

Geographic Variation of Populations of  
Mimic Shiners, *Notropis volucellus* (Cope 1865)

and

Sand Shiners, *Notropis stramineus stramineus* (Cope 1865)

(Cyprinidae),

in Manitoba and Southern Ontario

by

Beverly M. Horn

A thesis  
Submitted to the Faculty of Graduate Studies  
in Partial fulfilment of the Requirements  
for the Degree of

MASTER OF SCIENCE

Department of Zoology  
University of Manitoba  
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IN MANITOBA AND SOUTHERN ONTARIO

BY

BEVERLY M. HORN

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba  
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## ABSTRACT

*Notropis volucellus volucellus* and *N. stramineus stramineus* are morphologically similar, especially in areas of sympatry. I investigated the morphological, biogeographic and reproductive relationships between them in Manitoba and Southern Ontario. I wished to determine which characteristics could be used reliably to distinguish between them in zones of allopatry and sympatry and to determine what, if any, reproductive isolating mechanisms function in zones of sympatry. Weekly collections were made at several sites in Ontario in 1987 and 1988, and in Manitoba in 1989 and 1991. Standard characteristics of field caught and museum specimens were subjected to discriminant function analysis to determine which characteristics discriminated between the species as a whole, between species within province, within species between province, and between allopatric and sympatric populations of both species in Ontario. The species were more distinct from each other in Manitoba than in Ontario. Ontario and Manitoba populations of *N. s. stramineus* were more distinct than Ontario and Manitoba populations of *N. s. volucellus*. Both allopatric and sympatric populations of the two species were more similar to heterospecifics from the same type of site than they were to conspecifics from the other type of site. Sympatric populations were largely allochronic, both in site use and sexual maturation, or were numerically dominated by one or the other species. Gonadosomatic Indices of both sexes were plotted against water temperature and compared between populations over time. In both provinces in both species testes matured at 15° C and threshold temperature for spawning was 18-20°C. Allopatric populations of both species in Ontario and *N. s. stramineus* in Manitoba were sexually mature by the start of the collecting season. Allopatric populations of both species in Ontario have prolonged spawning periods, and *N. s. stramineus* may be a multiple spawner. Manitoba populations of both species have single, relatively short spawning periods.

## ACKNOWLEDGEMENTS

I wish to thank Dr. K. W. Stewart for coercing me into doing this project, and for rendering moral and financial support.

I received help and encouragement from Dr. E. J. Crossman and Mr. E. Holm of the Royal Ontario Museum, Department of Ichthyology and Herpetology, which also loaned me many specimens. The Ontario Ministry of Natural Resources permitted me to make collections in Ontario and provided me with lists of all collection sites from which these species have been collected in Ontario. This was invaluable for locating my own collecting sites in unfamiliar territory.

At various times I was helped in the field, in Manitoba by K. W. Stewart, B. McCulloch, J. D. Tyson, G. Hanke, R. Kenny, S. Kenny and L. Sawka, and in Ontario by E. J. Crossman, E. Holm and others from the ROM.

This study would have been impossible without the assistance of Beverly Himick in 1987 and Mark Stewart in 1988, who looked after my cats in Manitoba, and Mr. Denis Delorme who provided affordable housing during my field seasons in southern Ontario.

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## INTRODUCTION

*Notropis volucellus* (Cope 1865), the northern mimic shiner, and *N. stramineus stramineus* (Cope 1865), the sand shiner, were originally recognized as separate species by Cope (1865) and confirmed as such by Hubbs & Greene (1927). Hubbs & Greene (1927) also recognized that *Hybopsis missuriensis* Cope 1871 is actually a western subspecies of *N. s. stramineus*, and renamed it *N. s. missuriensis* (Cope 1871). *N. volucellus* includes at least one (Mayden 1989) or two (Gilbert 1978) undescribed subspecies. A third possible subspecies, *N. v. wickliffi* Trautman 1931, may be elevated to full species status (Gilbert 1978) although Mayden (1989) makes no mention of it. The reader is referred to Gilbert (1978) for the nightmarish nomenclatural history of these species.

There have been many attempts to ascertain the relationships of these species to each other and to other *Notropis* species (Amemiya & Gold 1990, Becker 1983, Gold et al. 1978, 1979, Hubbs & Hubbs 1958, Hubbs & Raney 1947, Lee et al. 1980, Mayden 1989, Snelson 1971, Suttkus 1959, Trautman 1931). Based on morphometric data, Mayden (1989) describes a *volucellus* species-group composed of two clades, one including *N. volucellus* plus *N. ozarcanus* Meek 1891, *N. spectrunculus* (Cope 1868), *N. tropicus* Hubbs and Miller 1975, and *N. buchanani* Meek 1896. The sister-clade includes *N. heterolepis* Eigenmann and Eigenmann 1893, *N. emiliae* (Hay 1881) and *N. maculatus* (Hay 1881). Based on chromosomal characteristics, Amemiya and Gold (1990) removed *N. maculatus* and *N. emiliae* from this assemblage and returned *N. emiliae* to its original genus *Opsopoeodus*. Both authors agree that the affinities of *N. s. stramineus* to other *Notropis* species remain uncertain.

Gross morphology of live specimens of *N. volucellus* and *N. s. stramineus* is similar, becoming more so in areas of sympatry where they may be indistinguishable (Fig. 1a, *N. s. stramineus* at arrow) (Crossman and Holm 1986, pers. comm.), suggesting the possibilities of convergent adaptation and/or hybridization of these species. (*N. v. volucellus* and *N. v. wickliffi* are both known to hybridize (rarely) with other *Notropis* species (Bailey 1960, Mayhew 1983)). Pigment patterns, such as "mousetracks" (Becker 1983) along the lateral line, pigment depositions around the anus extending as a midventral stripe to the base of the tail, and especially the middorsal stripe (Fig. 2a) (Scott & Crossman 1973, Trautman 1957) which are frequently used to differentiate these species, are unreliable because they are variable within living members of both species. The middorsal stripe in particular is usually represented in life by an iridescent yellow or green stripe (Fig. 1b, at arrow) which is not identical to the dark stripe which frequently appears only after death (Fig. 2a).

*N. volucellus* and *N. s. stramineus* are both widely distributed in North America (Fig. 3) with broad areas of potential sympatry.

*N. volucellus* is frequently described as a lacustrine (Becker 1983, Hanych et al. 1983, Moyle 1973) or riverine species (Smith et al. 1981). It is, however, apparently much more plastic than this. This study and records from Galveston Bay (Conner & Suttkus 1986, Evermann 1892) and Mobile Bay (Swift et al. 1986) suggest that *N. volucellus* tolerates a wide variety of temperatures, turbidities, salinities and water velocities. This environmental plasticity almost certainly accounts for its wide distribution, and its tolerance of high levels of turbidity probably accounts for its survival in agricultural and industrialized areas.

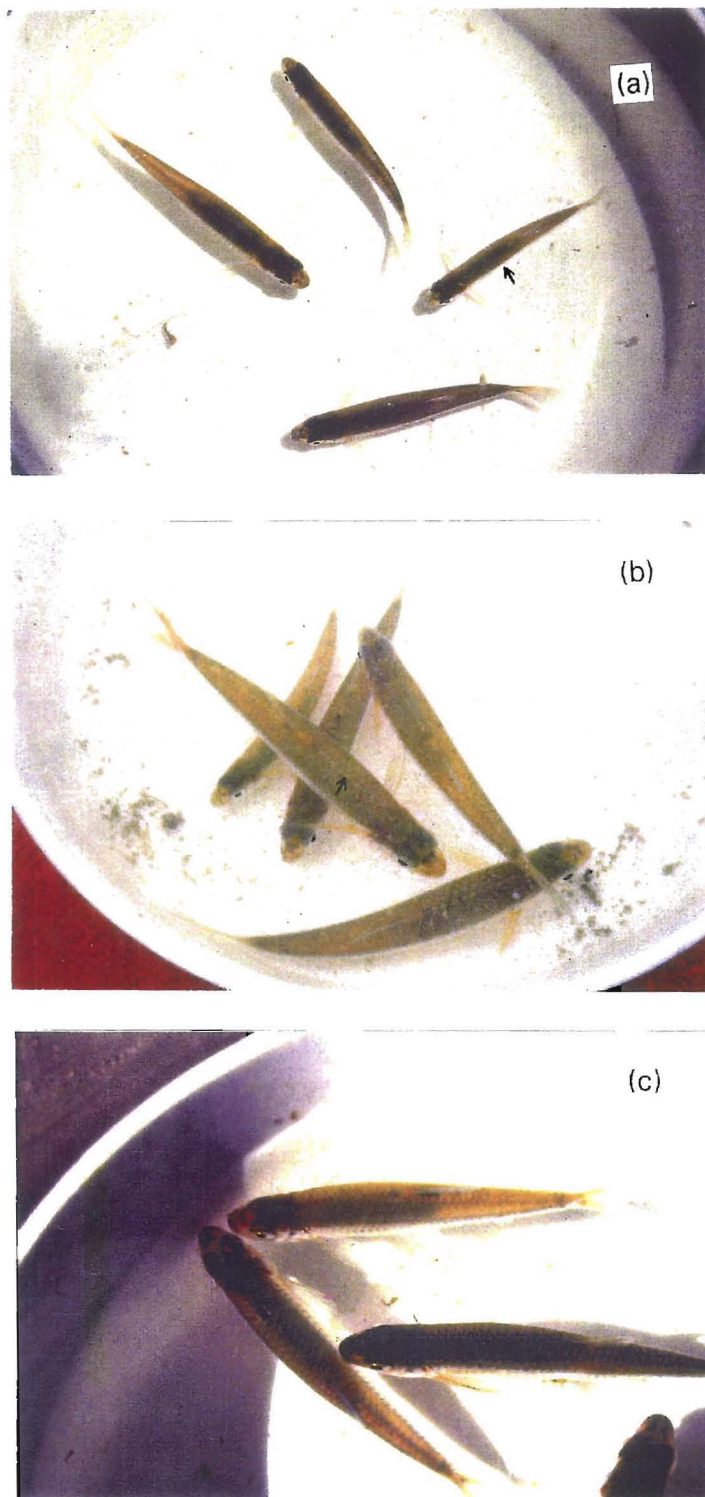


Fig. 1. Living specimens; (a) three *Notropis volucellus* and one *N. stramineus* from Indian Brook, ON; (b) *N. stramineus* from Duffin's Creek, ON; (c) *N. volucellus* from the Welland River, ON.

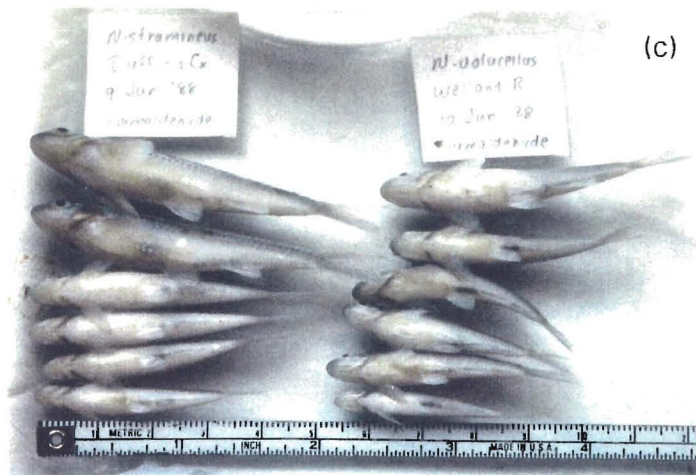
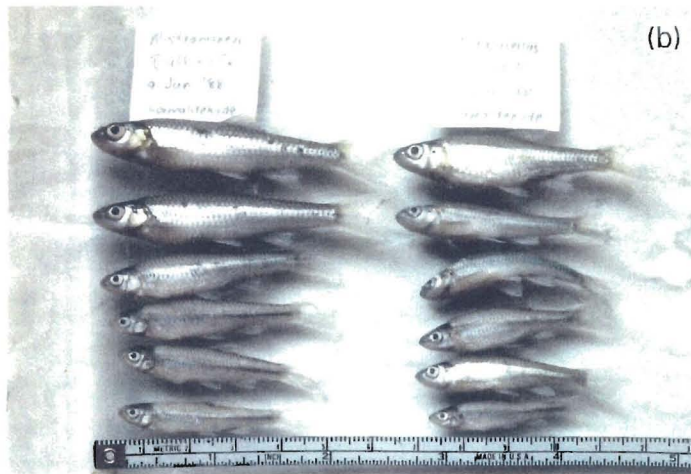
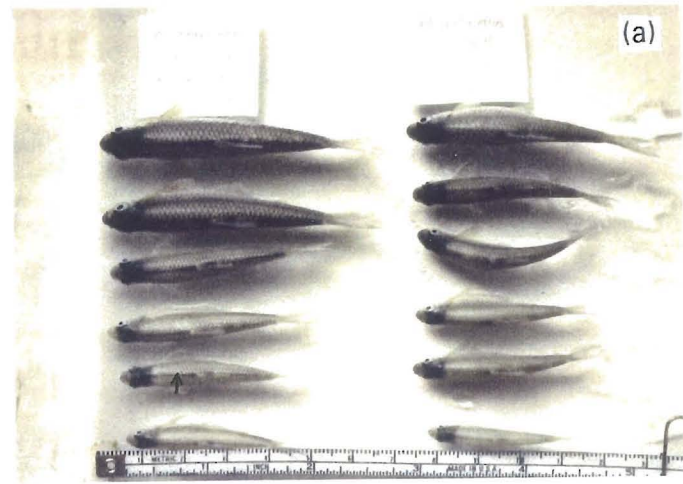


Fig. 2. Preserved specimens of *Notropis stramineus stramineus* (left) from Duffin's Creek, ON and *N. volucellus* (right) from the Welland River, ON. ((a) dorsal, (b) lateral, (c) ventral)

