Const strPopTab As String = "IERM_Population"
 Const strHabTab As String = "IERM_HabitatSupply"
 Const strAgeTab As String = "IERM_AgeStructure"

 Dim i As Long, j As Long, n As Long, t As Long
 Dim iDay As Long, g As Integer                                'array elements
 Dim DayCt As Integer, AgeCt As Integer, YearCt As Integer     'array counters

 Dim strSQL As String
 Dim PathStr As String
 Dim dbFish As DAO.Database, rst As DAO.Recordset              'database properties

 Dim YearArr() As Integer
 Dim TotalFry As Long, TotalSwim As Long

 Dim temp() As Double, currstrand() As Double, LakeArea() As Long     ‘habitat variables
 Dim YACT() As Double, JACT() As Double, SPACT() As Double
```

```
 Dim FFACT() As Double, AACT() As Double, AreaACT() As Double, Dim STF() As Double
                                                                    ' life stage variables
 Dim TotalEggs As Long, EDPD() As Long, EggsDeposited() As Long, Eh As Single
 Dim SpawnDays As Integer, Spawned As Single, Spawn() As Double
 Dim Hatchlings() As Long

 Dim Fry() As Long, FDEN As Single, swim As Double, swimsize As Single
 Dim YOY1() As Long, YOY2() As Long, yoysize As Single
 Dim m As Single, nn As Double
 Dim total7!, totalg!

'---Bioenergetics parameters:
 Dim CA As Single, CQ As Single, CTO As Single, CTM As Single, RA As Single
 Dim RB As Single, CB As Single, RQ As Single, RTO As Single, RTM As Single
 Dim ACT As Single, SDA As Single, fa As Single, UA As Single, p As Single
 Dim w As Single, CONW As Single, CONY As Single, CONX As Single, v As Single
 Dim RESPW As Single, RESPY As Single, RESPX As Single, RV As Single
 Dim CONS As Single, F As Single, RESP As Single, sda1 As Single
 Dim EXC As Single, ARESP As Single, w1 As Single, GOACT As Single
 Dim ACTG As Single, GRL As Single, HRF As Single, growth As Single

 Dim length() As Double, length1() As Double                        'population variables
 Dim fishage() As Integer, MalePop() As Long, FemalePop() As Long
 Dim MLength() As Double, FLength() As Double
 Dim SPArea() As Double, JAArea() As Long
 Dim AAHR As Long, JAHR As Long, AHR As Long

 Dim TotalYOY As Long, TotalHatchlings As Long, TotalFish As Long      'annual totals
 Dim TotalSurv As Long, TotalBiomass As Double, TotalMature As Long
 Dim TotalMatureBiomass As Double, AvgWeight As Double

 Dim numbFish() As Long, numbSurv() As Long, weightFish() As Double    'daily totals
 Dim biomassMale() As Double, maturefishbiomass() As Double
 Dim biomassFemale() As Double, matureFish() As Long
 Dim matureMales() As Long, matureFemales() As Long
'=============================================================
'= Population Model: Initialization
'=============================================================
 Set dbFish = pMDBWS.OpenDatabase(App.Path & "\" & MDB_Fish)
'-----------------------------------------------------------
'- Delete existing pike population results for current reach:
'-----------------------------------------------------------
 strSQL = "DELETE * FROM IERM_Population " & _
        "WHERE ((SpeciesID ='" & SpeciesID & "') " & _
         "AND (RchGroupID = '" & ReachGroupID & "'));"
 dbFish.Execute strSQL
'-----------------------------------------------------------
'- Create array of years based on habitat supply output:
'-----------------------------------------------------------
 strSQL = "SELECT DISTINCT Year FROM " & strHabTab & ";"
 Set rst = dbFish.OpenRecordset(strSQL)
```

