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SPECKLED TROUT POPULATION PARAMETERS, HABITAT CONDITIONS, AND MANAGEMENT STRATEGIES IN LAKES IN NOVA SCOTIA, CANADA

AMY RYAN[1] AND JOHN L. MACMILLAN[2]

[1] *Ocean Tracking Network, Steele Ocean Sciences Building, Dalhousie University, 1355 Oxford Street, Halifax, Nova Scotia B3H 4R2*

[2] *Inland Fisheries Division, Nova Scotia Department of Fisheries and Aquaculture, Pictou, Nova Scotia B0K 1H0*

ABSTRACT

A principal components analysis was conducted on the results of published reports and data sets from technical papers that include speckled trout *Salvelinus fontinalis* population estimates from 14 Nova Scotia lakes. The purpose of this paper was to identify the factors that influenced trout density and biomass. Population parameters, including mean fork length (cm), population density (n/ha), and population biomass (kg/ha), relative to variation in lake size, acidity, and competitor species were assessed and compared among lakes. Populations with small mean length and slow growth displayed larger fish density and biomass suggesting density-dependence. Acidic conditions potentially impact spawning potential and reduced recruitment that resulted in small population density and larger trout. The number of other fish species present in the lakes was used as an index of competition and had the greatest impact on trout density and biomass in Nova Scotia lakes. Yellow perch seemed to have the most impact of all the competitor species. In five lakes that contained yellow perch the mean trout population biomass was 0.19 kg-ha^{-1} (0.2,SD) compared to 4.5 kg-ha^{-1} (0.26, SD) in nine lakes that did not contain perch species. Lentic habitat conditions can greatly influence the potential success of different fisheries management strategies.

INTRODUCTION

Each spring and summer, thousands of anglers pursue their favorite sportfish, the speckled trout in Nova Scotia. Lentic speckled trout fisheries and populations are diverse and are influenced by a number of factors in the province (Alexander, 1975, Alexander & Merril 1976, Alexander *et al*. 1986, Smith 1938 &1940, Halfyard *et al*.

* Author to whom correspondence should be addressed: john.l.macmillan@novascotia.ca

2008, Hayes & Livingstone, 1955, Munro & MacMillan 2012, Ginn *et al*. 2007, and Heggelin 2008, Peterson & Martin-Robichaud 1989). Understanding the significance of certain factors that impact sport fish populations can often provide a foundation for the development of effective management strategies to improve fisheries. In some cases, changes in water quality of salmonid fisheries have been impacted by habitat changes that are associated with land use, water quality, climate change, invasive species, and overfishing (NSDAF 2014). Surface waters in large regions of Nova Scotia have been impacted by acid precipitation (Ginn *et al*. 2007, Kerekes *et al*. 1982), and has resulted in the extirpation of several Atlantic salmon populations (DFO, 2013). Compared to Atlantic salmon, speckled trout are more tolerant of acidified conditions and are able to successfully inhabit some acidic (pH< 5.0) lakes. Speckled trout populations in lakes may use shallow shoals with groundwater seeps as spawning locations and success can be reduced from changes in water quality. In some cases, acidification can impact trout population size and age structure, as low pH is associated with low recruitment (Ikuta *et al*. 2003).

The presence of other fish species can impact trout populations through direct predation or competition for food and space (Browne & Rasmussen 2009, Hayes & Livingstone 1955, Munro & MacMillan 2012). Many fish competitor species of speckled trout prefer warmer temperatures and warming associated with land clearing and climatic changes has an important influence on reducing habitat for cold water species (Shuter & Post 1990). Warm water temperatures restrict speckled trout to thermal refugia in the hypolimnion of deep stratified lakes. In small shallow lakes speckled trout rely on cool water in spring seeps as surface water temperatures warm (Biro 1998). Crowded conditions in thermal refugia can impact survival by increasing the potential for transmission of disease and the susceptibility to predation and exploitation (MacMillan *et al*. 2008, Coutant 1987). Larger lakes may provide diverse habitat that may be occupied by more competitors to speckled trout (Peterson & Martin-Robichaud 1989). Mixed competition-predation interactions between speckled trout and other fish species have been suggested to play an important role in limiting the abundance and biomass of speckled trout populations in some lakes because they often compete for the same resource and pose potential predatory effects at different size stages (Smith 1938, Quinn *et al*. 1994, Browne & Rasmussen 2009, Munro & MacMillan, 2012). Yellow perch, white perch, smallmouth bass, and chain pickerel tend to be the biggest threat to trout because they are efficient predators, more abundant, and are able to adapt and utilize a wide variety of habitats (Browne & Rasmussen 2009, Munro & MacMillan 2012, Fraser 1978). In Nova Scotia, speckled trout catches were inversely correlated with all freshwater species with the exception of stickleback species (Alexander *et al*. 1986).