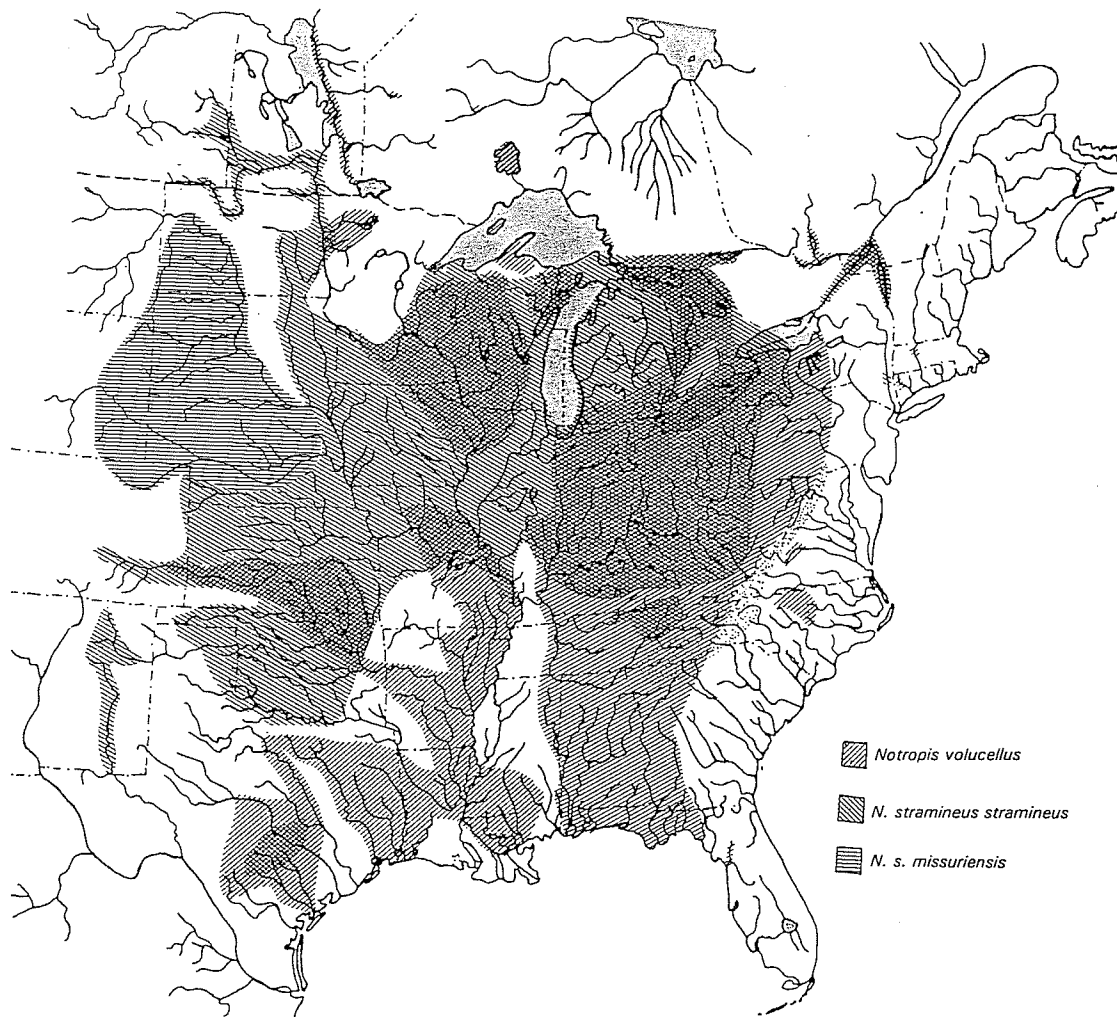


Fig. 3. Distributions of *Notropis volucellus* (including its putative subspecies), *N. stramineus stramineus* and *N. s. missouriensis* in North America (after Lee et al. 1980, Scott and Crossman 1973).

*N. s. stramineus* also occurs in lakes and rivers (Bailey 1951) but is more frequently associated with smaller streams (Becker 1983, Scott & Crossman 1973, Summerfelt & Minckley 1969, Tanyolaç 1973). It has been collected from turbid water in the Kansas River drainage (Summerfelt & Minckley 1969, Tanyolaç 1973) and the Assiniboine River (Stewart 1993, pers. comm.) but appears to be intolerant of turbidity elsewhere where it can tolerate both inorganic and organic pollution as long as the water is clear (Smith et al. 1981). In southern Ontario it is being replaced by *N. volucellus* in areas where it was formerly common (Crossman 1987, pers. comm.), presumably because of this requirement for clear water. The apparent discrepancies in habitat requirements among different populations raises questions about the relationships of these populations to each other.

Behavioural characteristics of *N. volucellus* differ among populations (Black 1945, Hanych et al. 1983, Moyle 1973). Hanych et al. (1983) describe extensive nocturnal onshore movements, explained as a predator-avoidance behaviour, however Black (1945), and Moyle (1973) both describe nocturnal offshore movements. Helfman (1981) (in Hanych et al. 1983) suggests that because of the variability of freshwater ecosystems freshwater fish "may have evolved behavioural plasticity sufficient to alter daily movements according to prevailing conditions".

A study of life history characteristics of *N. volucellus* was conducted by Black (1945). Life history studies of both *N. s. stramineus* and *N. s. missuriensis* were conducted by Tanyolaç (1973) and of *N. s. missuriensis* by Summerfelt & Minckley (1969). Black (1945) was unable to locate spawning



sites or observe spawning behaviour of *N. volucellus*, and was unable to induce spawning in aquaria. Summerfelt & Minckley (1969) and Tanyolaç (1973) did not attempt to observe spawning behaviour. Comparisons of reproductive parameters of the two species have not been published.

Because *N. stramineus stramineus* and *N. volucellus* have overlapping distributions in Southern Ontario but not in Manitoba (Fig. 3), I felt that a comparison of morphometric and reproductive characteristics of the two species, within and between these areas would contribute to knowledge of the relationship between them. Specifically I have attempted to determine which morphometric characteristics can be used reliably to differentiate these two species and if the degree of intra- and interspecific variation differs between allopatric and sympatric populations. I have compared reproductive characteristics of sympatric and allopatric populations to determine if there is any difference between and/or within species in either situation.

Sites for which only one or the other species is known are defined as allopatric. For the purposes of this work I have subdivided sympatric sites into potentially sympatric and actually sympatric sites. Potentially sympatric sites are those for which I have collections of both species, but from different dates. Actually sympatric sites are represented by collections containing both species.

## MATERIALS AND METHODS

### A. Collecting Protocol

Two field seasons (1987, 1988) were conducted in southern Ontario where both allopatric and sympatric populations of *Notropis volucellus* and *N. s. stramineus* occur. Prospective collection sites in southwestern Ontario were identified from collection records of the Ontario Ministry of Natural Resources (Fig. 4). Prospective collection sites in Manitoba (Fig. 6) were identified in consultation with K. W. Stewart. Collections were made from the Souris River (*N. s. stramineus*) in 1989, and from the Winnipeg River (*N. volucellus*) in 1989 and 1991. Final choice of collecting sites in both provinces was limited by the requirements of a lone collector, which also precluded electrofishing and night collecting, except during the 1991 season when I received assistance in the field.

In Ontario, during both field seasons, weekly collections were made at sites where either or both species could be collected consistently (Table 1, Fig. 5). Collecting began during the second week of May (both years), which is the nineteenth week of the year, and was continued through Week 26 (July 4 1987) or Week 29 (July 20 1988). Collecting sites in Manitoba (Table 2, Fig. 7) were selected following the same criteria as for Ontario. Collecting began during the third week of May (Week 20) and continued until Week 42 (mid-October 1989) or Week 34 (late August 1991). Collections of *N. volucellus* were very small in 1989, necessitating the additional season in 1991 during which all collections were made during and after dusk.

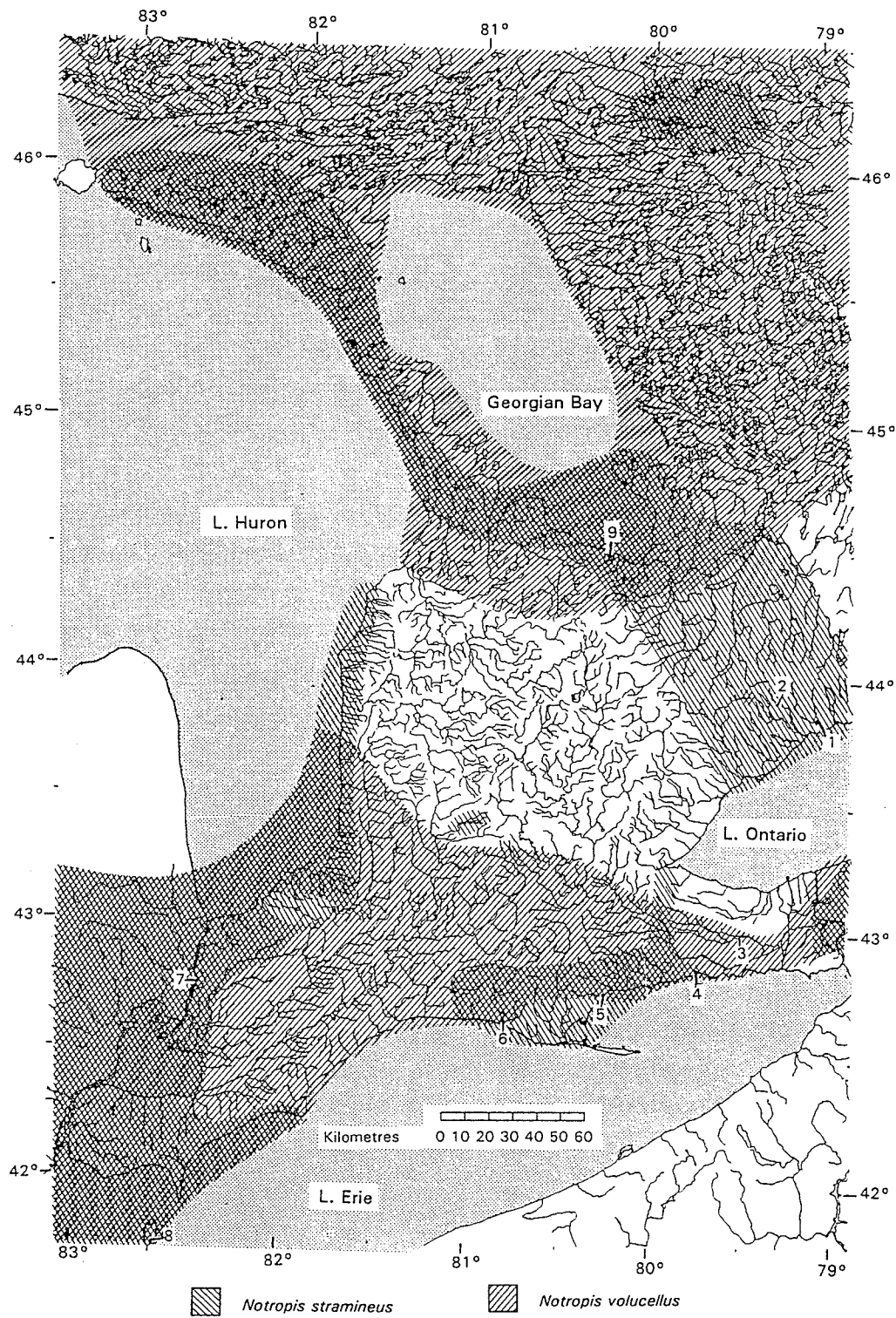


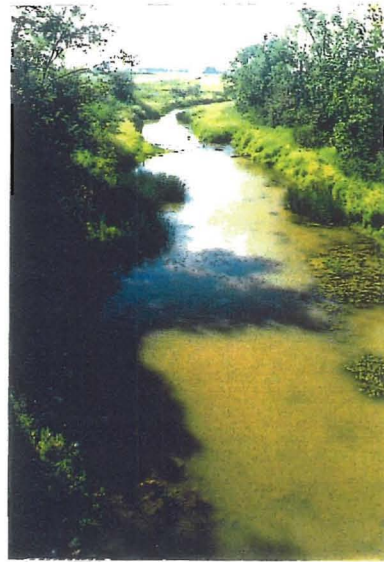
Fig. 4. Distribution of *Notropis volucellus volucellus* and *N. stramineus stramineus* in southern Ontario. Collecting sites are indicated by numbers. 1. Duffin's Creek, 2. Little Rouge River, 3. Welland River, 4. Wardell's Creek, 5. South Otter Creek, 6. Young's Creek, 7. Bowen's Creek, 8. Pelée Island, 9 Indian Brook.

Table 1. Collection sites in southern Ontario. Depth, and current data were estimated in 1987. (<sup>1</sup> *Notropis stramineus*, <sup>2</sup> *N. volucellus*, <sup>3</sup> both species).

Site	Latitude N Longitude W	Water Temperature °C	Depth cm	Clarity cm	Current cm/s	Habitat
Duffin's Creek <sup>1</sup> 1987	43 51 04	20.0-24.0		clear	moderate to strong	sand, becomes turbid only briefly after heavy rain, empties into Lk. Ontario
1988	79 03 36	12.0-24.0	20-80	20-80	9-67	
Little Rouge R. <sup>1</sup> 1987	43 55 27	13.5-22.0		clear	moderate	sand and scattered boulders in riffle, fine silt over sand in deeper holes downstream from riffle, Lk. Ontario
1988	79 16 53	11.0-27.0	58-85	35-82	4-38	
Indian Brook <sup>3</sup> 1988	44 32 52 80 25 30	14.0-25.0	17-100	17-100	0-33	sand in shallows, some boulders in scour hole, Georgian Bay
Bowen Creek <sup>3</sup> 1988	42 46 26 82 27 53	12.0-25.0	25-80	25-75	0-16	lake boats draw water out of creek and push it back in. Scour hole on east end of culvert turbid, shallow water in St. Claire R. end clear
South Otter Creek <sup>3</sup> 1987	42 38 37	17.0-20.0		turbid	slow to moderate	sand and a little silt near shore, Lk. Erie
1988	80 47 40	15.0-25.0	17-53	17-25	7-78	
Wardell's Creek <sup>3</sup> 1988	42 50 50 79 46 40	11.0-27.0	0-74	45-74	0-16	sand and silt, gravel near bank, Lk. Erie
Young's Creek <sup>3</sup> 1987	42 45 20 80 15 20	15.0-17.0	0-70	70	30-45	sand, Lk. Erie
Peléé Island <sup>3</sup> 1987	41 44 45 82 38 40	21.0-24.0	0-50	50	0	sand, Lk. Erie
Welland River <sup>2</sup> 1987	43 01 35	22.0-29.5		turbid	slow to moderate	sand and coarse gravel in riffle, boulders, silt and some vegetation in pools below riffle, Niagara R.
1988	79 39 30	15.0-29.0	28-50	15-45	0-48	



(a) Duffin's Creek



(b) Welland River



(c) South Otter Creek



(d) Indian Brook

Fig. 5. Some Ontario collecting sites (a) *Notropis stramineus stramineus*, (b) *N. volucellus*, (c & d) both species.