```
 With rst
   .MoveLast:  .MoveFirst
   YearCt = .RecordCount
   ReDim YearArr(1 To YearCt)
  For t = 1 To YearCt                              'Start of Main Year Loop*******************
     YearArr(t) = rst("Year")
     rst.MoveNext
   Next t
  .Close:  Set rst = Nothing
 End With
'-----------------------------------------------------------
'-  Read Species Initial Population Structure:
'-----------------------------------------------------------
  strSQL = "SELECT * FROM " & strAgeTab & " " & _
          "WHERE (SpeciesID = '" & SpeciesID & "') " & _
          "ORDER BY Age DESC;"
  Set rst = dbFish.OpenRecordset(strSQL)
  With rst
   .MoveLast:  .MoveFirst
   AgeCt = .RecordCount

   ReDim fishage(AgeCt) As Integer, MLength(AgeCt) As Double, FLength(AgeCt) As Double
   ReDim MalePop(AgeCt) As Long, FemalePop(AgeCt) As Long, numbFish(AgeCt) As Long
   ReDim matureMales(AgeCt) As Long, matureFemales(AgeCt) As Long
   ReDim SPArea(AgeCt) As Double, EggsDeposited(AgeCt) As Long
   ReDim JAArea(AgeCt) As Long

   For n = 1 To AgeCt
     fishage(n) = .Fields("Age")
     MalePop(n) = .Fields("Males_IC")
     FemalePop(n) = .Fields("Females_IC")
     MLength(n) = .Fields("MLength_IC")
     FLength(n) = .Fields("FLength_IC")
   .MoveNext
   Next n
   .Close:   Set rst = Nothing
End With
'=================================================================
'=  Population Model Simulation
'=================================================================
  For t = 1 To YearCt

  Debug.Print "Computing population for year " & t
 '=================================================================
 '=  Initialize Population-Related Variables:
'=================================================================
   growth = 0
   yoysize = 0
   AAHR = 0
   JAHR = 0
```

```
   TotalEggs = 0
   SpawnDays = 0
   TotalFish = 0
   TotalSurv = 0
   AvgWeight = 0
   TotalBiomass = 0
   TotalMature = 0
   TotalMatureBiomass = 0
   TotalYOY = 0
   TotalHatchlings = 0
'==================================================================
 '= Calculate Total Egg Production by Age Class:
'==================================================================

 '----------- Calcs Necessary for Total Eggs that Can Be Deposited -----------

 '---Step #1: Compute the number of mature males based on the following assumptions:
 '  1) 0% of males w/ length <= Lmin are mature
 '  2) 100% of males w/ length > Lmax are mature
 '  3) For males with (Lmin < L <= Lmax), % mature is calculated as: (%mature) = (L- Lmin)/((Lmax+1)
- (Lmin-1))

 'Note - same calculation for females
  For n = 1 To AgeCt

    Select Case MLength(n)
     Case 300 To 450
      matureMales(n) = Abs((0.0066 * MLength(n) - 1.98)) * MalePop(n)
     Case Is < 300
      matureMales(n) = 0
     Case Is >= 450
      matureMales(n) = MalePop(n)
    End Select

    Select Case FLength(n)
     Case 350 To 500
      matureFemales(n) = Abs((0.0066 * FLength(n) - 2.3113)) * FemalePop(n)
     Case Is < 350
      matureFemales(n) = 0
     Case Is >= 500
      matureFemales(n) = FemalePop(n)
    End Select

  '---Step #2: Compute the total number of eggs deposited based on # of mature females as computed

EggsDeposited(n) = (((FLength(n) / 10) ^ 3.527) * 0.000006) * matureFemales(n) '
        TotalEggs = EggsDeposited(n) + TotalEggs

SPArea(n) = matureFemales(n) * (160 * (FLength(n) ^ 2) + 3.1416 * ((FLength(n) * 80) ^ 2)) / 1000000
    If FLength(n) < 349 Then SPArea(n) = 0
```