Overfishing has been cited as the main cause of the decline of many speckled trout fisheries and regulations to restrict harvest have been used to increase the size of sea run trout caught by anglers in rivers in Nova Scotia (MacMillan & Madden 2007). However, in lake habitats, exploitation may be a less important factor influencing trout populations compared to water quality and competition and regulations are used primarily to sustain fisheries (MacMillan *et al*. 2013, Munro & MacMillan 2012). Each year about 400 trout lakes are stocked to improve fisheries through the use of catchable sized trout in spring or small fall fingerling trout. Return to the angler creel of stocked small fall fingerling trout can be limited and influenced by habitat conditions in lakes compared to stocking large trout in the spring that are immediately available to the angler (Wiley *et al*. 1993).

The objective of this study was to compare the known population estimates of speckled trout and evaluate the importance of several environmental parameters (lake size, lake acidity) and species interactions (competition) potentially regulating speckled trout population parameters in 14 Nova Scotian lakes. These data can be used to evaluate the potential success of fishery management strategies.

METHODS

Study area

Two main geological regions exist in Nova Scotia and separate the province along an east and west axis that runs from Digby to Canso. The southern uplands is located south of the Digby to Canso axis and is characterized by shallow soils and bedrock comprised of mainly granite, slate and greywacke. Most of the lakes in Nova Scotia and in this study (11) are located in the southern uplands where soil and water tend to be nutrient poor and acidic (Fig 1). Waters that flow from northern regions of Nova Scotia tend to be more slightly more productive and less acidic to neutral pH (Davis and Brown 1996). Water quality and morphological parameters in each study lake

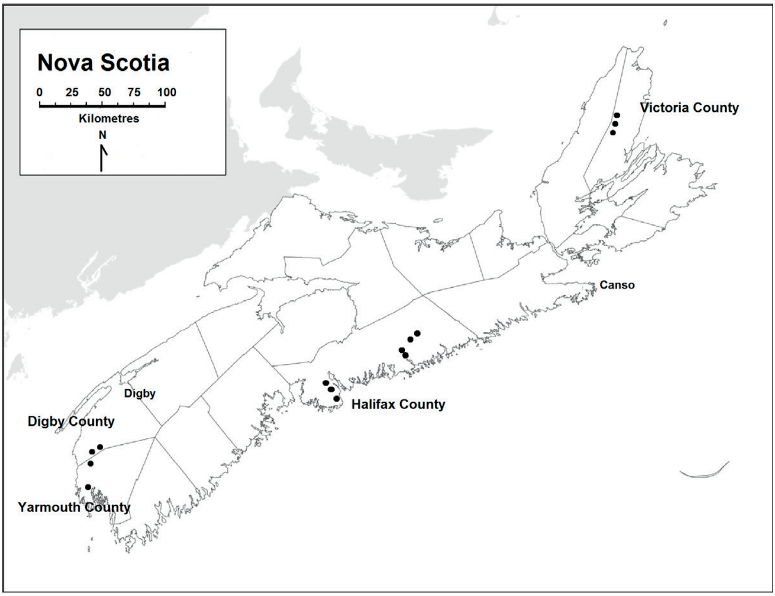

Fig 1 **Provincial distribution of the 14 lakes sampled and their respective counties in Nova Scotia.**

included pH, mean depth, and surface area. Collection of water quality parameters, pH and conductivity from lakes sampled prior to 1974 were described by Smith (1938 & 1940) and Alexander & Merrill (1976). Water quality parameters from lakes sampled after 1974 were evaluated at the Queen Elizabeth Queen Elizabeth II Health Sciences Centre, Halifax, Nova Scotia. Fourteen lakes in the dataset were acidic and the only exception was Ingonish Lake (pH=7.4). Low levels of alkalinity, CaCO3, were recorded from six of the lakes in the survey, mn = 2.4 mg-l-1 (2.1,SD). Mean conductivity was 37.8 (14.7, SD) umho-cm^{-1} in ten study lakes was reflective of the low productivity that characterizes most of the surface waters in Nova Scotia (Alexander *et al*. 1986).

Population estimates

Fish population and habitat data in this study (Table 1) were compiled from journal publications and datasets from technical reports between 1934 and 2011 (Smith 1940 & 1938, Halfyard *et al*. 2008, Alexander & Merrill 1976, Heggelin 2008). Methods to assess the number in the speckled trout population included the use of piscicides during the 1930s and mark-recapture techniques during later surveys.

Table 1 Summary of speckled trout population parameters, other fish species, pH, and lake surface area from 14 Nova Scotia Lakes.