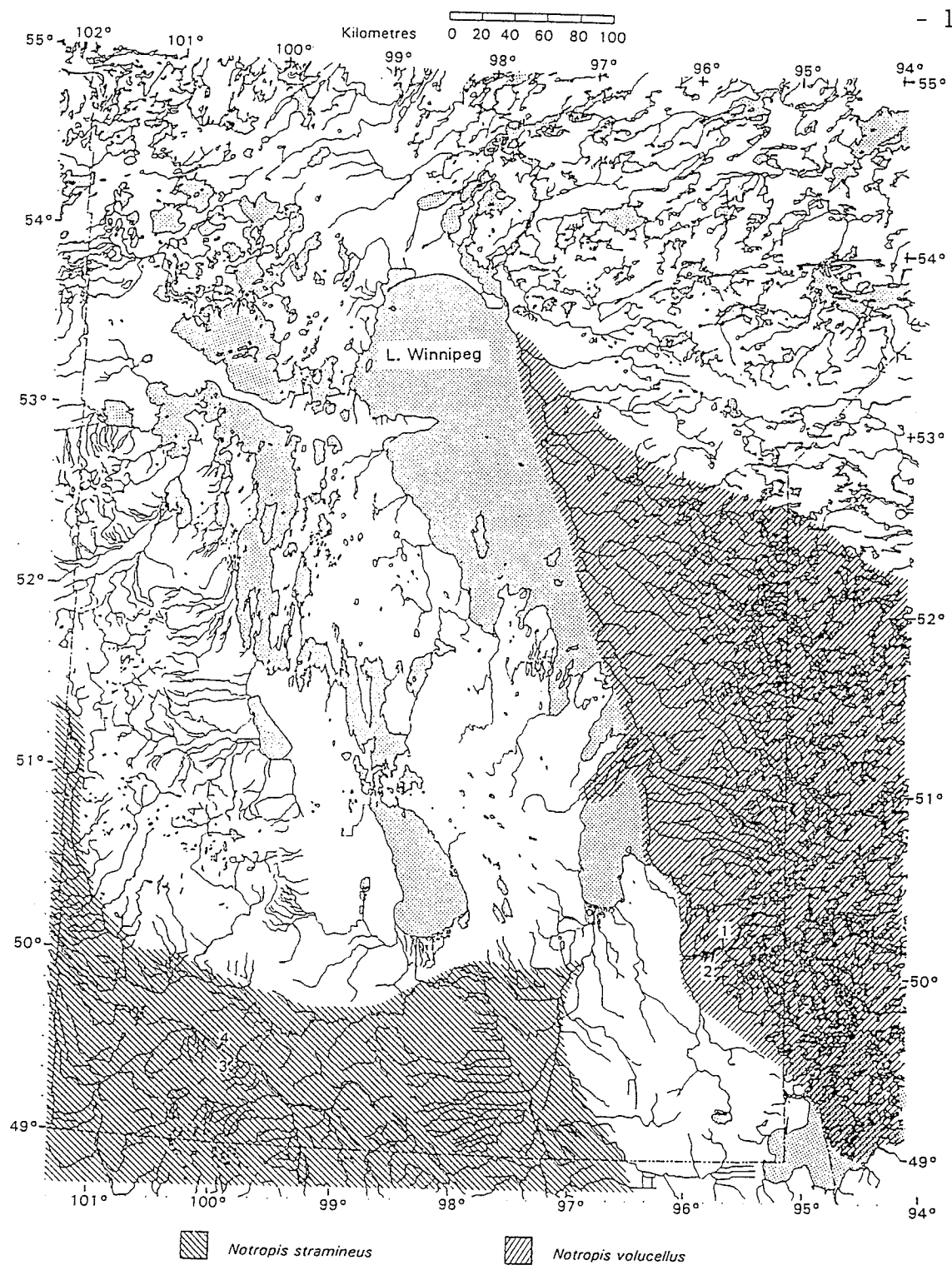


Fig. 6. Distributions of *Notropis volucellus volucellus* and *N. stramineus stramineus* in Manitoba. Collecting sites are indicated by numbers.  
1. Barrier Bay, 2. Dorothy Lake, 3. Souris River at Provincial Road 346,  
4. Souris River at Hwy 10.

Table 2. Collection sites in Manitoba. Depth and clarity measurements were not made in 1991 because collecting was done at night. (<sup>1</sup> *Notropis stramineus*, <sup>2</sup> *N. volucellus*).

Site	Latitude N Longitude W	Water Temperature °C	Depth cm	Clarity cm	Current cm/s	Habitat
Barrier Bay <sup>2</sup> 1989	50 10 25 95 41 50	10.0-25.0	36-100	36-100	0	sand, sparse non-emergent vegetation near shore and boat-launch grid
1991		13.0-22.0				
Dorothy Lake <sup>2</sup> 1989	50 08 50 95 00 48	21.0-24.0	80-113	80-113	0	sand and boat launch grid
1991		15.0-23.0				
Souris River <sup>1</sup> Hwy 10- 1989	49 30 08 99 59 30	7.0-26.0	92-108	92-108	0-4	sand, a little vegetation near shore
Souris River <sup>1</sup> PTR 346 - 1989	49 27 42 99 52 20	7.0-29.0	29-60	29-60	0-36	shale



(a) Souris River - PTR 346



(b) Souris River - Hwy 10



(c) Barrier Bay



(d) Dorothy Lake

Fig. 7. Manitoba collecting sites. (a) & (b) *Notropis stramineus stramineus*, (c) & (d) *N. volucellus*.



At each site, on each sampling occasion, I measured air and water temperature and briefly described climatic and habitat characteristics (Appendix A). I had no means of measuring current, depth or clarity in 1987 and described them qualitatively. In subsequent years I measured clarity and depth using a secchi disc with a graduated cord attached. I estimated current by measuring the time it took a tethered net float to move 2 metres. This provided only a comparison of surface current, and was very imprecise on windy days.

Most collections were made with 6 m bag seine (4 mm mesh bag 1987, 10 mm mesh bag 1988-1991) with one end anchored to shore and weighted with a coil of lead line. A few collections were made with a 1.2 m seine with 6 mm mesh. Minnow traps were tried in some sites which were inaccessible to seining, but were unsuccessful. All fish collected were anaesthetized with MS222, then killed and fixed with 10% formaldehyde. Ontario collections were held in formaldehyde soaked cheesecloth until returned to Manitoba at which time they were rinsed in water for 24 hours before being transferred to 70% isopropanol. Manitoba collections were rinsed and transferred to alcohol after three days in formaldehyde.

Dymond (1926) observed that formaldehyde fixation followed by alcohol preservation results in overall shrinkage of approximately 5-6 % and that this is unequal, the head shrinking less than soft body parts. Because these two species are similar in size I assumed that they would be affected equally and this shrinkage should not seriously affect the outcome of species comparisons.

## B. Laboratory Protocol

### a. Museum Collections

A database of morphometric characteristics (Table 3) was constructed, using identified specimens borrowed from the Royal Ontario Museum, and the Stewart Hay Memorial Museum in the Zoology Department of the University of Manitoba.

Materials borrowed from museums are listed below including museum catalogue number or accession number (if collection was not catalogued). The number of specimens examined is given in parentheses following the museum number. ROM ICH refers to the Royal Ontario Museum Ichthyology collection. ROM ACC refers to Royal Ontario Museum Accession Number. MZF refers to the Stewart Hay Memorial Museum fish collection.

#### *Notropis volucellus*

- Ontario specimens - ROM ICH 7882 (189); 43340 (172); 42168 (25); 37360 (10); 39517 (25); 43369 (51); 41715 (75); 25962 (12); 11834 (10); 35793 (281); 43027 (4); 43337 (181); 37367 (31); 36450 (25); ROM ACC 4600 - CN HW83-57 (36); CN HW83-79 (22)  
- Manitoba specimens - ROM ICH 19420 (4); 14895 (56); 14746 (7); 18745 (59);  
MZF 763 (90); 760 (7); 1457 (5); 1419 (10); 1446 (1); 761 (1); 758 (1);

#### *Notropis stramineus stramineus*

- Ontario specimens - ROM ICH 42167 (19); 36910 (41); 14076 (39); 8951 (36); 14066 (90); 43026 (4); 23798 (72); 37104 (21); 30813 (11)  
ROM ACC 4600 - CN HW83-28 (8); CN HW83-45 (15)  
- Manitoba specimens - MZF 747 (23); 750 (25); 754 (25); 738 (10); 733 (13)

Specimens which I collected were compared with and added to this database and will be accessed by the Stewart Hay Memorial Museum.

Table 3. Character set used in database. All measurements accurate to 0.1 mm. All except standard length were transformed to 1000ths of standard length. Pigment was coded by distribution (AP and DS) and degree (Pig) and the product of these (AP\* and DS\*) entered into the database.

**Counts**

- AR - anal fin rays
- LL - lateral line - first complete pored scale to base of hypural plate
- P1 - pectoral fin rays

**Measurements**

- SL - Standard Length - snout to hypural plate
- PD - PreDorsal - origin of dorsal fin to snout
- PP - PrePelvic - origin of pelvic fin to snout
- CP - Caudal Peduncle - insertion of anal fin to hypural plate
- HL - Head Length - snout to posterior margin of bony operculum
- HW - Head Width at articulation of operculum
- SN - Snout Length - anterior margin of orbit to tip of snout
- UJ - Upper Jaw length - symphysis to posterior end maxilla
- CW - Chin Width - width between posterior ends of maxillae
- AW - Angular Width - width at posterior end of angulars
- ED - Eye Diameter - anterior-posterior width of bony orbit
- SH - Scale Height - exposed height of lateral line scale 7, where possible.
- SW - Scale Width - exposed width of lateral line scale 7, where possible.

**Ratios**

- PPPD = PP/PD
- HWHL = HL/HW
- SNHL = SN/HL
- UJHL = UJ/HL
- EDHL = ED/HL
- SNUJ = UJ/SN
- AWHW = AW/HW
- CWHW = CW/HW
- AWCW = AW/CW
- UJCW = UJ/CW
- SWSH = SW/SH

**Pigment Codes**

AP - Anal Pigment

- 0 - absent
- 1 - anus
- 2 - anal fin
- 3 - anus and anal fin
- 4 - anal fin to tail
- 5 - anus to tail

DS - midDorsal Stripe

- 0 - absent
- 1 - dorsal fin only
- 2 - head to posterior of dorsal fin
- 3 - dorsal fin to tail
- 4 - head to half way between dorsal and tail
- 5 - head to tail

Pig

- 1 - indistinct - scattered melanophores
- 2 - distinct - solid line of melanophores

AP\* = AP x Pig  
 DS\* = DS x Pig

Pigment characters were coded and measurements and counts follow Hubbs and Lagler (1958) except where specified (Table 3). Initially measurements were made using a Vernier dial calliper, and later a Mitutoyo digital calliper. All specimens were hand held during measurements. Fin ray and scale counts were made under a Wild-Leitz dissecting microscope. Measurements were taken to the nearest 0.1 mm and were converted to 1000ths of standard length (SL) following current practice (Hubbs 1951). Standard ratios were also included in the database (Table 3).

#### b. Field Collections

All specimens from collections with 25 or fewer fish were examined. Samples of 25 were drawn from larger collections and randomized as follows. Twenty-five numbers between 1 and N (size of the collection) were drawn from a random numbers table (Zar 1984). Specimens were size ranked in a pan and counted, in ascending size order, into sample jars. The 25 matching the random number series were separated for study. All these specimens were subjected to the same counts and measurements as museum specimens and species identification tested against the museum database.

Each specimen sampled was pat-dried on paper towelling and weighed (to the nearest 0.1 mg) on a Sartorius balance, sexed and the development of nuptial tubercles on males, or presence or absence of yolked eggs in ovaries of females was coded (Table 4).

I measured reproductive condition of all individuals sampled from Ontario collections and one half of the individuals of each sex from Manitoba

Table 4. Condition and reproductive characters and codes used to describe degree of tuberculation in males and presence or absence of yolked eggs in females.

**Condition and Reproductive characters**

TW - total body weight - mg

GW - gonad weight - mg

$$\text{GSI - gonadosomatic index} = \frac{GW}{(TW - GW)} \times 1000$$

EGG - Egg diameter - average of ten largest from mid-ovary  
-  $\mu$

**Sex - Codes**

1 - female

- 0 - yolk absent
- 1 - yolk present

2 - male

- 0 - no tubercles
- 1 - fins
- 2 - snout
- 3 - head
- 4 - chin
- 5 - fins, snout
- 6 - fins, head
- 7 - fins, cheek
- 8 - fins, head, snout
- 9 - fins, head, cheek
- 10 - fins, snout, head, cheek
- 11 - 10 + operculum
- 12 - 11 + nape
- 13 - 12 + chin

collections containing more than 12 fish. The latter were chosen by taking the first and each alternate member of each sex as they were drawn from the sample jar. The gonads were removed, pat-dried and weighed. Testes were replaced. Ten of the largest eggs were removed from the ovaries and measured using a Nikon Alphaphot compound microscope with a 1mm eyepiece micrometer. The average diameter of ten of the largest eggs was recorded in microns and the ovary replaced. No attempt was made to count eggs, or obtain a true average diameter for all eggs in an ovary. A Gonadosomatic Index (GSI) was calculated for each fish.

$$GSI = \frac{\text{gonad weight}}{(\text{total weight} - \text{gonad weight})} \times 1000$$

### **C. Statistical Procedures**

#### a. Discriminant Analysis

The morphometric database was subjected to BMDP7D Description of Groups (Dixon 1983) which performs tests for equality of variances, grouped means comparisons assuming unequal variances and pairwise means comparisons using T tests, providing Bonferroni estimates of significance of the pairwise comparisons. Transformations to stabilize variances (Box & Cox 1964) produced no change in outcome and were abandoned.

BMDP7M Discriminant Function Analysis (Jennrich & Sampson 1983), which is robust to departures from a normal distribution (Srivastava & Carter 1983), was used to determine which set(s) of variables discriminated between and among the different populations. BMDP7M tests equality of group means of the discriminant variables using Wilks' Lambda multivariate analysis of variance statistic and provides an approximate F statistic transformation which

can be compared with the F distribution. Significance of the canonical discriminant functions was tested using the method described in Manly (1986).

Direct measurements are necessarily intercorrelated with the ratios produced from them which could adversely affect the reliability of the analysis (Zar 1984). Because fish are usually described and compared in terms of the ratios (Becker 1983, Lee et al. 1980, Scott and Crossman 1973) only standard (SL) and caudal peduncle (CP) lengths, as well as ratios, meristic and colour characters were included in the analysis.

I pooled the provincial samples of each species and compared them. I then made comparisons between species within Manitoba and Ontario, within species between Manitoba and Ontario and among allopatric (sites where only one of the species has ever been recorded) and sympatric (sites where both species have been recorded, although not necessarily together) populations in Ontario. Potentially sympatric collections of each species came from the same site but not at the same time. Actually sympatric collections contained both species.

#### b. Reproductive Characteristics

Weekly means of reproductive characters of each collection were plotted against each other, by species and province, and their relationships determined by linear regression using SigmaPlot 4.0(© Jandel Corporation). As a result of this analysis, further comparisons were confined to the gonadosomatic indices (GSI).

T-tests (Zar 1984) were used to compare GSI's on a week by week basis. The allopatric populations of *N. volucellus* from the Welland River and *N. stramineus* from Duffin's Creek and the Little Rouge River were compared between years and with each other with the 2 years' data combined. The Manitoba collections were treated similarly, comparing Winnipeg River *N. volucellus* between years, and Souris River *N. stramineus* between sites.

Data from all potentially sympatric sites were combined and compared within and between species with the allopatric populations. The five individual sympatric collections, from five different sites, in five different weeks, were tested independently.

Manitoba populations were compared with both subsets (allopatric and potentially sympatric) of Ontario.