```
   'from Minns et al. 1996 used to calculated home range - area of required _
   'habitat based on length
JAArea(n) = (MalePop(n) * ((2.74 * MLength(n) ^ 1.52)) + (FemalePop(n) * (2.74 * FLength(n) ^ 1.52)))
/ 1000000
If JAArea(n) = Null Then JAArea(n) = 20000000

      'code to calculate AAHR = total area required by adults
      'if they each had individual home ranges
    If n <= 7 Then AAHR = JAArea(n) + AAHR
    If JAHR > 20000000 Then JAHR = 20000000
     'code to calculate JAHR = total area required by juveniles
     'if they each had individual home ranges
    If n > 7 Then JAHR = JAArea(n) + JAHR
    If JAHR > 20000000 Then JAHR = 20000000

    numbFish(n) = MalePop(n) + FemalePop(n)
    TotalFish = numbFish(n) + TotalFish

  Next n
'==========================================================================
'= Daily Simulation of Fry/YOY Bioenergetics:
'==========================================================================
'--------------------------------------------------
'- Read Habitat Supply Output:
'--------------------------------------------------
strSQL = "SELECT * FROM " & strHabTab & " " & _
          "WHERE ((Year = " & YearArr(t) & ") " & _
            "AND (SpeciesID = '" & SpeciesID & "') " & _
            "AND (RchGroupID = '" & ReachGroupID & "')) " & _
          "ORDER BY Date; "
Set rst = dbFish.OpenRecordset(strSQL)

With rst
    .MoveLast: .MoveFirst
    DayCt = rst.RecordCount

    ReDim temp(DayCt), FFACT(DayCt), Hatchlings(DayCt)
    ReDim EDPD(DayCt), currstrand(DayCt), SPACT(DayCt)
    ReDim YACT(DayCt), JACT(DayCt), AACT(DayCt)
    ReDim LakeArea(DayCt), STF(DayCt), AreaACT(DayCt)

    SpawnDays = 0
   For i = 1 To DayCt
     temp(i) = .Fields("Temperature")
     STF(i) = .Fields("STF")
     currstrand(i) = .Fields("WL_Change")
     SPACT(i) = .Fields("Spawn_WSA")
     FFACT(i) = .Fields("Fry_WSA")
     YACT(i) = .Fields("YOY_WSA")
     JACT(i) = .Fields("Juvenile_WSA")
     AACT(i) = .Fields("Adult_WSA")
```

```
      LakeArea(i) = .Fields("Total_Area")

      .MoveNext
    Next i
   .Close:   Set rst = Nothing
End With

'---------------------------------------------------
'- Define/Refine Spawning Window (egg-hatch):
'---------------------------------------------------

  For i = 1 To DayCt
    '---This code totals the number of days available for spawning (ie. when spawning
    '---area (Sarea)>0).
    If i > 160 Or temp(i) < 4 Or temp(i) > 11 Then SPACT(i) = 0
    If SPACT(i) > 0 Then SpawnDays = SpawnDays + 1
    If SpawnDays = 0 Then SpawnDays = 1
  Next i

'---------------------------------------------------
'- Compute Daily Egg Deposition & Survival to Hatch:
'---------------------------------------------------
  Spawned = TotalEggs / SpawnDays   'Even daily distribution of eggs during spawning window...
  For i = 1 To DayCt
  If SPACT(i) > 0 Then EDPD(i) = Spawned

    If EDPD(i) > 0 Then
      Eh = EDPD(i)
      iDay = i
      growth = 0

    '---Calculate development time and survival for each egg group give temperature:
      Do While growth < 100     'Threshold for swim-up...
        growth = (1.26 * (Exp(0.3 * temp(iDay)))) + growth
      '---This code checks for stranding events (see table - Year column, WLchange '---If change is <1
          eggs are multiplied by that value
      '---to represent a proportional decrease in survival with decreases in water levels