County	Lake	Lats Longs	Year	Area (ha)	Biomass kg-ha^{-1}	Density N-ha^{-1}	*Other Fish species	pH	*Data Cited
Yarmouth	Lake Jesse	4402 6600	1934	18	0.3	2	BB EL KF YP GS WP WS ST CC	5.9	Smith 1938
Digby	Boarsback	4409 6556	1936	23	0.1	1	BB EL KF YP GS WS	4.4	Smith 1938
Yarmouth	Tedford	4406 6600	1936	77	0	0	BB EL KF YP GS WP ST	5.7	Smith 1938
Yarmouth	Trefry	4350 6002	1938	22	0	0	BB EL KF YP GS WP ST SM GA	6.5	Smith 1940
Halifax	Big Indian	4435 6342	1974	106	1.6	10	EL GS KF ST	5.5	Alexander & Merrill 1976
Victoria	Ingonish	4635 6035	1996	32	3.8	35	EL	7.4	NSDFA
Halifax	Fourth	4453 6242	2005	12	2.3	10	EL BB GS	5.8	NSDFA
Halifax	Bluewoods	4452 6251	2005	25	0.5	2	EL YP WS	5.7	NSDFA
Halifax	Northeast	4450 6252	2007	63	3.0	12	EL	4.9	Halfyard et al. 2008
Halifax	Arnold	4450 6253	2007	12	8.7	58	EL	5.2	Halfyard et al. 2008
Victoria	Larken	4631 6037	2008	12	4.1	44	EL	6.6	NSDFA
Victoria	Round	4629 6040	2008	14	8.4	95	EL KF	6.8	NSDFA
Halifax	Blueberry	4437 6341	2011	27	5.7	32	EL KF GS	5	NSDFA
Halifax	Portuguese Cove	4431 6332	2011	19	3.0	16	EL KF	4.8	NSDFA
	Mean (SD)				**33 (29)**	**3 (2.9)**	**23 (28)**	**5.7 (0.8)**	

Other Fish species : El= eel, WP=white perch, BB = brown bullhead, WS = White sucker, YP =yellow perch, KF = banded killifish, GS = golden shiner, ST = stickleback, GA = gaspereau, CC= creek cub, and SM = smelt.
Data cited: NSDFA = Nova Scotia Department of Fisheries and Aquaculture

Fish populations in Boarsback Lake, Tedford Lake, Lake Jesse and Trefry Lake were assessed by Smith (1938 & 1940) using lethal means with a piscicide. The piscicide, copper sulphate, was applied to the waters of the target lake at an approximate concentration of 3 ppm. After piscicide application the numbers, lengths and weights of each fish species were assessed in a specific length of shoreline. Counts of each fish species per shoreline length were extrapolated to the total shoreline length to estimate population number of each species in each lake. Weights of each species were assessed through direct measurements estimated from weight-length equations (Smith 1940). Populations of trout in Boarsback Lake, Tedford Lake, Lake Jesse and Trefry Lake were absent or very small in number and that would have limited the effectiveness of other more commonly used assessment techniques such as mark and recapture. As a result the four lakes studied by Smith (1938 & 1940) were included in our study to represent a region of the province that is known to support relatively small numbers of speckled trout.

Population density and biomass estimates from Smith (1938 & 1940) were incorporated directly into this paper and data from more recent studies were available for the analysis described below. The[2] number of speckled trout (>age 1+y) was estimated in ten lakes from the Adjusted-Petersen method: $N = (M+1) * (C+1) / (R+1)$, where N is the population estimate, M is the number of fish marked, C is the number of fish in the capture sample, and R is the number of recaptures in the capture sample, as described in Ricker (1975). Population estimates from capture-recapture were conducted during a single season (April - October) and based on the number of recaptures being greater than two individuals to minimize statistical bias (Ricker 1975). Dorsal fin clips were used to mark speckled trout in Ingonish Lake. Population estimates in Arnold Lake and Northeast Lake were conducted by using individually numbered carlin tags and adipose fin clips. Clove oil was the anesthetic used during the tagging process as described by Blackman (2002). Adipose fin clips were used to mark trout in all other lakes that were assessed using Adjusted Petersen methods. Other fish species in the study lakes included golden shiner *Notemigonus crysoleucas*, white perch *Morone americana*, yellow perch *Perca flavescens*, white sucker *Catostomas commersonii*, creek chub *Semotilus atromaculatus*, Lake chub *Couesius plumbeus*, American eel *Anquilla rostrata*, Killifish *Fundulus diaphanus*, brown bullhead *Ameiurus nebulosus*, Gaspereau, *Alosa* sp., American smelt

*Osmerus morda*x, and stickleback: *Alpeltes quadracus, Pungitius pungitius, Gasterosteaus* spp.

Length, weight, and biomass

Lengths from post 1973 surveys were available for comparison and mean lengths of older than 1+y trout were compared among these lakes (Table 2). Mean length of speckled trout populations was correlated with mean length at age of 2+y and 3+y trout ($P<0.05$), and was used as an index of growth. Weights were sampled on individual trout from most lakes. When only lengths were sampled, weight-length relationships were used to estimate weight from length data. Recaptures were removed from the estimate of weight-length relationships and length data parameters for each lake to avoid bias. Insufficient weight data was available on two lakes in this study and a standard weight-length relationship, $wt = 0.0105FL^{3.04}$, $r^2 = 0.939$, n=100, that included a randomized combined sample of 25 weights and lengths from Northeast Lake, Arnold Lake, Portuguese Lake, and Blueberry Lake was used to estimate individual weights of fish in Fourth Lake and Blue Woods Lake. Biomass was presented in terms of $kg\text{-}ha^{-1}$.