GSI's of the different population groups were tested over time using analysis of variance. Where the ANOVA indicated that weekly means were unequal Tukey's multiple comparisons test was used to identify where the variation occurred (Zar 1984).

Weekly GSI's of different population subgroups (by species in Manitoba, by species and site type in Ontario) were pooled and plotted against time (collection week) to illustrate weekly trends. Weekly GSI's of the individual collections of the population subgroups were plotted against water temperature and regression lines fitted using SigmaPlot 4.0 (© Jandel Corporation, 1986-1989).



## RESULTS

### A. Morphometric Comparisons

#### a. Manitoba and Ontario Populations Pooled

Univariate statistics of characters not included in the discriminant function analysis are presented in Table 5, discriminant characters in Table 6 and standardized canonical coefficients of the discriminant functions in Table 7. The discriminant functions of all the comparisons were significant at  $p = 0.05$  (Table 8.)

Very few characters had equal variances (Tables 5, 6). The only character with equal means between the pooled populations was UJHL (upper jaw/head length).

Discriminant function analysis of the pooled populations assigned individuals to their correct species group with 98.6% accuracy. A discriminant function score of 0.71 represented the cutoff between the two species (*N. volucellus*  $\leq 0.71$ , *N. s. stramineus*  $\geq 0.72$ ) (Fig. 8a). Most, but not all, 'misidentified' individuals, those which fell beyond these limits, were collected from potentially sympatric sites, or were from sympatric collections (Table 9.). This was especially true for *N. s. stramineus* in which 91.7% of misidentifications were from sympatric sites, whereas 64.5% of misidentified *N. volucellus* were from sympatric sites.

PPPD (prepelvic length/predorsal length) contributes most to the discriminant score, followed by SWSH (scale width/scale height), HWHL and

Table 5. Univariate statistics (means  $\pm$  2 standard deviations) of characters not included in the discriminant analysis. Data are presented for the pooled populations and for each species by province. Superscripts indicate pairs with equal means at  $p = 0.05$ , \* indicates characters with equal variances. (PD predorsal length, PP prepelvic length, HL head length, HW head width, SN snout length, UJ upper jaw length, CW chin width, AW angular width, ED eye diameter, SH scale height, SW scale width)

Character	<i>N. s. stramineus</i> n = 1054	<i>N. volucellus</i> n = 2030	<i>N. s. stramineus</i>		<i>N. volucellus</i>	
			Ontario n = 614	Manitoba n = 440	Ontario n = 1550	Manitoba n = 480
PD	513.663 $\pm$ 28.910	521.784 $\pm$ 31.914	511.209 $\pm$ 30.678	517.147 $\pm$ 24.598	521.460 $\pm$ 32.224	522.814 $\pm$ 30.852
PP*	504.287 $\pm$ 32.310	495.271 $\pm$ 31.740	499.258 $\pm$ 32.292 <sup>1</sup>	511.426 $\pm$ 26.448	494.684 $\pm$ 31.102	497.141 $\pm$ 33.446 <sup>1</sup>
HL	249.465 $\pm$ 29.746	245.725 $\pm$ 18.800	242.083 $\pm$ 27.774	259.944 $\pm$ 17.252	245.155 $\pm$ 19.202	247.539 $\pm$ 16.970
HW	132.530 $\pm$ 19.994	128.163 $\pm$ 13.864	126.895 $\pm$ 14.882	140.531 $\pm$ 14.712	127.928 $\pm$ 14.506	128.909 $\pm$ 11.476
SN	72.151 $\pm$ 12.752	74.670 $\pm$ 9.900	69.219 $\pm$ 10.612	76.308 $\pm$ 10.758	75.286 $\pm$ 9.618	72.711 $\pm$ 9.772
UJ	72.975 $\pm$ 11.728	71.697 $\pm$ 8.836	69.631 $\pm$ 8.466	77.714 $\pm$ 8.814	71.415 $\pm$ 8.236	72.594 $\pm$ 10.330
CW*	59.886 $\pm$ 12.060	57.317 $\pm$ 11.900	57.525 $\pm$ 10.314	63.179 $\pm$ 11.208	56.710 $\pm$ 10.320	59.274 $\pm$ 15.334
AW*	21.714 $\pm$ 12.488	15.763 $\pm$ 12.886	19.797 $\pm$ 11.650	24.388 $\pm$ 11.632	15.037 $\pm$ 12.132	18.108 $\pm$ 14.088
ED	82.757 $\pm$ 9.968	85.637 $\pm$ 11.922	83.531 $\pm$ 10.382	81.658 $\pm$ 8.910	84.213 $\pm$ 10.908	90.172 $\pm$ 10.384
SH	46.916 $\pm$ 10.056	60.735 $\pm$ 11.354	46.143 $\pm$ 10.460	48.011 $\pm$ 9.020	60.542 $\pm$ 11.386	61.349 $\pm$ 11.174
SW	23.698 $\pm$ 6.590	23.157 $\pm$ 5.542	22.858 $\pm$ 6.482 <sup>1</sup>	24.891 $\pm$ 5.986	23.221 $\pm$ 5.310 <sup>1</sup>	22.956 $\pm$ 6.212 <sup>1</sup>

Table 6. Univariate statistics (means  $\pm$  2 standard deviations) of characters included in the discriminant analysis. Anal Ray counts are included here because they were included in preliminary analyses. Data are presented for the pooled populations and for each species by province. Superscripts indicate pairs with equal means at  $p = 0.05$ , \* indicates characters with equal variances. (AR anal rays, LL lateral line scales, P1 pectoral fin rays, DS dorsal stripe, AP anal pigment, SL standard length, PP prepelvic length, PD predorsal length, HW head width, HL head length, SN snout length, ED eye diameter, UJ upper jaw length, AW angular width, CW chin width, SW scale width, SH scale height).

Character	<i>N. s. stramineus</i> n = 1054	<i>N. volucellus</i> n = 2030	<i>N. s. stramineus</i>		<i>N. volucellus</i>	
			Ontario n = 614	Manitoba n = 440	Ontario n = 1550	Manitoba n = 480
AR	7.012 $\pm$ 0.380	8.027 $\pm$ 0.602	7.024 $\pm$ 0.360 <sup>1</sup>	6.996 $\pm$ 0.300 <sup>1</sup>	8.002 $\pm$ 0.564	8.105 $\pm$ 0.688
LL	34.846 $\pm$ 2.598	36.493 $\pm$ 1.972	35.570 $\pm$ 2.092	33.836 $\pm$ 1.750	36.443 $\pm$ 2.018	36.654 $\pm$ 1.783
P1	14.123 $\pm$ 1.593	13.552 $\pm$ 1.675	14.031 $\pm$ 1.644	14.252 $\pm$ 1.481	13.590 $\pm$ 1.716	13.431 $\pm$ 1.512
DS	9.188 $\pm$ 3.750	3.746 $\pm$ 4.880	8.808 $\pm$ 4.421	9.718 $\pm$ 2.214	4.037 $\pm$ 5.185	2.806 $\pm$ 3.054
AP	4.614 $\pm$ 5.665	7.867 $\pm$ 5.684	3.261 $\pm$ 4.537	6.502 $\pm$ 4.867	7.405 $\pm$ 5.998	9.356 $\pm$ 2.948
SL*	418.041 $\pm$ 132.382	412.074 $\pm$ 124.001	423.837 $\pm$ 142.450 <sup>1</sup>	409.852 $\pm$ 115.119	421.447 $\pm$ 121.809 <sup>1</sup>	381.806 $\pm$ 111.131
CP*	263.327 $\pm$ 34.250	258.606 $\pm$ 32.849	267.861 $\pm$ 36.200	257.000 $\pm$ 26.617	260.506 $\pm$ 33.345	252.469 $\pm$ 27.884
PP/PD	0.981 $\pm$ 0.063	0.949 $\pm$ 0.071	0.975 $\pm$ 0.065	0.989 $\pm$ 0.057	0.948 $\pm$ 0.067	0.950 $\pm$ 0.082
HW/HL	1.887 $\pm$ 0.263	1.920 $\pm$ 0.199	1.909 $\pm$ 0.275 <sup>1</sup>	1.854 $\pm$ 0.229	1.920 $\pm$ 0.204 <sup>1</sup>	1.922 $\pm$ 0.182 <sup>1</sup>
SN/HL*	0.289 $\pm$ 0.042	0.304 $\pm$ 0.042	0.289 $\pm$ 0.043	0.293 $\pm$ 0.039 <sup>1</sup>	0.307 $\pm$ 0.039	0.294 $\pm$ 0.043 <sup>1</sup>
ED/HL	0.333 $\pm$ 0.051	0.349 $\pm$ 0.044	0.346 $\pm$ 0.043 <sup>1</sup>	0.314 $\pm$ 0.034	0.344 $\pm$ 0.041 <sup>1</sup>	0.365 $\pm$ 0.039
UJ/HL*	0.293 $\pm$ 0.035 <sup>1</sup>	0.292 $\pm$ 0.035 <sup>1</sup>	0.288 $\pm$ 0.034	0.299 $\pm$ 0.033	0.292 $\pm$ 0.031 <sup>1</sup>	0.294 $\pm$ 0.045 <sup>1</sup>
UJ/SN*	1.017 $\pm$ 0.160	0.964 $\pm$ 0.151	1.013 $\pm$ 0.161 <sup>1</sup>	1.023 $\pm$ 0.159 <sup>1</sup>	0.952 $\pm$ 0.142	1.002 $\pm$ 0.156 <sup>1</sup>
AW/HW	0.163 $\pm$ 0.084	0.122 $\pm$ 0.098	0.155 $\pm$ 0.084	0.173 $\pm$ 0.079	0.117 $\pm$ 0.092	0.140 $\pm$ 0.108
CW/HW	0.452 $\pm$ 0.076	0.447 $\pm$ 0.095	0.453 $\pm$ 0.073 <sup>1</sup>	0.450 $\pm$ 0.081 <sup>1</sup>	0.444 $\pm$ 0.083	0.460 $\pm$ 0.121 <sup>1</sup>
AW/CW	0.359 $\pm$ 0.162	0.269 $\pm$ 0.185	0.341 $\pm$ 0.163	0.383 $\pm$ 0.151	0.261 $\pm$ 0.180	0.298 $\pm$ 0.191
UJ/CW	1.223 $\pm$ 0.230	1.263 $\pm$ 0.260	1.220 $\pm$ 0.228 <sup>1</sup>	1.239 $\pm$ 0.231 <sup>12</sup>	1.269 $\pm$ 0.243	1.242 $\pm$ 0.308 <sup>2</sup>
SW/SH	0.508 $\pm$ 0.138	0.384 $\pm$ 0.103	0.499 $\pm$ 0.140	0.522 $\pm$ 0.13	0.386 $\pm$ 0.104	0.376 $\pm$ 0.099

Table 7. Standardized canonical coefficients produced by various comparisons of population subsets. POOLED - Manitoba and Ontario populations of each species pooled; MB, ON - between species in Manitoba and Ontario respectively; VOL, STR - *N. volucellus* and *N. s. stramineus* respectively, between province; VOLONT, STRONT - sympatric and allopatric populations of each species compared; SYMALL - comparison of species pooled as sympatric and allopatric populations. (LL lateral line, P1 pectoral fin rays, DS dorsal stripe, AP anal pigment, SL standard length, CP caudal peduncle length, PP prepelvic length, PD predorsal length, HW head width, HL head length, SN snout length, UJ upper jaw length, AW angular width, CW chin width, SW scale width, SH scale height)

Character	POOLED	MB	ON	VOL	STR	VOLONT	STRONT	SYMALL
LL	-0.026	-0.046	-0.020	-0.007	0.015	0.028		0.02
P1	0.012	0.001	0.011	0.021	-0.022	0.014	0.103	0.022
DS	0.015	0.028	0.013	0.003	-0.001	0.003	-0.009	0.004
AP	-0.005	-0.004	-0.006	-0.003	-0.004	0.003	0.005	0.004
SL	-0.000	-0.001	-0.000		0.000	0.001		0.001
CP	0.000		0.000	0.001	0.001	0.000		0.000
PP/PD	1.775		2.801		-0.245	0.183	-0.593	
HW/HL	-0.211			0.392	0.077	0.176	0.103	0.150
SN/HL	-0.329		-0.442	0.536		0.131		2.325
UJ/HL				0.973	-9.873	0.244		-2.943
ED/HL	-0.061	-1.003	0.086	-0.697	1.659			
UJ/SN							0.300	1.190
AW/HW		-0.495		-0.080				
CW/HW				-0.965	0.134	0.274	-0.568	0.103
AW/CW		0.687	0.103		-0.126	-2.592	3.790	-1.220
UJ/CW				-0.574				
SW/SH	0.437	0.524	0.555		-0.140	0.960	-4.208	
CONSTANT	0.472	41.307	-4.719	15.759	-40.417	-59.783	11.975	-103.112

Table 8. Results of tests of significance of the canonical function  $Z_j = \sum CC_i X_i$  ( $CC_i$  = canonical coefficient,  $X_i$  = value of the variable) for all comparisons made. STR - *Notropis stramineus*, VOL - *N. volucellus*; MB - Manitoba, ON - Ontario; SYM - sympatric sites, ALL - allopatric sites.