        If currstrand(iDay) >= currstrand(iDay + 1) Then
          Eh = Eh * currstrand(iDay + 1)
        ElseIf currstrand(iDay) < currstrand(iDay + 1) Then
          Eh = Eh
        End If

        iDay = iDay + 1

      Loop

    '---This calculates survival using time to hatch given temperature again,

Hatchlings(iDay - 1) = ((Eh * (2.7182818 ^ (-(0.056 * (iDay - i))))) *currstrand(iDay - 1)) +_
```

```
        Hatchlings(iDay - 1)
     If (iDay - 1) > 190 Then Hatchlings(iDay - 1) = 0
    End If

  '---Track hatchlings:
    TotalHatchlings = Hatchlings(i) + TotalHatchlings
  Next i

'------------------------------------------------------
'-  Fry Development Stage (hatch to swim-up):
'-  (surviving on yolk sac reserves to exogenous feeding)
'------------------------------------------------------

  ReDim Fry(DayCt) As Long
  TotalFry = 0
  For i = 1 To DayCt
  If Hatchlings(i) > 0 Then

     FDEN = (((FFACT(i)) ^ 1.11) / (((FFACT(i)) ^ 1.11) + 250 * _
                 (Hatchlings(i) ^ 1.11))) * Hatchlings(i)

    '---Loop calculates hatchlings growth and survival to exogenous
    '---feeding (swim-up stage)
     iDay = i
     growth = 0

    Do While growth < 100
          growth = (1.26 * (Exp(0.3 * temp(iDay)))) + growth

     '---Again check for stranding during this time if WLchange <1 get decrease in hatchlings:
       If currstrand(iDay) >= currstrand(iDay + 1) Then
         FDEN = FDEN * currstrand(iDay + 1)
       ElseIf currstrand(iDay) < currstrand(iDay + 1) Then
         FDEN = FDEN
       End If
      iDay = iDay + 1
    Loop

     Fry(iDay - 1) = (Fry(iDay - 1) + (FDEN * (2.7182818 ^ _
              (-(0.056 * (iDay - i))) * currstrand(iDay - 1))))
 End If

 TotalFry = TotalFry + Fry(iDay - 1)   'Checking...
Next i
'------------------------------------------------------
'-  Swim-Up Growth to Piscivory:
'------------------------------------------------------
'---Bioenergetics model for YOY starts here ie. growth pre-50mm

  ReDim YOY1(DayCt) As Long
```

```
'Pike parameters from Farrell's (changed Sept 14) group only for YOY, adults uses
'Wisconsin
  CA = 0.228
  CB = -0.355
  CQ = 2.391
  CTO = 26.25
  CTM = 34
  RA = 0.06
  RB = -0.126
  RQ = 2.1
  RTO = 28
  RTM = 34       'this changed from 29 in bioenergetics model cause river temps sometimes exceed 29
°C and RESP is undefined
  ACT = 1.04     'when RV <1
  SDA = 0.14
  fa = 0.13
  UA = 0.07
  p = 1
  w = 0.1

  TotalSwim = 0

  For i = 1 To DayCt

   If Fry(i) > 0 Then

    swim = Fry(i)
    iDay = i        'Initialize day counter...
    swimsize = 0

    Do While (swimsize < 50)
     CONW = Log(CQ) * (CTM - CTO)
     CONY = Log(CQ) * (CTM - CTO + 2)
     CONX = ((CONW ^ 2) * (1 + ((1 + (40 / CONY)) ^ 0.5) ^ 2) / 400)
     v = (CTM - temp(iDay)) / (CTM - CTO)

     RESPW = Log(RQ) * (RTM - RTO)
     RESPY = Log(RQ) * (RTM - RTO + 2)
     RESPX = ((RESPW ^ 2) * (1 + ((1 + (40 / RESPY)) ^ 0.5) ^ 2) / 400)
     RV = (RTM - temp(iDay)) / (RTM - RTO)