Capture techniques

Live trapping with a box trap was used in Fourth Lake, Round Lake, Larken Lake, and Northeast Lake. A large box trap (3 m x 3 m x 1 m) with a mesh size of 1 cm^2 was set in less than 3m depth. A lead (50 m x 1 m) was used to guide fish into the entrance of the box trap and was positioned perpendicular to the shore. Live trapping with small fyke nets was used to capture and mark trout in Blue Woods Lake, Portuguese Cove Lake, and Blueberry Lake. Each fyke net consisted of two hoop nets that were attached with a 0.5 m x 5 m lead. Hoop nets had a depth of 0.5 m, leading to a series of 6 circular hoops and a bag at the tail. Mesh size for nets was 1 cm^2. A gill net (33.3 m x 3.3 m) with a three panel mesh size (3.4cm, 5.2cm, and 7.5cm) was used during the capture phase in Fourth Lake. Alexander & Merrill (1976) used angling, live trapping, and gill netting to capture speckled trout in Big Indian Lake. Angling was used to capture salmonids in all surveys conducted after 1973 (Table 3). Mortality associated with live trapping and angling was minimal and was not considered a factor in reducing number of marked trout available for recapture.

Different methods used during marking and capturing may have resulted in selectivity bias that would result in length differences

Table 2 Mean length and age in years of brook trout captured in 10 lakes in Nova Scotia.

Lake Name	**Age 1 N**	**FL (cm)**	**SD**	**Age 2 N**	**FL (cm)**	**SD**	**Age 3 N**	**FL (cm)**	**SD**	**Age 4 N**	**F (cm)**	**SD**
Fourth	22	16	1.8	23	23.4	1.8	13	29.5	2.2	1	38	-
Round	21	12.8	1	28	17.3	2.2	6	27.2	2.6			
Larkin	7	13.6	1	31	20.1	2.2	12	24.2	2.3			
Northeast	18	19.1	2.3	42	23.1	2.6	53	28.2	2	1	32	-
Arnold	9	15	3.2	82	23.6	1.8	19	26.3	1.2			
Blue Woods	1	13	-	10	24	2.5	15	28.6	1.6	1	36.5	-
Ingonish Lake	3	13.5	1.4	19	20.8	2.1	31	22	2.1	1	24	-
Portuguese Cove	3	15.8	1.4	25	24	2	5	30.6	3.5			
Blueberry Lake	3	15.9	1.2	33	22.5	2.3	5	24.8	1.7			
Big Indian Lake	40	15.6	1.8	74	22.7	2.1	15	29.9	2.4	2	35.4	2.6
Mean		**15**	**1.9**		**22.1**	**2.1**		**27.1**	**2.8**		**32.6**	**5.6**

Table 3 Parameters of speckled trout from capture-recapture population assessments in 10 Nova Scotia Lakes.

County	Lake	Year	Marked	Captured	Recaptured	Population estimate	95% c.i. lw	95% c.i. up	Total kg	Forklength (cm) min	Forklength (cm) max	Methods M marking C capture	Month (s) M marking C capture
Halifax	Big Indian*	1974	93	167	14	1031	575	2075	170	21.0	37.2	Angling trapping M netting C	Jun Jul M Jul Aug C
Victoria	Ingonish	1996	88	101	7	1135	540	2063	122	17.2	25.4	Angling MC	Sep MC
Halifax	Fourth	2005	35	30	8	124	66	254	29	20.0	38.0	Angling trapping M netting C	May Jun M Aug C
Halifax	Blue Woods	2005	16	12	3	59	24	146	12	19.0	30.5	Angling trapping MC	May MC
Halifax	Northeast	2007	202	44	11	761	441	1427	191	21.6	32.2	Angling trapping M netting C	Apr May Jun M Oct C
Halifax	Arnold	2007	45	77	5	718	283	1794	106	19.8	28.2	Angling M netting C	May Jun M Sep C
Victoria	Larken	2008	61	77	8	537	288	1099	50	16.8	33.0	Angling trapping M netting C	Jun Jul Aug M Oct C
Victoria	Round	2008	105	256	20	1297	857	2064	116	15.1	33.1	Angling trapping M netting C	Jun Jul Aug M Oct C
Halifax	Blueberry	2011	144	106	16	913	575	1521	152	19.3	29.0	Angling trapping M netting C	May Jun M Oct C
Halifax	Portuguese Cove	2011	76	33	8	291	156	595	56	20.5	35.0	Angling trapping M netting C	May Jun M Oct C

among marked, captured, and recaptured trout in each lake. The size of the marked and captured trout indicated that the 1+y cohort was often underrepresented. A total of 730 scales were used to determine mean length at age in ten populations (post-1973). To address this potential bias scale analysis was used to estimate mean length age and the length midpoint between the 1+y and 2+y cohorts. Fish with lengths larger than the midpoint were included in population estimates. Removal of speckled trout with lengths within the 1+y cohort from marked, captured, and recaptured trout in populations estimates for each lake resulted in the detection of no significant differences among these groups using ANOVA on Ranks, $P<0.5$.