Comparisons	Number		p	m	$\lambda$	v	$\emptyset^2$	$\chi^2_{0.05,v}$
	STR	VOL						
Pooled	1054	2030	12	2	4.815	12	5433.545	21.026
MB	440	480	9	2	15.895	9	2585.025	16.919
ON	614	1550	11	2	3.659	11	3318.424	19.675
	ON	MB						
STR	614	440	13	2	3.307	13	1526.683	22.362
VOL	1550	480	12	2	0.554	12	891.649	21.026
	SYM	ALL						
STR	475	176	9	2	0.304	9	171.074	16.919
VOL	1034	480	13	2	0.956	13	1010.042	22.362
Pooled	1510	655	12	2	0.392	12	713.410	21.026

Test statistic:  $\emptyset_j^2 = \left\{ \sum_{i=1}^m n_i - 1 - \frac{1}{2} (p + m) \right\} \ln (1 + \lambda_j)$

v = degrees of freedom = p + m - 2j

p = number of variables,

m = number of groups,

$\lambda_j$  = eigenvalue of canonical function j (Manly 1986)

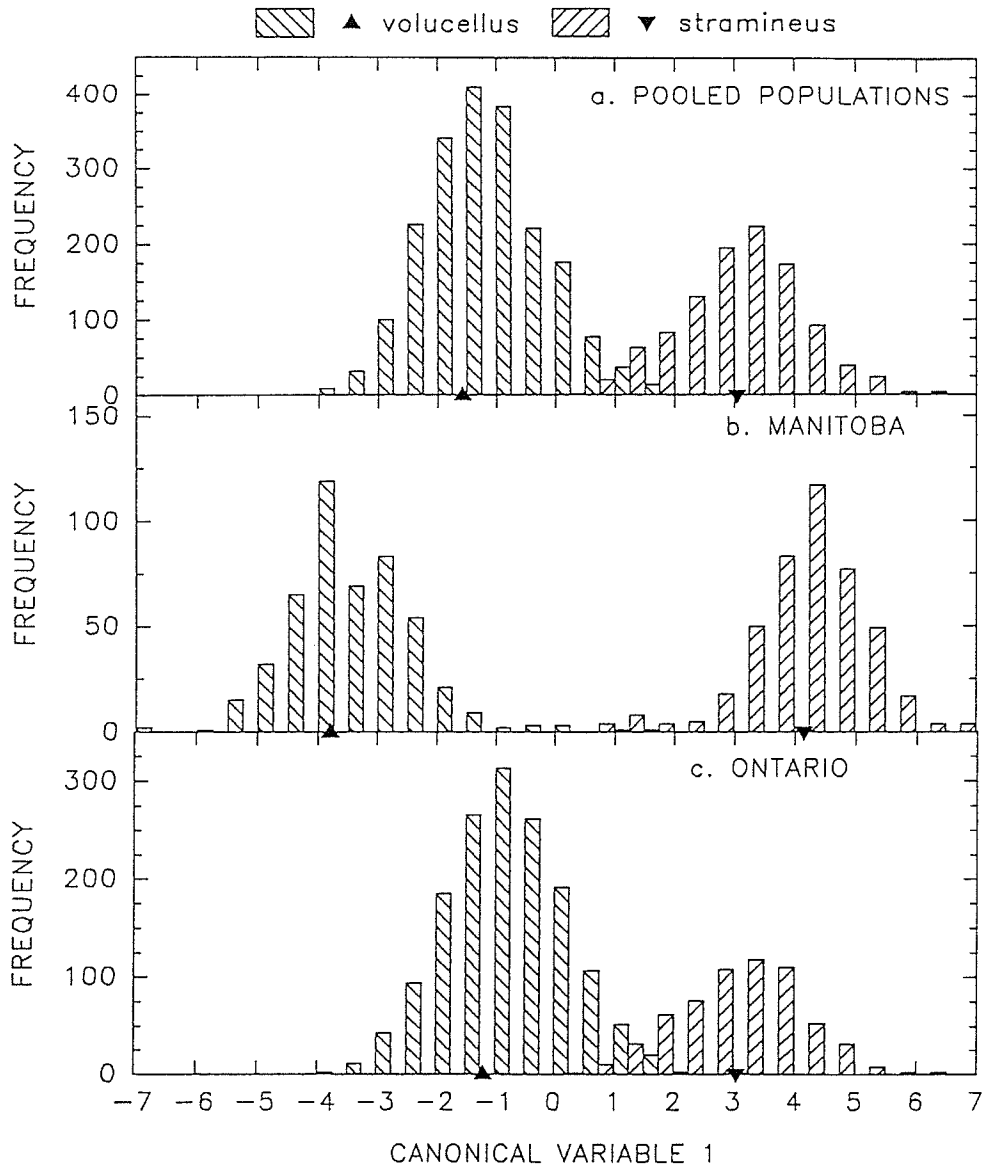


Fig. 8. Between species comparisons of *Notropis volucellus* and *N. stramineus* along canonical variable 1. (a) Ontario and Manitoba populations of each species pooled, (b) Manitoba populations, (c) Ontario populations.  $\blacktriangledown$  mean value of *N. stramineus* a. = 3.04, b. = 4.16, c. = 3.04.  $\blacktriangle$  mean value of *N. volucellus* a. = -1.58, b. = -3.81, c. = -1.20.

Table 9. Misidentified specimens tabulated by type of collection site (Allopatric (other species unknown from the site), Potentially sympatric (other species known from the site but not caught with this collection), Actually Sympatric (both species included in this collection)) with their mean *a posteriori* probabilities of identification with the species to which they are assigned *a priori*.

Site Type	Allopatric		Potentially Sympatric		Actually Sympatric	
Species	n	<i>p</i>	n	<i>p</i>	n	<i>p</i>
<i>N. stramineus</i>	1	0.106	3	0.396 ± 0.007	9	0.367 ± 0.108
<i>N. volucellus</i>	10	0.315 ± 0.178	6	0.329 ± 0.130	14	0.191 ± 0.129

SNHL (respectively head width and snout length/head length). This canonical variable demonstrates that *N. volucellus* overall has a smaller narrower head with a longer snout than *N. s. stramineus* and that its dorsal fin originates more posteriorly in relation to the pelvic fins. *N. s. stramineus* has shorter, more rounded lateral line scales than *N. volucellus*. This last characteristic is the only one which could be useful in differentiating live specimens in the field.

Anal Ray counts were not included after initial analyses because they overwhelmed all other characters, classifying all specimens with 7 or fewer rays as *N. s. stramineus* and all with 8 or more as *N. volucellus*. The count can be approximated by the caudal peduncle length. Other meristic characters, such as lateral line scale (LL) and pectoral fin ray (P1) counts make some contribution to all discriminant functions (Table 7). *N. s. stramineus* has significantly fewer LL and significantly more P1 than *N. volucellus* in the pooled and both provincial populations.

#### b. Species Comparisons Within Province

Manitoba populations (Fig. 8b) are most strongly discriminated by EDHL, because *N. volucellus* has both a shorter head and larger eye than *N. s. stramineus*. Both AWHW and AWCW (angular width/ head width and chin width respectively) contribute strongly to this canonical variable primarily because of the greater width between the angulars in *N. s. stramineus*. SWSH also is important. Ontario populations (Fig. 8c) are discriminated primarily by PPPD, followed by SWSH, SNHL and AWCW. The species in Manitoba are more distinct than they are in Ontario. Manitoba populations were classified with 99.8% accuracy, assigning 2 of 442 *N. volucellus* to *N. s. stramineus*.



These are 2 of the 10 misidentified *N. volucellus* from allopatric sites (Table 9). Ontario populations were classified with 98.2 % accuracy, and represent the remainder of misidentified individuals in Table 9.

### c. Species Comparisons Between Province

Comparisons within species between province produced less clearcut discrimination, especially between *N. volucellus* populations (Fig. 9). For both species the dominant element of the canonical variable was UJHL. In both species both HL and UJ are significantly shorter in Ontario than in Manitoba (Table 5). All the important discriminators between *N. volucellus* populations relate to head shape. Ontario populations have shorter narrower heads, with a shorter upper jaw but with proportionately longer snouts. Other characters with important effects relate to the shape of the mouth which is shorter and narrower in Ontario. *N. stramineus* populations in Manitoba have proportionately larger heads and mouths, but smaller eyes than Ontario populations, and the dorsal fin is not displaced as far posteriorly. In both species LL is higher in Manitoba than in Ontario. P1 is higher in Manitoba for *N. stramineus* and lower for *N. volucellus*.

### d. Comparisons of Allopatric and Sympatric Populations in Ontario.

Univariate statistics (means  $\pm$  2 standard deviations) of allopatric and sympatric populations of both species are presented in Table 10 and 11. Standardized canonical coefficients are presented in Table 7.

As one would expect the discrimination between these subpopulations is not as clearcut (Fig. 10) as between provincial subpopulations. In contrast to

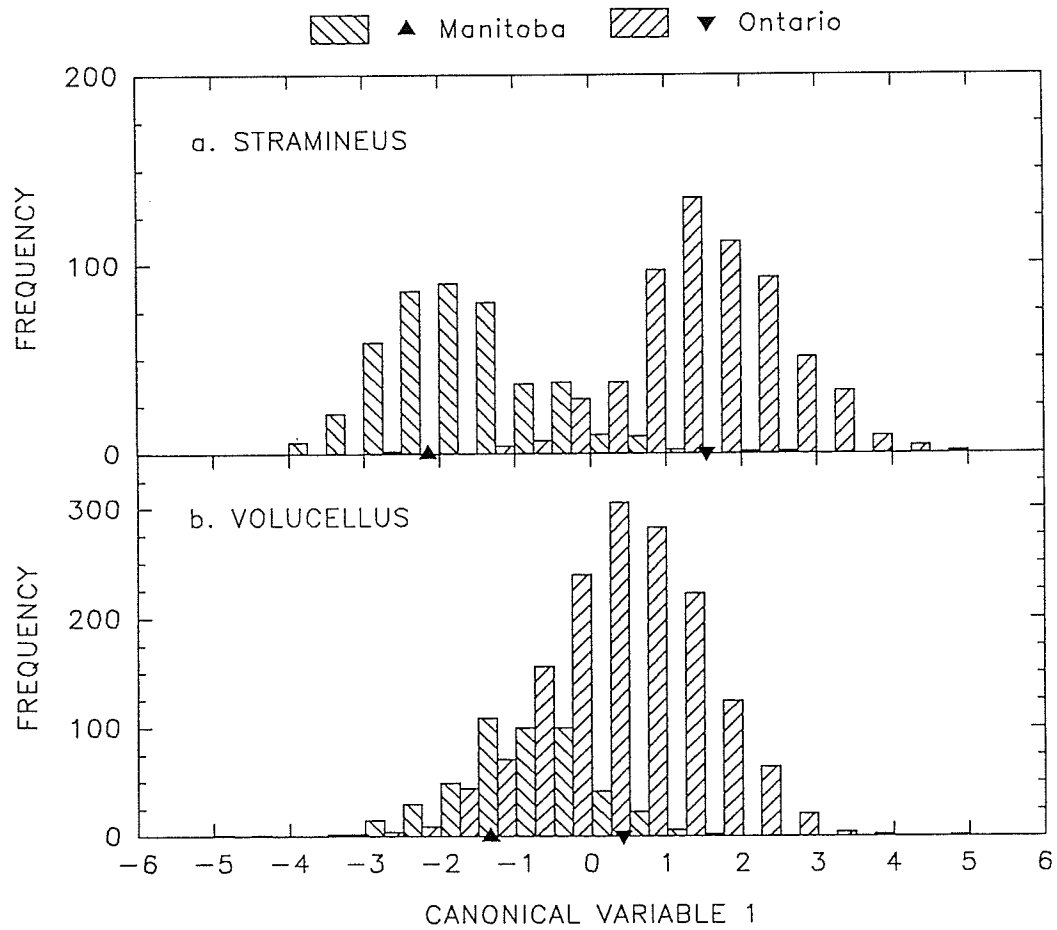


Fig. 9. Discrimination within species between province.  $\blacktriangledown$  means Ontario populations *N. stramineus* = 1.54, *N. volucellus* = 0.41,  $\blacktriangle$  means of Manitoba populations *N. stramineus* = -2.15, *N. volucellus* = -1.34.

Table 10. Univariate statistics (means  $\pm$  2 standard deviations) of variables not included in the discriminant function analysis of allopatric and sympatric populations of *N. volucellus* and *N. s. stramineus* in Ontario. Superscripts indicate pairs with equal means at  $p = 0.05$ . (PD predorsal length, PP prepelvic length, HL head length, HW head width, SN snout length, UJ upper jaw length, CW chin width, AW angular width, ED eye diameter, SH scale height, SW scale width)

Character	<i>N. s. stramineus</i>		<i>N. volucellus</i>	
	Sympatric n = 475	Allopatric n = 176	Sympatric n = 1034	Allopatric n = 480
PD	513.302 $\pm$ 30.190	508.731 $\pm$ 35.552	522.803 $\pm$ 30.562	518.062 $\pm$ 34.982
PP	499.120 $\pm$ 31.298 <sup>1</sup>	499.086 $\pm$ 35.292 <sup>12</sup>	496.072 $\pm$ 30.886 <sup>2</sup>	491.453 $\pm$ 30.464
HL	241.928 $\pm$ 28.496 <sup>1</sup>	242.326 $\pm$ 14.644 <sup>12</sup>	244.432 $\pm$ 19.548 <sup>2</sup>	247.067 $\pm$ 18.144
HW	126.632 $\pm$ 14.776 <sup>1</sup>	126.926 $\pm$ 14.644 <sup>1</sup>	125.982 $\pm$ 12.718 <sup>1</sup>	132.558 $\pm$ 17.178
SN	69.126 $\pm$ 11.116	71.143 $\pm$ 10.236	75.886 $\pm$ 9.382	73.848 $\pm$ 9.644
UJ	69.770 $\pm$ 8.338 <sup>1</sup>	69.623 $\pm$ 8.468 <sup>1</sup>	71.224 $\pm$ 8.068	71.842 $\pm$ 8.706
CW	56.792 $\pm$ 9.374 <sup>1</sup>	59.011 $\pm$ 11.752	56.718 $\pm$ 10.504 <sup>1</sup>	56.812 $\pm$ 10.046 <sup>1</sup>
AW	19.415 $\pm$ 11.752 <sup>1</sup>	19.526 $\pm$ 11.838 <sup>1</sup>	13.853 $\pm$ 11.304	17.696 $\pm$ 12.502
ED	83.560 $\pm$ 10.416 <sup>1</sup>	82.777 $\pm$ 9.956 <sup>1</sup>	83.120 $\pm$ 10.586 <sup>1</sup>	86.919 $\pm$ 9.778
SH	47.850 $\pm$ 11.326	43.663 $\pm$ 9.422	60.264 $\pm$ 11.430	61.440 $\pm$ 11.186
SW	23.118 $\pm$ 6.416 <sup>1</sup>	22.560 $\pm$ 6.614 <sup>12</sup>	23.284 $\pm$ 5.456 <sup>13</sup>	22.952 $\pm$ 4.862 <sup>123</sup>

Table 11. Univariate statistics (means  $\pm$  2 standard deviations) of discriminant variables of allopatric and sympatric populations of *N. volucellus* and *N. s. stramineus* in Ontario. Superscripts indicate equal means at  $p = 0.05$ . (AR anal rays, LL lateral line, P1 pectoral fin rays, DS dorsal stripe, AP anal pigment, SL standard length, CP caudal peduncle, PP prepelvic fin length, PD predorsal fin length, HW head width, HL head length, SN snout length, UJ upper jaw length, ED eye diameter, AW angular width, CW chin width, SW scale width, SH scale height).