     CONS = CA * (w ^ CB) * p * (v ^ CONX) * Exp(CONX * (1 - v))
     F = fa * CONS
     RESP = RA * (w ^ RB) * (RV ^ RESPX) * Exp(RESPX * (1 - v))
     sda1 = SDA * (CONS - F)
     EXC = UA * (CONS - F)
     ARESP = (ACT * RESP)

     growth = (CONS * (1 - 0.308)) - (2 * RESP)
     w1 = w + (w * growth) 'g
     GRL = (w1 ^ 0.33) + 6 'mm
```

```
        HRF = ((2.74 * (GRL ^ 1.52)) * swim)

        ACTG = (GRL * ((FFACT(iDay) ^ 0.96) / ((FFACT(iDay) ^ 0.96) + 0.0101 * ((HRF / 1000000) ^
0.96))))

        swimsize = swimsize + ACTG

        m = (0.1 * (2.71828 ^ (-0.0765 * swimsize)))
        n = (swim * (2.71828 ^ (-m)))
        If n < swim Then swim = n

        iDay = iDay + 1
      Loop
      YOY1(iDay - 1) = n + YOY1(iDay - 1)
    End If
    TotalSwim = TotalSwim + YOY1(iDay - 1)
  Next i
'---------------------------------------------------
'-  YOY Development Stage:
'---------------------------------------------------
'---YOY stage equals growth to end of the first season
  ReDim YOY2(DayCt) As Long

  For i = 1 To DayCt

   If YOY1(i) > 0 Then
     swim = YOY1(i)
     iDay = i
     Do While temp(iDay - 1) > 9 And (iDay - 1) < 300
        w = 0.3
        CONW = Log(CQ) * (CTM - CTO)
        CONY = Log(CQ) * (CTM - CTO + 2)
        CONX = ((CONW ^ 2) * (1 + ((1 + (40 / CONY)) ^ 0.5) ^ 2) / 400)
        v = (CTM - temp(iDay)) / (CTM - CTO)

        RESPW = Log(RQ) * (RTM - RTO)
        RESPY = Log(RQ) * (RTM - RTO + 2)
        RESPX = ((RESPW ^ 2) * (1 + ((1 + (40 / RESPY)) ^ 0.5) ^ 2) / 400)
        RV = (RTM - temp(iDay)) / (RTM - RTO)

        CONS = CA * (w ^ CB) * p * (v ^ CONX) * Exp(CONX * (1 - v))
        F = fa * CONS
        RESP = RA * (w ^ RB) * (RV ^ RESPX) * Exp(RESPX * (1 - v))
        sda1 = SDA * (CONS - F)
        EXC = UA * (CONS - F)
        ARESP = (ACT * RESP)

       growth = (CONS * (1 - 0.308)) - (2 * RESP)
       w1 = w + (w * growth)
       GRL = (w1 ^ 0.33)
       HRF = ((2.74 * (GRL ^ 1.52)) * swim)
```

```
      ACTG = (GRL * ((YACT(iDay) ^ 0.96) / ((YACT(iDay) ^ 0.96) + 0.0101 * ((HRF / 1000000) ^
0.96))))
      total7! = total7! + ACTG
      yoysize = total7! + 50
      m = (0.1 * (2.71828 ^ (-0.0765 * total7!)))
      nn = (swim * (2.71828 ^ (-m)))

      If nn < swim Then swim = nn
     iDay = iDay + 1
   Loop
    YOY2(iDay - 1) = nn + YOY2(iDay - 1)
   End If
   total7! = 0
   TotalYOY = YOY2(i) + TotalYOY