Statistical Analysis

Analyses to examine the influence of environmental variables on several trout population parameters were conducted on the assessment data where population and density estimates were already determined (as above) from 14 lakes in Nova Scotia (Table 1). All analyses and plots were conducted using R-statistical software (R (Core Team 2015). A principal components analysis (PCA) on the correlation matrix was used to identify patterns, and highlight similarities and differences in the lake data. Principal components one and two account for the majority of the variability in the data and were therefore used for further analyses. To examine the relationships among the lakes, the scores of principal component one were plotted against the scores for principal component two and the loadings were plotted on top of the scores in order to reveal any relations among the variables. Variables that appear in close proximity have high correlation. Lakes that appear in close proximity demonstrate similar parameters. Missing loadings indicate that a factor does not load on that component. An item was considered significant if the factor loading was greater than 0.5.

Spearman's correlation matrix was used to identify relationships and collinearity between environmental parameters (lake surface area and pH), competitor species (inferred from other fish species present in each lake), and speckled trout population parameters (trout population density and biomass). As mean forklength (FL) was only available for ten of the lakes examined in this analysis, separate analyses were conducted on the data to examine the factors that regulate FL. Independent (predictor) variables were lake surface area, pH, and the number of other fish species present. Linear and multiple regression analyses were used to identify the statistically significant ($\alpha=0.05$)

predictor variables that regulate speckled trout population parameters (density, biomass, and FL). The Aikaike Information Criterion (AIC) value, model coefficients, r^2, and p-values were estimated for each model. The Shapiro-Wilk and Breusch-Pagan tests were used to investigate the normality and homoscedasticity of the residuals, respectively (P>0.05). The data were not normally distributed, and therefore a square root transformation was used prior to conducting the linear and multiple regression analyses. The relative fit of the regression models was evaluated using AIC. The lowest AIC revealed the model that best predicted mean FL, trout population density, or trout population biomass. Multiple regression models were only accepted if all partial regression coefficients were significant (P<0.05).

RESULTS

Trout population biomass and trout population density from 14 Nova Scotia lakes ranged between 0 and 8.7 kg/ha and between 0 and 95 trout/ha, respectively. The majority of the lakes sampled contained less than 15 trout/ha and the mean population biomass was 3.0 (±2.9, SD) kg-ha-1. Mean FL of speckled trout from 10 of the lakes sampled was 23.8 (±2.5, SD) cm and ranged from 19.5 to 27.3 cm. The mean pH was 5.7 (±0.9, SD) and ranged from 4.4 to 7.4 and the lake surface areas ranged from 12 ha to 106 ha. The number of other fish species in the study lakes ranged between 1 (American eel) and nine (Table 1). The majority of the catch was two and three year old trout and oldest speckled trout captured was 4 years old (Table 2). The results of the PCA of the 14 lakes (forklength removed) using the correlation matrix indicated that principal component one and principal component two accounted for most of the variability in the data, accounting for 58% and 21%, respectively. The first principal component is strongly correlated with three of the variables (Table 4). The first principal component increases with decreasing population density and biomass and increasing number of other species present. This suggests that lakes with higher numbers of competitor species tend to have lower trout population density and biomass. The second principal component is strongly correlated with two of the variables, decreasing area and increasing pH values. A plot of the scores and loadings between component one and component two demonstrated that Tedford, Boar's Back, Jesse, and Trefry lakes, from Halifax,

Table 4 **Summary of the principal components analysis using the correlation matrix to assess the important parameters regulating the size, population density and biomass of speckled trout in 14 Nova Scotia lakes. Proportions of variance accounted for by each component, as well as the respective loadings are presented. Missing loadings indicate that a factor does not load on that component.**

	Principal Components				
	1	2	3	4	5
Proportion of Variance	0.5783004	0.2102907	0.1631539	0.04430323	0.003951766
Variables					
Area	0.263	**-0.508**	0.8	0.182	
Trout population density	**-0.571**			0.452	-0.682
Trout population biomass	**-0.565**	-0.185		0.364	0.717
*CS	**0.508**	0.301	-0.154	0.788	
pH	-0.165	**0.785**	0.576		0.126

*CS = number of competitor species

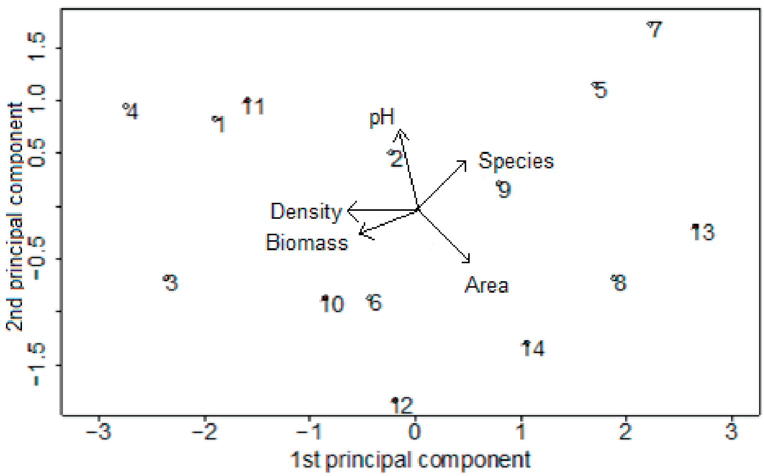

Fig 2 **Relationship between the scores of the first principal components to the second using the correlation matrix on the 14 Nova Scotian lakes. The arrows are the loadings of each of the variables on either of the components.**

Yarmouth, and Digby counties, were associated with higher numbers of other species present (Fig 2). These lakes also had the lowest trout population density and biomass estimates. Ingonish, Larkin and Round lakes, all from Cape Breton, had the highest pH values; 7.4, 6.6 and 6.8, respectively and the only other species present in each lake was American eel and the banded killifish (Round Lake only).