Character	<i>N. s. stramineus</i>		<i>N. volucellus</i>	
	Sympatric n = 475	Allopatric n = 176	Sympatric n = 1034	Allopatric n = 480
AR	7.060 $\pm$ 0.508 <sup>1</sup>	7.011 $\pm$ 0.302 <sup>1</sup>	8.023 $\pm$ 0.542 <sup>2</sup>	8.002 $\pm$ 0.456 <sup>2</sup>
LL	35.674 $\pm$ 2.202 <sup>1</sup>	35.528 $\pm$ 1.851 <sup>1</sup>	36.696 $\pm$ 1.769	35.879 $\pm$ 2.118
P1	14.111 $\pm$ 1.631	13.813 $\pm$ 1.606 <sup>1</sup>	13.780 $\pm$ 1.543 <sup>1</sup>	13.144 $\pm$ 1.736
DS	8.278 $\pm$ 5.074	9.744 $\pm$ 2.270	4.597 $\pm$ 5.109	2.648 $\pm$ 3.919
AP	3.760 $\pm$ 5.208	2.813 $\pm$ 4.235	7.968 $\pm$ 5.237	6.187 $\pm$ 6.764
SL	421.964 $\pm$ 136.301	438.131 $\pm$ 149.500 <sup>1</sup>	437.755 $\pm$ 106.988 <sup>1</sup>	382.821 $\pm$ 118.620
CP	268.404 $\pm$ 37.500 <sup>1</sup>	265.335 $\pm$ 30.248 <sup>12</sup>	259.940 $\pm$ 29.184 <sup>3</sup>	261.612 $\pm$ 41.304 <sup>23</sup>
PP/PD	0.970 $\pm$ 0.066	0.981 $\pm$ 0.062	0.948 $\pm$ 0.059 <sup>1</sup>	0.950 $\pm$ 0.083 <sup>1</sup>
HW/HL	1.912 $\pm$ 0.289 <sup>1</sup>	1.914 $\pm$ 0.218 <sup>1</sup>	1.942 $\pm$ 0.182	1.868 $\pm$ 0.213
SN/HL	0.285 $\pm$ 0.046	0.294 $\pm$ 0.037	0.311 $\pm$ 0.039	0.299 $\pm$ 0.037
UJ/HL	0.289 $\pm$ 0.034 <sup>1</sup>	0.288 $\pm$ 0.034 <sup>1</sup>	0.292 $\pm$ 0.030 <sup>12</sup>	0.291 $\pm$ 0.034 <sup>2</sup>
ED/HL	0.347 $\pm$ 0.044 <sup>1</sup>	0.342 $\pm$ 0.040 <sup>12</sup>	0.340 $\pm$ 0.039 <sup>2</sup>	0.352 $\pm$ 0.040
UJ/SN	1.019 $\pm$ 0.167	0.982 $\pm$ 0.132 <sup>1</sup>	0.942 $\pm$ 0.136	0.976 $\pm$ 0.146 <sup>1</sup>
AW/HW	0.152 $\pm$ 0.086 <sup>1</sup>	0.153 $\pm$ 0.084 <sup>1</sup>	0.110 $\pm$ 0.088	0.134 $\pm$ 0.094
CW/HW	0.448 $\pm$ 0.069 <sup>1</sup>	0.465 $\pm$ 0.079	0.450 $\pm$ 0.082 <sup>1</sup>	0.429 $\pm$ 0.079
AW/CW	0.338 $\pm$ 0.173 <sup>1</sup>	0.327 $\pm$ 0.147 <sup>1</sup>	0.240 $\pm$ 0.167	0.307 $\pm$ 0.176
UJ/CW	1.238 $\pm$ 0.224	1.189 $\pm$ 0.238	1.266 $\pm$ 0.238 <sup>1</sup>	1.273 $\pm$ 0.256 <sup>1</sup>
SW/SH	0.487 $\pm$ 0.135	0.519 $\pm$ 0.149	0.389 $\pm$ 0.104	0.376 $\pm$ 0.094

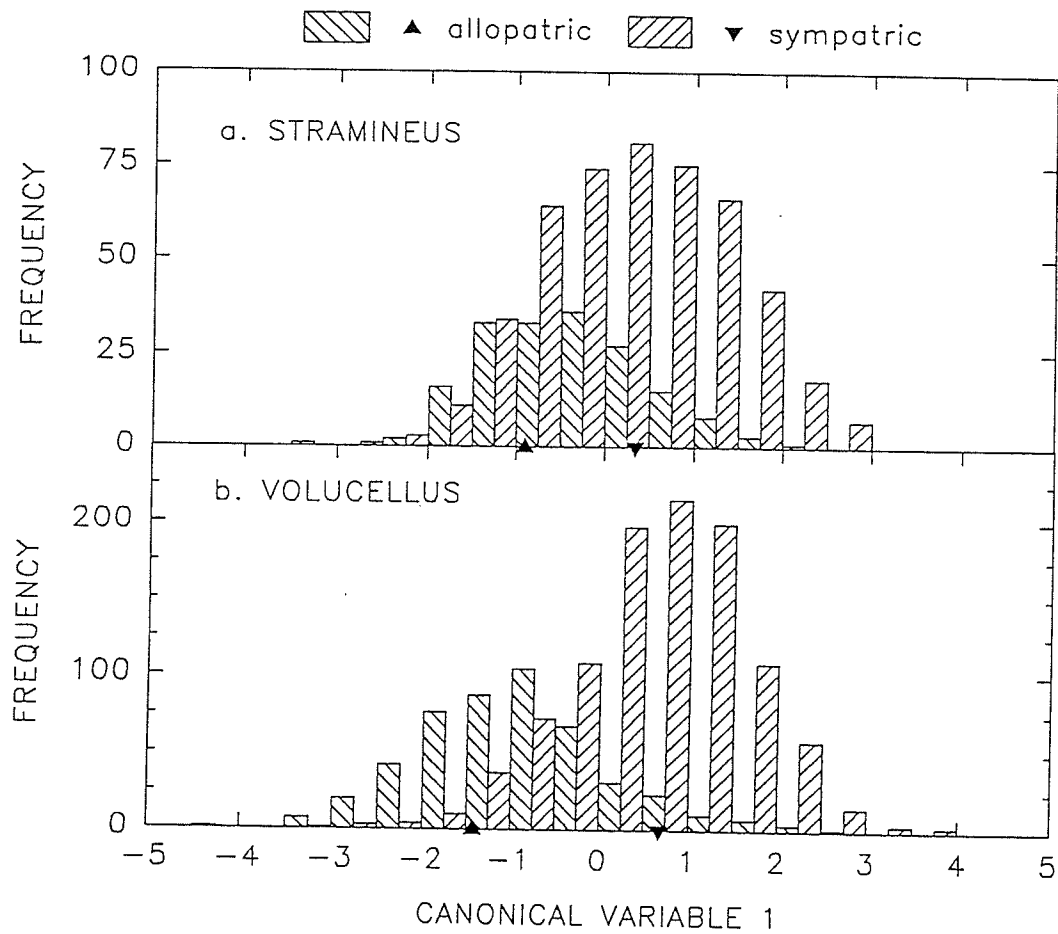


Fig. 10. Comparison of sympatric and allopatric populations of a. *Notropis stramineus*, and b. *N. volucellus*.  $\blacktriangle$  means of allopatric populations, *N. volucellus* = -1.43, *N. stramineus* = -0.90.  $\blacktriangledown$  means of sympatric populations, *N. volucellus* = 0.67, *N. stramineus* = 0.34.

the comparisons between provinces, the greater difference here occurs between the populations of *N. volucellus*, which were classified correctly (as allopatric or sympatric) 85.8% of the time as opposed to *N. stramineus* which was classified correctly 70.2% of the time.

*N. volucellus* populations (Fig. 10b) are differentiated primarily by AWCW because allopatric populations have a significantly wider angular width. SWSH also makes a significant contribution, allopatric populations having taller, narrower scales. Other components relate to head size and shape, allopatric populations having a larger head and mouth than sympatric populations. Both LL and P1 are significantly higher in sympatric populations.

*N. stramineus* populations (Fig. 10a) are differentiated primarily by SWSH and AWCW. Allopatric populations have significantly shorter, rounder scales and significantly broader chins. PPPD has a strong effect because the dorsal fin of allopatric populations does not originate as far posteriorly. Other important components of canonical variable 1 include CWHW and SNUJ which relate to the broader chin, and longer snout but shorter upper jaw of allopatric populations. P1 is significantly higher in sympatric populations but there is no significant difference in LL.

A between species comparison within each type of site (Fig. 11) demonstrates that both species are more similar to heterospecifics from the same type of site than they are to conspecifics from the other type of site. The contributing components to this comparison are all related to head and mouth size and shape, the two species generally varying in the opposite direction

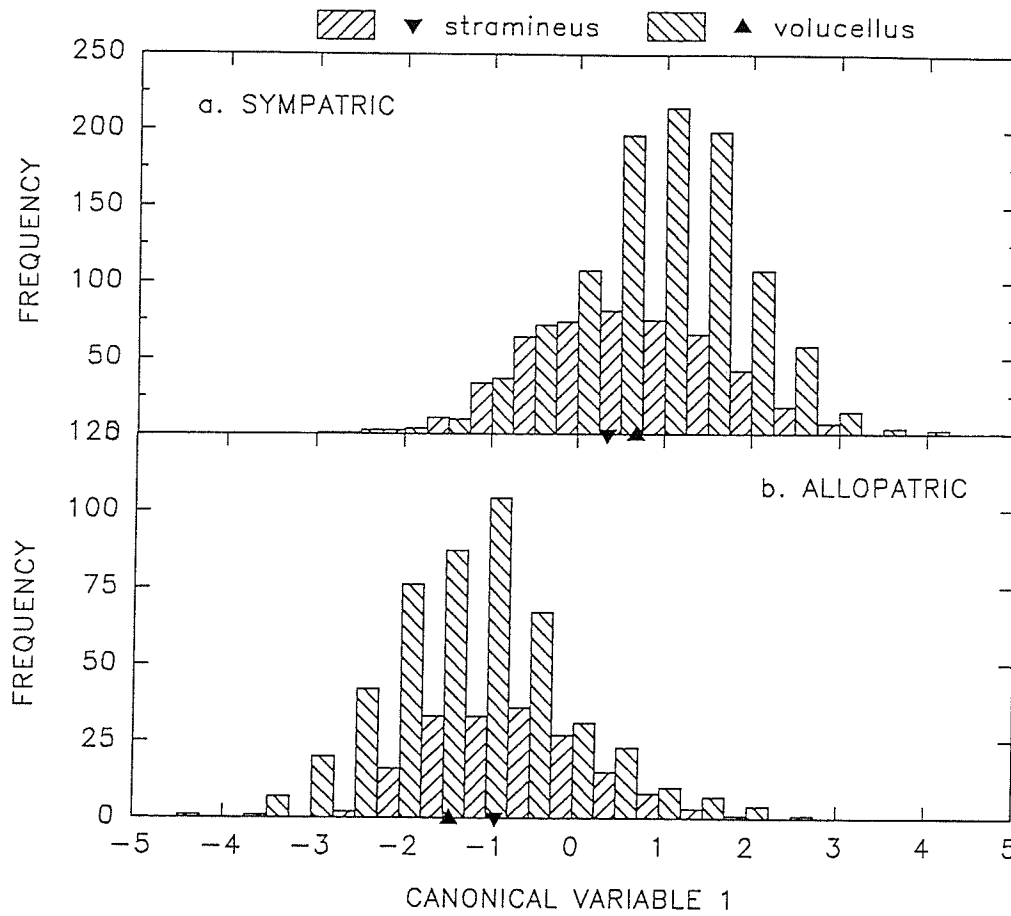


Fig. 11. Discrimination of *N. stramineus* and *N. volucellus* populations compared by; a. sympatric sites, b. allopatric sites. ▲ means of *N. volucellus*, ▼ means of *N. stramineus*.

(Tables 10, 11), that is if a character value is larger in the sympatric than the allopatric population of one species it is smaller in the sympatric population of the other species.

### **B. Comparisons of Reproductive Characteristics.**

GSI's of females are significantly correlated with egg diameter and with % of individuals with yolked eggs (Fig. 12). The broad scatter at higher 'yolk' values is due to the coding of any ovary with any yolked eggs as 1. The correlation of GSI of males with development of nuptial tubercles was significantly greater than 0 ( $p = 0.05$ ) for both populations of *N. stramineus*, but not for either population of *N. volucellus*.

Males of both species develop nuptial tubercles prior to and during the breeding season. In both species, tubercles first develop along pectoral fin rays. They then develop on the snout and top of the head, spreading to the cheeks and operculum and onto the 'chin'. Males of *N. stramineus* also develop a band of tiny tubercles from the back of the head to the origin of the dorsal fin, and a single row along the exposed margins of the anterior body scales. The head tubercles appear to be the same in both species. They are small, barely discernable without magnification, and sharply pointed. The pectoral fin tubercles of *N. volucellus* are similar to the head tubercles, arranged as two to three rows along each ray. The pectoral fin tubercles of *N. stramineus*, are minute, arranged in several rows along each fin ray, and form a shagreen-like texture. I observed no intermediates in this character in either species.



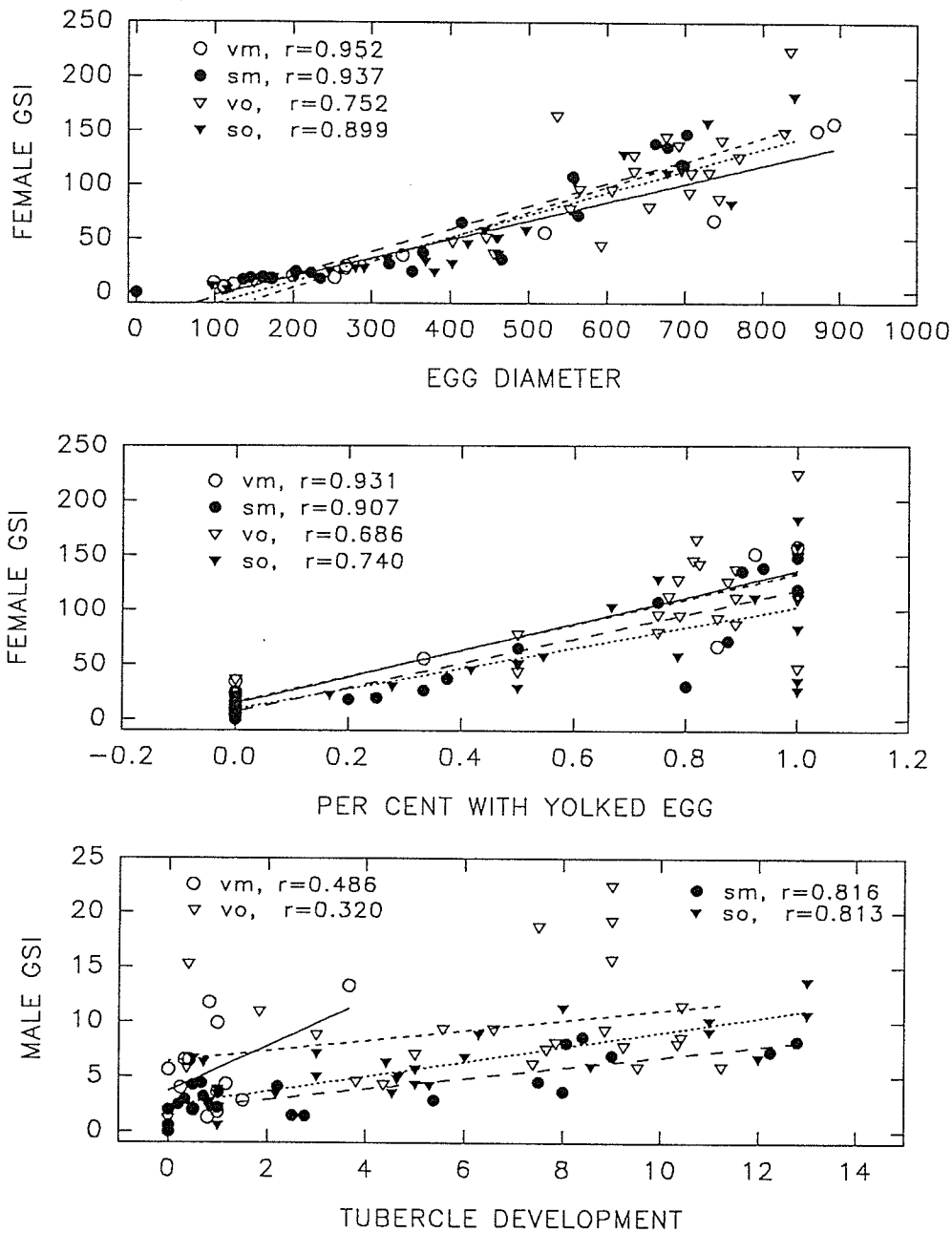


Fig. 12. Weekly averages of reproductive characteristics plotted against each other and fitted with regression lines. a. Female gonadosomatic index (GSI) against egg diameter. b. Female GSI against % of individuals bearing yolked eggs. c. Male GSI against development of nuptial tubercles. vm, vo = *Notropis volucellus* in Manitoba and Ontario respectively, sm, so = *N. stramineus* in Manitoba and Ontario respectively.

a. Ontario Populations

The different year collections of *N. volucellus* from the allopatric site in the Welland River produced significant differences in GSI's only in week 23 (Table 12). The only comparison possible among the sympatric sites, between South Otter Creek and Indian Brook males in week 27, produced a significant difference, but sample sizes were so low, 2 and 1 respectively, that little confidence can be placed in this result. Comparisons of allopatric with sympatric populations demonstrated significant differences in GSI for both sexes in most weeks (Fig. 13, Table 13), but this result has to be interpreted with caution because the data for sympatric sites represent pooled samples from different sites, in different years, generally with very low sample sizes.