  Next i
  If TotalYOY = 0 Then TotalYOY = 2

'===========================================================================
'=  Compute Juvenile & Adult Growth
'===========================================================================
  ReDim length(DayCt), length1(DayCt)
  ReDim numbSurv(DayCt), weightFish(DayCt)
  ReDim biomassMale(DayCt), biomassFemale(DayCt)
  ReDim matureFish(DayCt), maturefishbiomass(DayCt)
   For g = 1 To 2
    For n = 1 To AgeCt
     If g = 1 Then length1(n) = MLength(n) Else length1(n) = FLength(n)
     If length1(n) = 0 Then length1(n) = 150

     w = (0.000004 * (length1(n) ^ 3.059)) / 1000

     For i = 1 To DayCt
      '---Determine life stage:
      If n <= 7 Then        'Life stage is adult...
        AreaACT(i) = AACT(i)
        AHR = AAHR
      Else                  'Life stage is juvenile...
        AreaACT(i) = JACT(i)
        AHR = JAHR
      End If
     '---Bioenergetics growth calculation:
      If temp(i) >= 10 Then
      iDay = i
        CA = 0.2045
        CB = -0.18
        CQ = 2.59
        CTO = 24
        CTM = 34
        RA = 0.00246
```

```
    RB = -0.18
    RQ = 2.1
    RTO = 28
    RTM = 31
    ACT = 1
    SDA = 0.14
    fa = 0.2
    UA = 0.07
    p = 1

  CONW = Log(CQ) * (CTM - CTO)
  CONY = Log(CQ) * (CTM - CTO + 2)
  CONX = ((CONW ^ 2) * (1 + ((1 + (40 / CONY)) ^ 0.5) ^ 2) / 400)
  v = (CTM - temp(iDay)) / (CTM - CTO)

  RESPW = Log(RQ) * (RTM - RTO)
  RESPY = Log(RQ) * (RTM - RTO + 2)
  RESPX = ((RESPW ^ 2) * (1 + ((1 + (40 / RESPY)) ^ 0.5) ^ 2) / 400)
  RV = (RTM - temp(iDay)) / (RTM - RTO)

  CONS = CA * (w ^ CB) * p * (v ^ CONX) * Exp(CONX * (1 - v))
  F = fa * CONS
  RESP = RA * (w ^ RB) * (RV ^ RESPX) * Exp(RESPX * (1 - v))
  sda1 = SDA * (CONS - F)
  EXC = UA * (CONS - F)
  ARESP = (ACT * RESP)

  growth = (CONS * (1 - 0.308)) - (2 * RESP)
  w1 = w + (w * growth) 'g
  GRL = (w1 ^ 0.33)  'mm
  totalg! = totalg! + GRL
  GOACT = (totalg! * ((AreaACT(i) ^ 0.96) / ((AreaACT(i) ^ 0.96) + 0.0101 _
         * (AHR ^ 0.96))))
  End If
Next i
length1(n) = GOACT + length1(n)
totalg! = 0

If fishage(n) = 1 And length1(n) > 280 Then              'limits to growth
    length1(n) = 280
  ElseIf fishage(n) = 2 And length1(n) > 456 Then
    length1(n) = 456
  ElseIf fishage(n) = 3 And length1(n) > 610 Then
    length1(n) = 610
  ElseIf fishage(n) = 4 And length1(n) > 742 Then
    length1(n) = 742
  ElseIf fishage(n) = 5 And length1(n) > 852 Then
    length1(n) = 852
  ElseIf fishage(n) = 6 And length1(n) > 940 Then
    length1(n) = 940
  ElseIf fishage(n) = 7 And length1(n) > 1006 Then
```

```
      length1(n) = 1006
    ElseIf fishage(n) = 8 And length1(n) > 1050 Then
      length1(n) = 1050
    ElseIf fishage(n) = 9 And length1(n) > 1072 Then
      length1(n) = 1072
    ElseIf fishage(n) = 10 And length1(n) > 1100 Then
      length1(n) = 1100
   End If