Halifax County Lakes, Northeast and Big Indian, had the largest surface area and relatively low trout population density and biomass.

The correlation matrix indicates that trout population biomass was reduced in lakes with higher numbers of other species present (r = -0.81). Trout population density was also negatively correlated with the number of other species present in the lake (r = -0.85) and lake surface area (not significant). Neither trout population biomass nor density was related to pH. The results suggest that the numbers of other species present impacts trout population biomass and density. The results of the univariate and multivariate regression models are presented in Table 5. Using AIC to compare the regression models (selecting only the models where all partial regression coefficients were significant) determined that the best indicator of trout population biomass was the number of other species present ($r^2 = 0.68$; $P<0.001$). The best predictor of trout population density was also the number of other species present in the lake ($r^2 = 0.59$; $P = 0.001$; Fig 3). From this it can be inferred that the number of other fish present has the greatest impact on trout population biomass and density. Yellow perch seemed to have the most impact of all the competitor species. In five lakes that contained yellow perch the mean trout population biomass was 0.19 $kg\text{-}ha^{-1}$ (0.2, SD) compared to 4.5 $kg\text{-}ha^{-1}$ (0.26, SD) in nine lakes that did not contain perch species.

Table 5 Results of the univariate and multivariate regression models assessing the impact of lake acidity (pH), lake size (area, ha), and number of other species present (CS) on trout population biomass (kg/ha) and density (n/ha) in 14 Nova Scotia Lakes. AIC (Aikaike Information Criterion) values determined the best predictor model.

	Population Biomass (kg/ha)			Population Density (n/ha)		
n		14			14	
Shapiro-Wilk		P>0.1			P>0.1	
Breausch-Pagan		P>0.1			P>0.1	
Model:	*P*-value	r^2 value	*AIC value*	*P*-value	r^2 value	*AIC value*
pH	0.713	-0.01	**28.5223**	0.32	0.08	**62.5259**
*CS	**<0.001**	0.68	44.2764	**0.001**	0.59	74.0689
Area	0.263	0.1	42.9149	0.2	0.13	73.2976
pH + *CS	**0.002**	0.68	30.4524	**0.003**	0.65	62.6669
pH + Area	0.539	0.72	28.7545	0.33	0.18	**62.2654**
CS + Area	**<0.001**	0.11	44.8707	**0.003**	0.66	74.4375
pH + *CS + Area	**0.004**	0.72	30.7511	**0.006**	0.69	62.7697

*CS = number of other species; Significant *P*-values are highlighted bold.

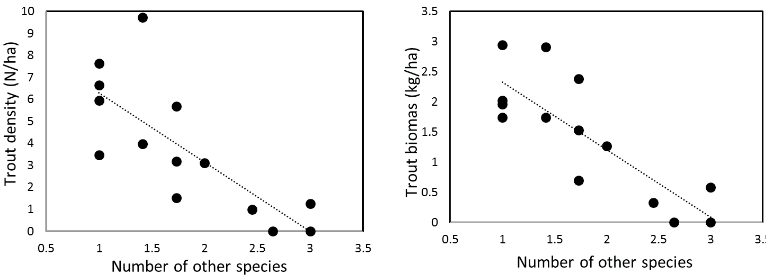

Fig 3 **Graph of the model with the greatest explanatory power given the data from AIC analysis for the predictor variables (pH, number of other species, and lake surface area) of trout population biomass: the square root transformed speckled trout population density (N-ha-1) and biomass (kg-ha^{-1}) versus number of other species present in 14 Nova Scotia lakes. Each circle represents a lake. Linear regression: Linear regression: Population density = -3.1562CS + 9.4625, r^2 = 0.60, P=0.001.Population biomass = -1.1188CS + 3.4424, r^2 = 0.68, P<0. 001.**

The correlation matrix of the 10 lakes sampled demonstrated negative associations between mean FL and lake pH (r = -0.54), and mean FL and trout population density (r = -0.81), respectively. However, mean FL was not associated with lake surface area or the number of other species present in the lake. The results of the univariate and multivariate regression models are presented in Table 6. Using AIC to compare the regression models determined that pH and trout population density were the best predictors of mean FL (r^2 = 0.85; P=0.001; Fig 4), suggesting that trout population density and lake pH both influenced fish growth.