Between year comparisons of *N. s. stramineus* from the allopatric site in Duffin's Creek revealed significant differences ( $0.01 < p < 0.05$ ) in female GSI's in weeks 23,24 and 26 and between male GSI's in week 23 (Table 14). Highly significant differences occurred only during week 21 among females and weeks 21 and 24 among males. Because between year sample sizes of females differed greatly in weeks 21, 23 and 26 (3:12, 2:13 and 14:4 respectively), male sample sizes differed in weeks 23 and 26 (2:12 and 13:7 respectively) and sample sizes were low in all other weeks I felt confident that it was not inappropriate to pool these data plus data from the Little Rouge River for further analyses. Sympatric populations demonstrated no significant difference in male or female GSI's for those weeks where comparisons could be made. Allopatric females differ from sympatric females in weeks 20-23 and males differ in week 23 (Fig. 14, Table 15). Differences were non-significant in other weeks. This

Table 12. Results of weekly comparisons of gonadosomatic indices of allopatric and sympatric population subsets of *Notropis volucellus* in Ontario. Means are pooled  $\pm$  2 standard deviations for that week. WR = Welland River, allopatric site, compared between 1987 and 1988. Sympatric collections are listed separately in weeks where collections were pooled. Postscript numbers indicate collection year. WC = Wardell's Creek, PR = Young's Creek in Port Ryerse, BC = Bowen's Creek, PI = Pelée Island, OC = South Otter Creek, IB = Indian Brook. |t| absolute value of the *t* statistic.

Week	Site	Female				Male			
		n	Mean $\pm$ 2s	t	Prob > t	n	Mean $\pm$ 2s	t	Prob > t
Allopatric Site									
19	WR	24	136.673 $\pm$ 200.180	1.284	NS	21	9.360 $\pm$ 8.636	0.037	NS
20		23	131.555 $\pm$ 170.938	0.253	NS	14	10.753 $\pm$ 8.962	0.855	NS
21		20	138.567 $\pm$ 161.493	0.755	NS	16	8.007 $\pm$ 5.584	0.765	NS
23		36	117.396 $\pm$ 150.632	1.992	0.028	14	5.429 $\pm$ 8.317	3.071	0.005
24		11	123.002 $\pm$ 90.629	0.366	NS	19	7.957 $\pm$ 6.113	0.428	NS
25		22	105.852 $\pm$ 81.906	1.453	NS	20	6.692 $\pm$ 5.890	1.691	NS
26		11	93.994 $\pm$ 93.637	0.107	NS	22	6.150 $\pm$ 4.554	0.192	NS
27		9	87.302 $\pm$ 68.730			16	4.589 $\pm$ 4.912		
28		14	43.878 $\pm$ 65.081			11	4.321 $\pm$ 4.175		
Sympatric Sites									
19	WC88	3	18.676 $\pm$ 21.568						
20	PR87	6	9.820 $\pm$ 134.189			7	6.410 $\pm$ 12.553		
21	BC88	20	36.471 $\pm$ 24.556			5	15.309 $\pm$ 4.708		
23		2	47.468 $\pm$ 2.892			2	13.350 $\pm$ 4.429		
24	PI87	8	77.760 $\pm$ 105.184			5	11.910 $\pm$ 7.637		
26	OC88					1	15.706 $\pm$ 0.000		
27	OC/IB 88	2	51.120 $\pm$ 117.608	NA		3	15.365 $\pm$ 24.635	18.410	<0.0005
	IB	2	51.120 $\pm$ 117.608			1	1.163 $\pm$ 0.000		
28	OC88	1	224.227 $\pm$ 0.000			2	19.227 $\pm$ 54.428		
29		2	149.754 $\pm$ 124.961			4	18.708 $\pm$ 6.931		

*Notropis volucellus* - Ontario

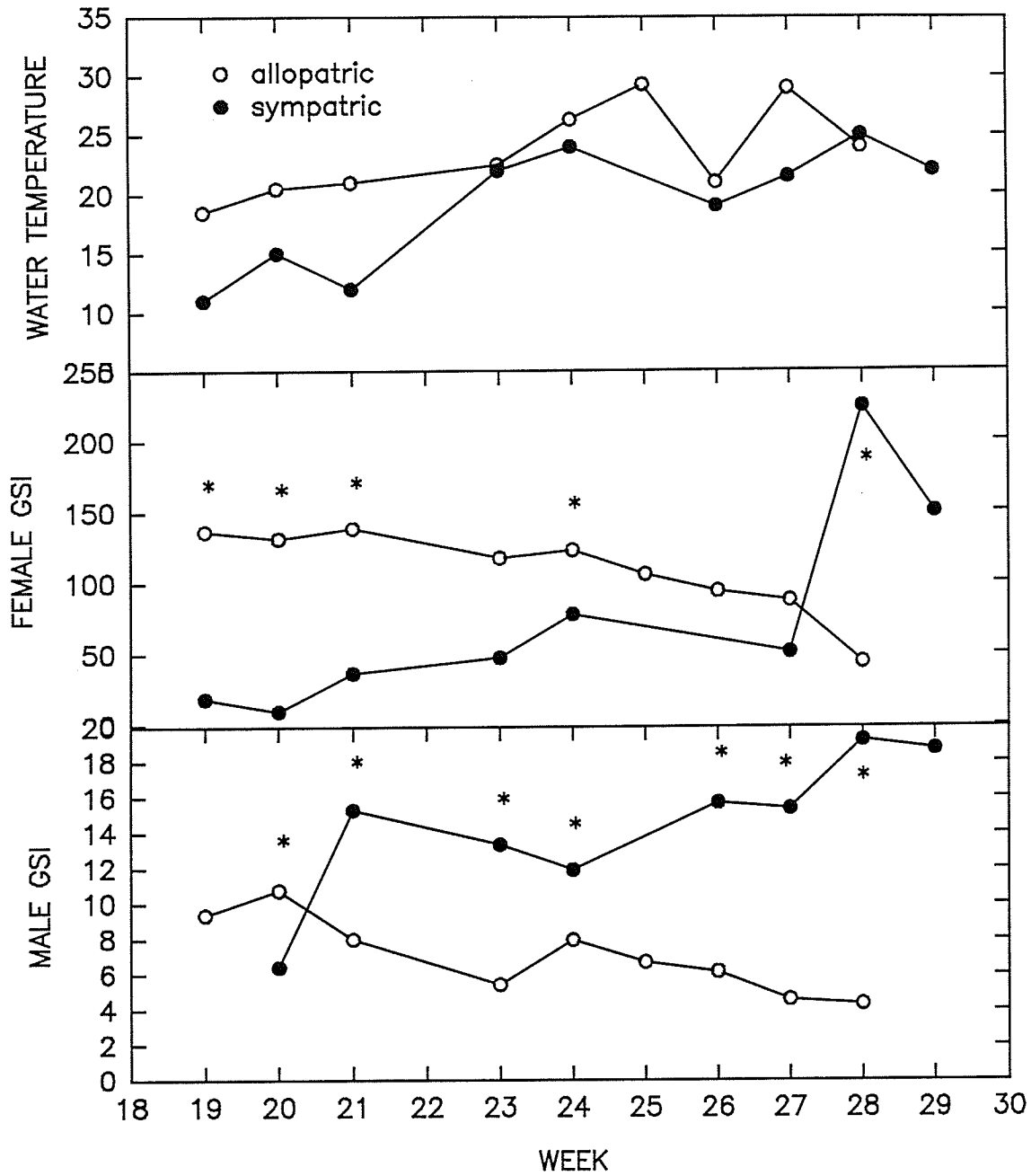


Fig. 13. Weekly averages of water temperature, and female and male gonadosomatic indices (GSI) of allopatric and sympatric Ontario populations of *Notropis volucellus*. \* indicates significant differences between species for that week.

Table 13. Results of weekly comparisons of gonadosomatic indices of *N. volucellus* from allopatric sites with *N. volucellus* from sympatric sites. n = number of specimens, sym = sympatric site, all = allopatric site, |t| = absolute value of the *t* statistic.

Week	Female				Male			
	n		t	Prob > t	n		t	Prob > t
	sym	all			sym	all		
19	3	24	2.006	0.029	0	21		
20	6	23	3.224	0.002	7	14	1.834	0.042
21	20	20	5.590	<0.0005	5	16	5.268	<0.0005
23	2	36	1.296	NS	2	14	2.587	0.010
24	8	11	2.010	0.031	5	19	2.451	0.010
25	0	22			0	20		
26	0	11			2	23	4.105	<0.0005
27	2	9	2.911	0.008	3	16	3.557	0.001
28	1	14	5.354	<0.0005	2	11	9.608	<0.0005
29	2				4			

Table 14. Results of weekly comparisons of gonadosomatic indices of allopatric and sympatric population subsets of *Notropis stramineus* in Ontario. Means are pooled  $\pm$  2 standard deviations for each week. DC = Duffin's Creek, allopatric site, compared between 1987 and 1988. Sympatric collections are listed separately in weeks where collections were pooled. Site abbreviations are defined in Table 12. |t| absolute value of the *t* statistic.

Week	Site	Female				Male			
		n	Mean $\pm$ 2s	t	Prob > t	n	Mean $\pm$ 2s	t	Prob > t
Allopatric Site									
21	DC	15	68.372 $\pm$ 121.209	4.252	<0.0005	16	7.769 $\pm$ 10.074	3.105	0.004
23		15	97.438 $\pm$ 16.311	2.887	0.007	14	6.932 $\pm$ 15.827	1.927	0.041
24		10	70.013 $\pm$ 134.937	2.322	0.025	13	5.829 $\pm$ 14.489	5.849	<0.0005
25		4	29.065 $\pm$ 64.728			5	6.348 $\pm$ 6.002	0.209	NS
26		18	73.766 $\pm$ 42.232	2.025	0.031	20	3.770 $\pm$ 5.767	0.505	NS
27		1	2.966 $\pm$ 0.000			3	5.084 $\pm$ 8.426		
28		2	19.119 $\pm$ 38.885			7	5.953 $\pm$ 6.617		
29		4	50.971 $\pm$ 89.444			11	4.838 $\pm$ 6.723		
Sympatric Sites									
19	WC88	3	26.913 $\pm$ 12.544			1	2.927 $\pm$ 0.000		
20	IB/PR	8	21.244 $\pm$ 14.521	0.824	NS	4	4.300 $\pm$ 6.692	2.008	NS
	PR87	2	14.214 $\pm$ 24.729			1	6.410 $\pm$ 0.000		
21	IB88	18	30.753 $\pm$ 33.320			7	7.114 $\pm$ 5.549		
23	IB/BC	12	22.718 $\pm$ 32.768			15	2.913 $\pm$ 4.497	0.933	NS
	BC88	0				2	4.301 $\pm$ 0.063		
24	PI87	7	48.217 $\pm$ 95.437	0.273	NS	8	6.316 $\pm$ 7.938		
25	OC87	1	14.006 $\pm$ 0.000			1	0.552 $\pm$ 0.000		
26	BC88					1	3.391 $\pm$ 0.000		
27	IB88					1	0.000 $\pm$ 0.000		
29	IB90	11	57.755 $\pm$ 131.103			6	3.397 $\pm$ 7.023		