   If g = 1 Then MLength(n) = length1(n) Else FLength(n) = length1(n)
  Next n
 Next g
'=====================================================================
'=  Compute Population Metrics for Current Year
'=====================================================================
 For n = 1 To AgeCt
  MalePop(n) = Round(MalePop(n) * 0.45, 0)
  FemalePop(n) = Round(FemalePop(n) * 0.65, 0)

  numbSurv(n) = MalePop(n) + FemalePop(n)
  TotalSurv = numbSurv(n) + TotalSurv

  weightFish(n) = ((0.000004 * (MLength(n) ^ _
    3.059) / 1000) + (0.000004 * (FLength(n) ^ 3.059) / 1000)) / 2
  AvgWeight = weightFish(n) + AvgWeight

  biomassMale(n) = MalePop(n) * ((0.000004 * (MLength(n) ^ 3.059) / 1000))
  biomassFemale(n) = FemalePop(n) * ((0.000004 * (FLength(n) ^ 3.059) / 1000))
  TotalBiomass = biomassMale(n) + biomassFemale(n) + TotalBiomass

  matureFish(n) = matureMales(n) + matureFemales(n)
  TotalMature = matureFish(n) + TotalMature
  maturefishbiomass(n) = matureFish(n) * weightFish(n)
  TotalMatureBiomass = maturefishbiomass(n) + TotalMatureBiomass
 Next n
'=====================================================================
'=  Write Results for Current Year to "IERM_Population"  Table:
'=====================================================================
 strSQL = "SELECT * FROM " & strPopTab & ";"
 Set rst = dbFish.OpenRecordset(strSQL)

 With rst
  .AddNew
  .Fields("RegPlan_ID") = RegPlanID
  .Fields("SpeciesID") = SpeciesID
  .Fields("RchGroupID") = ReachGroupID

  .Fields("Year") = YearArr(t)                              'this code fill in the following
parameters
  .Fields("Fish_Total") = TotalFish
  .Fields("YOY_Total") = TotalYOY
```

```
    .Fields("Hatchling_Density") = ((TotalHatchlings / (LakeArea(1))) * 10000) 'ha
    .Fields("YOY_Density") = (TotalYOY / (LakeArea(1)) * 10000)  'ha
    .Fields("JuvAdult_Density") = (TotalFish / LakeArea(1)) * 10000      'ha
    .Fields("Weight/fish") = AvgWeight / AgeCt
    .Fields("Biomass_Density") = (TotalBiomass / LakeArea(1)) * 10000
    .Fields("P/B") = TotalSurv / TotalBiomass
    .Fields("Mature_Density") = (TotalMature / LakeArea(1)) * 10000
    .Fields("Mature_Biomass") = (TotalMatureBiomass / LakeArea(1)) * 10000

    .Update
    .Close:   Set rst = Nothing
  End With
 '==========================================================================
 '= Update Population Age Structure for Next Simulation Year
 '==========================================================================
  For n = 1 To AgeCt    'Sorted in descending order so age class 1 is last element...
    If (n < AgeCt) Then      'Increment age classes...
      MalePop(n) = MalePop(n + 1)
      FemalePop(n) = FemalePop(n + 1)
      MLength(n) = (MLength(n + 1) + MLength(n)) / 2
      FLength(n) = (FLength(n + 1) + FLength(n)) / 2
    Else
      MalePop(n) = TotalYOY / 2
      FemalePop(n) = TotalYOY / 2
      MLength(n) = yoysize
      FLength(n) = yoysize
    End If
  Next n
'==========================================================================
'= Write Final Population Distribution to "IERM_AgeStructure"
'==========================================================================
 strSQL = "SELECT * FROM IERM_AgeStructure ORDER BY Age DESC;"
 Set rst = dbFish.OpenRecordset(strSQL)
 With rst
  .MoveLast:  .MoveFirst
  For n = 1 To AgeCt
   .Edit
   .Fields("Males") = MalePop(n)
   .Fields("Females") = FemalePop(n)
   .Fields("MLength") = MLength(n)
   .Fields("FLength") = FLength(n)
   .Update
   .MoveNext
  Next n
  .Close:   Set rst = Nothing
 End With
Next t                'End of Main Year Loop********************
'==========================================================================
'= Wrap Up Simulation:
'==========================================================================
```