DISCUSSION

Most anglers pursue wild speckled trout and much of the effort is directed on the 6700 lakes in the province (NSDFA 2014). Effective resource management is dependent on an understanding of the variety of factors that may influence target populations. The results of our analysis indicate that acidity (pH) and number of competitors are factors regulating speckled trout population parameters. Mean fork length increased as pH decreased and suggests that acidic conditions were not limiting growth as the largest mean lengths were detected in acidic lakes. Trout population density indecis were greater in less acidified lakes and mean size and the proportion of older fish in speckled trout populations was inversely related to pH in twelve

Table 6 **Results of the univariate and multivariate regression models assessing the impact of lake acidity (pH), lake size (area, ha), number of other species present (CS), and trout population density (n/ha) on mean forklength (FL, cm) of speckled trout in 10 Nova Scotia Lakes. AIC (Aikaike Information Criterion) values determined the best predictor model.**

	Forklength (cm)		
N	10		
Shapiro-Wilk	P>0.05		
Breausch-Pagan	P>0.1		
Model:	*P*-value	r^2 value	*AIC value*
pH	**0.008**	0.6	50.42220
*CS	0.312	0.13	42.60892
Area	0.2	0.2	49.59934
Density	**0.005**	0.65	41.18402
pH + *CS	**0.033**	0.62	44.00272
pH + Area	**0.02**	0.68	42.48817
pH + Density	**0.001**	0.86	**34.31876**
CS + Area	0.397	0.23	51.14234
CS + Density	**0.024**	0.65	43.16994
pH + *CS + Area	**0.063**	0.68	44.40223
pH + *CS + Density	**0.006**	0.86	36.28832
Area + pH + Density	**0.005**	0.87	35.69192
pH + *CS + Area + Density	**0.02**	0.87	37.50573

*CS = number of other species; Significant *P*-values are highlighted bold.

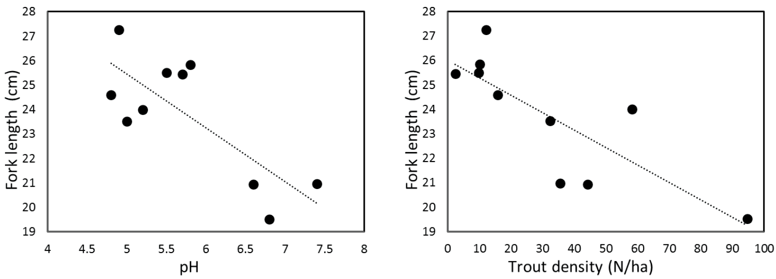

Fig 4 **Partial regression plots demonstrating the relationship between mean fork-length (FL, cm) and population density ((n ha^{-1}) and lake acidity (pH) for speckled trout captured from 10 Nova Scotia lakes. The predictive model is represented by the equation: mean FL = -1.4433pH – 0.0505density + 33.6799, r^2 = 0.86, P=0.001.**

lakes in the Tangier Grand Lake Wilderness Area (Heggelin, 2008). Speckled trout spawn in shallow shoals of lakes and these regions are usually associated with groundwater influence (Curry & Noakes 1995, Ridgway & Blanchfield 1998), and low pH has been associated with reduced spawning habitat and recruitment (Ikuta *et al*. 2003). Lakes with higher pH values (>5.0) have relatively greater spawning potential, increased trout population densities and intraspecific competition (Donald and Alger 1989). Many speckled trout populations observed in the relatively small, circumneutral (6.5-7.5 pH) lakes of the Cape Breton highlands - Ingonish, Larkin, and Round lakes - contained speckled trout with the smallest mean fork length and had the highest observed trout population densities. Similarly, trout population size structure among beaver ponds in Wyoming was inversely related to population density and a negative correlation between mean length and mean weight, and speckled trout population density (Johnson *et al*. 1992). Speckled trout growth is probably associated with trout population density or the level of crowding in Nova Scotia lakes.

Speckled trout population density and biomass was strongly related to the number of competitors in the lake and less so to the surface area. As the size of the lake and the number of competitor species increased, speckled trout population biomass ($kg\text{-}ha^{-1}$) and density ($n\text{-}ha^{-1}$) tended to decline. Species richness and the presence of competitors of speckled trout was related to lake size (Peterson & Martin-Robichaud 1989). Nine hundred and forty-nine lakes were assessed for the presence of fish species in Nova Scotia (NSDFA, unpublished). Fish species were categorized based on their potential impact on speckled trout populations. Species considered to be minor competitors of speckled trout included cyprinids, killifish, and sticklebacks. A total of 25% of the 492 lakes with a surface area less than 30 ha contained only minor competitors of speckled trout, while 5% of the 219 lakes with a surface area larger than 90 ha had minor competition for speckled trout. The inability of trout to compete with other species, specifically yellow perch, has been widely documented (Fraser 1978, Quinn *et al*. 1994, Browne & Rasmussen 2009, Munro & MacMillan 2012). Mixed competition-predation interactions between speckled trout and perch have been suggested to play an important role in limiting the numbers of speckled trout in some lakes (Smith 1938, Browne & Rasmussen 2009). Although yellow perch are a potential prey source for piscivorous-sized speckled trout, dietary overlap is common, as both species are generalists and, depending on their life history stage, feed on zooplankton, insects, and smaller fish. Yellow perch tend to dominate the competitive interaction between the two species because they are more efficient at feeding on their invertebrate prey, they tend to be more abundant, and are able to adapt and utilize a wide variety of habitats (Browne & Rasmussen 2009). As a result, the amount or type (smaller planktonic prey items) of food available to speckled trout is reduced, which can lead to a reduction in trout population biomass. In the presence of competitor species such as yellow perch, anecdotal accounts suggest that selective harvest on trout populations in Ontario Lakes has resulted in a decline in speckled trout catches (Browne & Rasmussen 2009). In lakes that support a complex species mix, speckled trout biomass and recruitment may be only a small proportion of the total fish biomass in a lake (Alexander 1975), and some trout populations could be easily over-exploited and replaced by a shift of abundance to under-exploited species such as perches (Rumsey *et al*. 2007).

One of the challenges facing sustainability of fish and wildlife resources is the introduction of invasive species that can out-compete native species. Although no invasive fish species were present in the study lakes, the rapid spread of invasive species (smallmouth bass and chain pickerel) is of particular concern as they have greatly influenced fish communities and fisheries in lakes in Nova Scotia. Paterson & Martin-Robichaud (1989) recorded that speckled trout were absent from many lakes that were inhabited by chain pickerel and smallmouth bass in Nova Scotia and New Brunswick. The presence of smallmouth bass and chain pickerel are suited for habitats in lakes and can tolerate large changes in temperature, giving them a competitive advantage over speckled trout populations. Since their introduction in the 1940's, smallmouth bass, has grown into a significant sportfishery and consequently their distribution has been greatly extended to over 200 lakes in the province (LeBlanc 2010). The increase in the number of lakes containing invasive fish species is primarily through natural migration or illegal introduction (McNeill 1995). Management strategies to reduce the rate of spread of invasive species included changes to legislation to prohibit the possession of live fish and angling closures for invasive species in about half of the province. Angling closures have been implemented to reduce the incentive that some anglers may have to introduce invasive species to expand angling opportunities for smallmouth and pickerel. Ongoing monitoring will be required to evaluate the results of recent initiatives to control the spread of invasive species in Nova Scotia.

Changes in angler accessibility has been cited as a probable reason why some trout lakes are over-exploited and how some fisheries may shift from primarily a trout fishery to a perch fishery (Rumsey et al 2007). This shift from trout to perch poses a potential limitation in our results as no index of exploitation was available on all of our study lakes. However, our results were similar to those reported by Quinn et al. (1994) and the impact of exploitation was minor compared to the impact of non-trout species in Ontario lakes. In general, speckled trout populations tend to be fast growing and early maturing and these characteristics provide a buffer against over-fishing compared to later maturing lake trout *Salvelinus namaycus*h, populations (Curry et al. 2003). Anglers in Nova Scotia have expressed concern about over-exploitation of speckled trout populations in lakes across the province and the need of restrictive regulations to protect the resource. In response to this concern, restrictive angling regulations have been implemented on a select few mainland lakes for the purpose of reducing the risk of a decline and sustaining trout fisheries. In comparison, liberal regulations have been used on several Cape Breton Highland lakes to encourage exploitation to thin out stunted trout populations. Similarly, artificial removal of Arctic char, *Salvelinus alpinus*, a closely related species to speckled trout, has been used to mimic exploitation and resulted in improved growth and age structure in stunted populations in lakes (Amundsen et al. 1993).

Stocking with spring catchable (>20cm) sized trout or small (<15cm) fall fingerlings is a common practice to enhance fisheries. Survival of trout to the angler creel is related to size of stocked trout, domestication of hatchery stock, and fish competitors in the lake (Wiley et al. 1993). Alexander (1972) estimated average angler recapture rates of 70% from stocking yearling and older brook trout in eight lakes located close to Halifax, Nova Scotia. Stocking large trout is successful in creating popular trout fisheries regardless of habitat condition or the presence of competitors as the large trout are immediately available for capture (Wiley et al. 1993). In comparison, Fraser (1972) evaluated the survival rate of stocked fingerlings in six Ontario Lakes. When introduced as fingerlings, brook trout recaptures ranged from 6% to 20% when wild brook trout and competitors were few or absent, while recaptures were less than 3% in lakes inhabited by yellow perch. The results of our study are obviously more relevant to a fall fingerling strategy that requires stocked trout to survive and grow over several months in the wild before they are available to be caught by anglers.

Lake acidity and competitor species are important factors influencing speckled trout population parameters in Nova Scotia. The effects of the factors that limit speckled trout populations could be exacerbated by increased habitat loss, illegal introductions of non-native species, and climate change. Most fish species considered as competitors of speckled trout are physiologically suited for warm conditions and warming temperatures could reduce the availability of suitable habitat for speckled trout and provide other fish species with a competitive advantage. The study highlights the importance of controlling the spread of invasive species and inclusion of fish species compositions into fishery management strategies that are directed toward lake habitats.

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