*Notropis stramineus* - Ontario

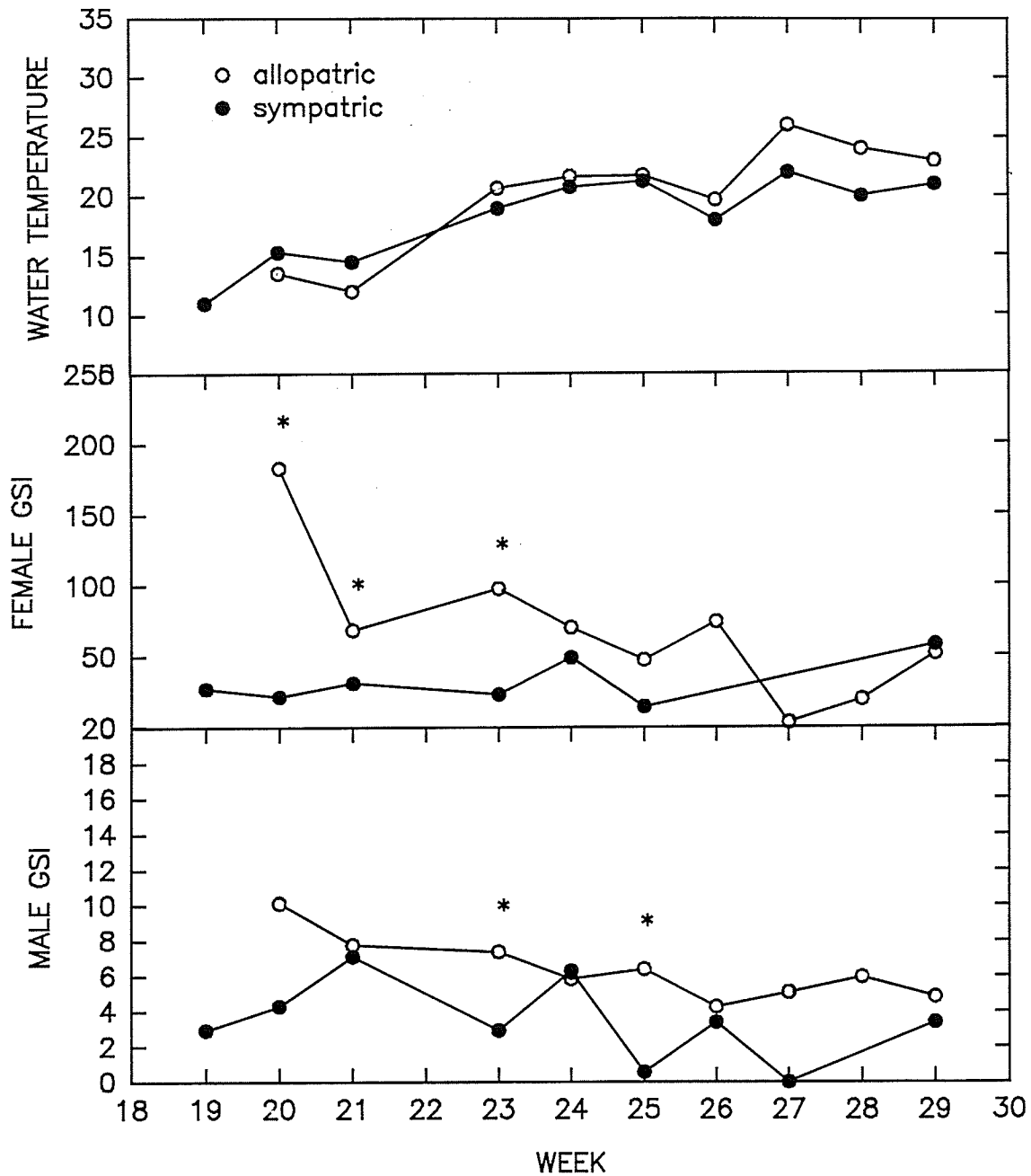


Fig. 14. Weekly averages of water temperature and female and male gonadosomatic indices (GSI) of allopatric and sympatric Ontario populations of *Notropis stramineus*. \* indicates significant differences between site types for that week. There are no significant differences among weeks in either population.

Table 15. Results of weekly comparisons of gonadosomatic indices of *N. stramineus* from allopatric sites (Duffin's Creek plus Little Rouge River) with *N. stramineus* from sympatric sites. |t| absolute value of the *t* statistic.

Week	Female				Male			
	n		t	Prob > t	n		t	Prob > t
	sym	all			sym	all		
19	3	0			1	0		
20	8	1	20.968	<0.0005	4	1	1.557	NS
21	18	15	2.506	0.009	7	16	0.320	NS
23	12	15	4.242	<0.0005	15	15	4.055	<0.005
24	7	10	0.705	NS	8	13	0.273	NS
25	1	6	0.793	NS	1	6	2.017	0.046
26	0	18			1	22	0.155	NS
27	0	1			1	3	1.045	NS
28	0	2			0	7		
29	11	4	0.189	NS	6	11	0.833	NS



last analysis suffers from the same limitations as the comparisons of allopatric and sympatric *N. volucellus*, with the exception that there were 5 collections from Indian Brook which provides rather more consistency to the data for sympatric collections of *N. stramineus*.

Comparisons between species in the allopatric sites show that for most weeks females of *N. volucellus* had significantly higher GSI's than those of *N. stramineus* (Fig 15, Table 16). This general trend is reversed in Week 20, which is, however, represented by only a single *N. stramineus* female. Males show a significant difference only in week 26. Both sexes of both species show a gradual but steady decline in GSI's over most of the collection period, however there is an apparent reversal of this trend within *N. stramineus* in week 27 among females and week 26 among males. This appears to coincide with an abrupt rise in water temperature.

Within the sympatric sites weeks 19 and 24 include only sympatric collections. Weeks 20, 23 and 27 include sympatric collections among others from sympatric sites (Table 17). Females show no significant difference between species and both species show a gradual increase in GSI from weeks 19 to 25, with a fairly abrupt increase thereafter (Fig. 16, Table 17). GSI's of male *N. volucellus* were significantly higher than those of *N. stramineus* in weeks 21, 23, 24 and 29, showing an overall increase over time as opposed to a general decrease over time among *N. stramineus*.

ANOVA's comparing weekly trends in the GSI's of the different populations demonstrated that for the period over which I collected there was

Allopatric Populations - Ontario

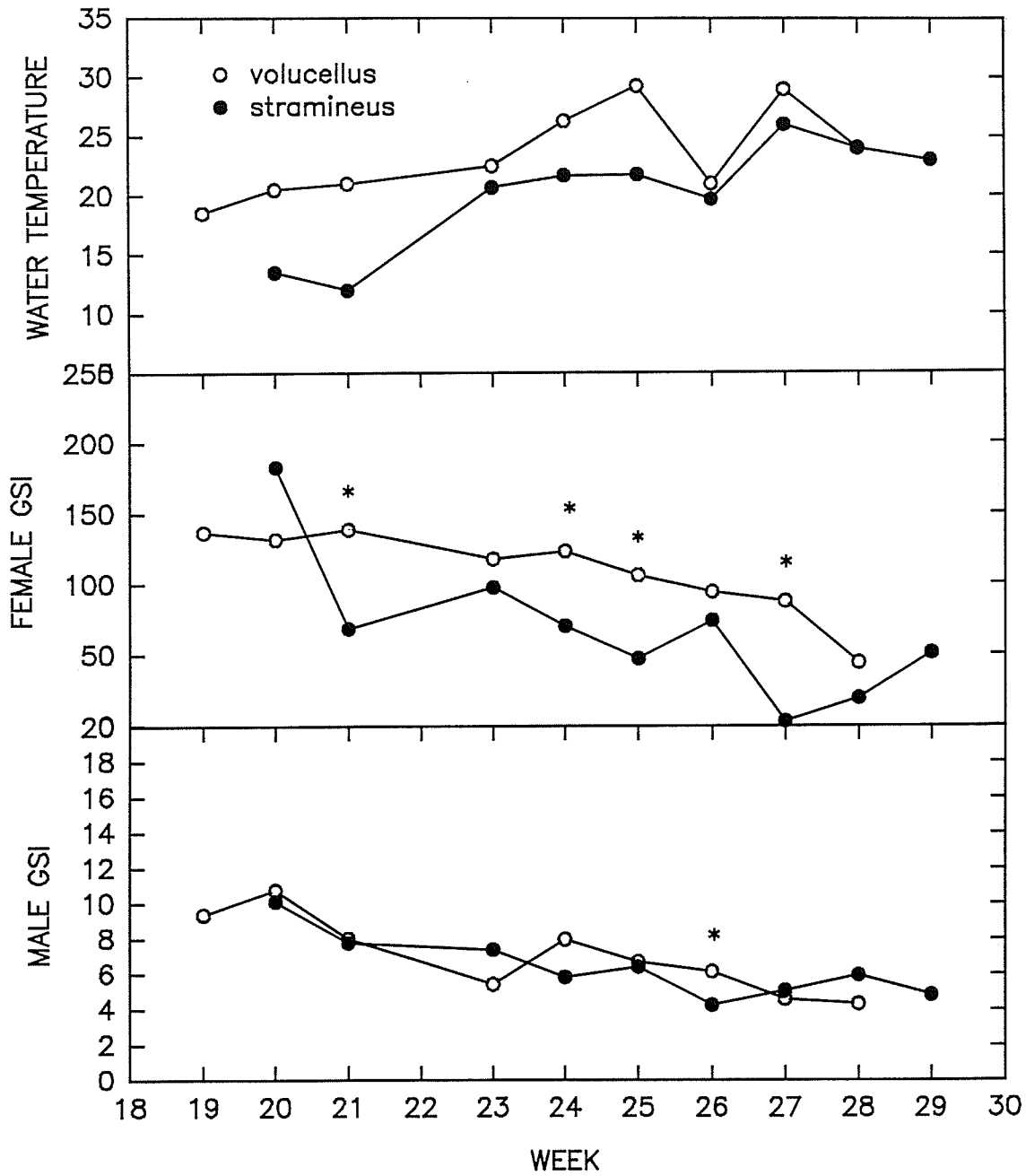


Fig. 15. Weekly averages of water temperature and female and male gonadosomatic indices (GSI) of allopatric Ontario populations of *Notropis stramineus* and *N. volucellus*. \* indicates significant differences between species for that week.

Table 16. Results of weekly comparisons of gonadosomatic indices of *N. stramineus* and *N. volucellus* from allopatric sites (Duffin's Creek plus Little Rouge River and Welland River respectively). |t| absolute value of the *t* statistic.

Week	Female				Male			
	n		t	Prob > t	n		t	Prob > t
	str	vol			str	vol		
20	1	23	0.587	NS	1	14	0.136	NS
21	25	10	2.220	0.018	16	16	0.134	NS
23	15	36	0.914	NS	15	14	1.352	NS
24	10	11	2.132	0.023	13	19	1.716	NS
25	6	22	5.795	<0.0005	6	20	0.197	NS
26	18	11	0.899	NS	22	22	2.251	0.016
27	1	9	2.328	0.023	3	16	0.289	NS
28	2	16	1.030	NS	7	11	1.292	NS

Table 17. Results of weekly comparisons of gonadosomatic indices of *Notropis stramineus* (str) and *N. volucellus* (vol) from sympatric sites. Sympatric collections are listed separately in weeks where collections were pooled. |t| absolute value of the *t* statistic.

Week	Female				Male			
	n		t	Prob > t	n		t	Prob > t
	str	vol			str	vol		
19	3	3	1.374	NS	1	0		
20	8	6	0.484	NS	4	7	0.615	NS
PR	2	6	0.088	NS	1	7	0.955	NS
21	18	20	1.213	NS	7	5	5.353	<0.0005
23	12	2	2.065	0.031	15	2	6.172	<0.0005
BC	0	2			2	2	5.778	<0.0005
24	6	8	1.112	NS	8	5	2.506	0.015
25	1	0			1			
26	0	0			1	1		
27	0	2			1	3	1.080	NS
IB	0	2			1	1		
28	0	2			0	4		
29	11	4	1.833	0.047	6	11	6.788	<0.0005

Sympatric Populations - Ontario

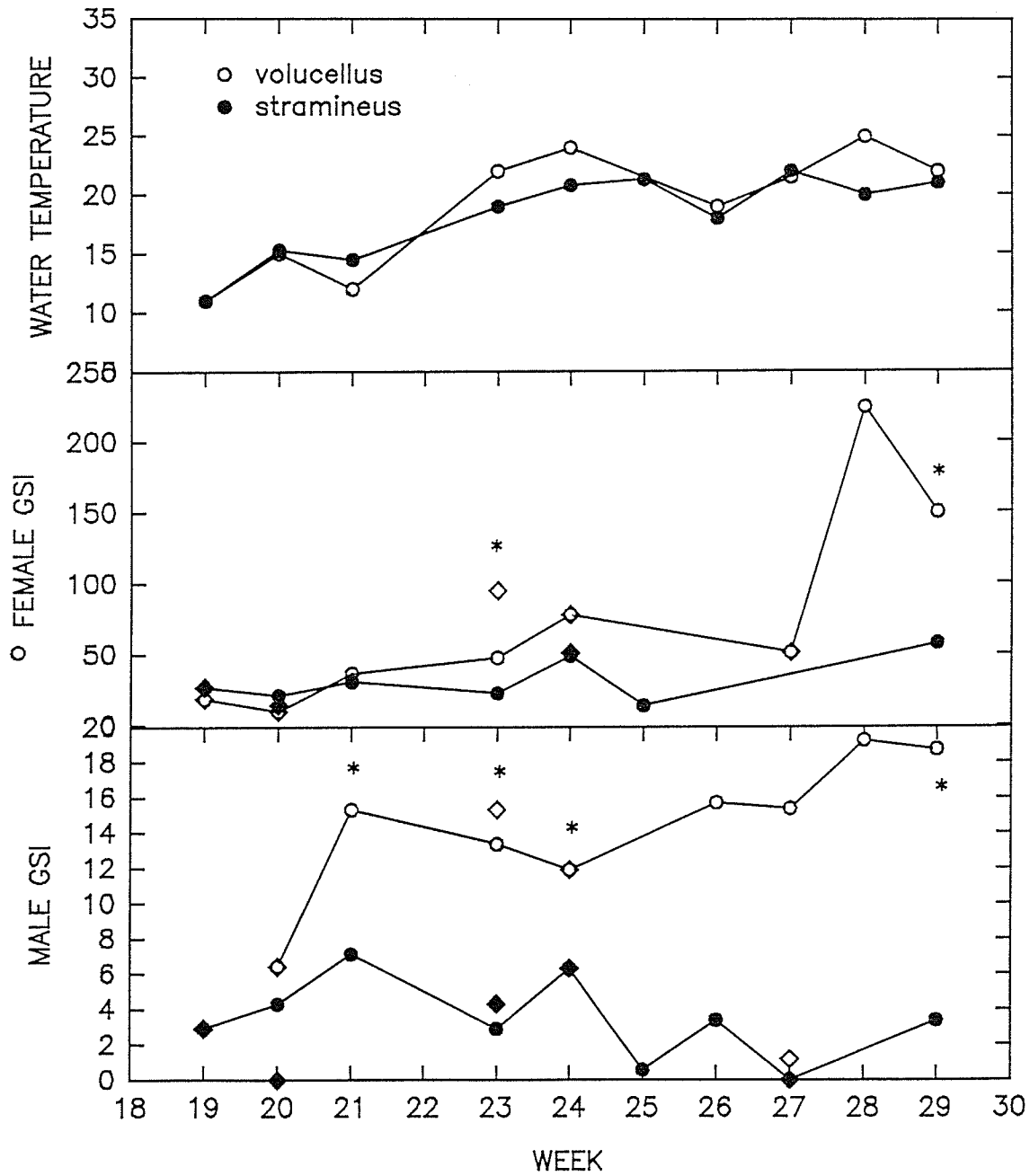


Fig. 16. Weekly averages of water temperature and female and male gonadosomatic indices (GSI) of sympatric Ontario populations of *Notropis stramineus* and *N. volucellus*. \* indicates significant differences between species for that week. ◇ *N. volucellus*, and ◆ *N. stramineus* from sympatric collections.

no difference in male or female GSI's of *N. stramineus* in Ontario (Fig. 14, Table 18). The apparent sharp drop in female GSI between weeks 20 and 21 is a sample size bias. There was only a single female caught in week 20.

There were differences over time within the *N. volucellus* populations (Fig. 13, Table 18, 19). Among allopatric collections the GSI of females from week 28 was significantly lower than the highest value (week 21), but was not significantly different from the next highest value (week 19). Among males there was no difference among weeks 21 - 28. GSI in week 20 was significantly higher than in weeks 23, 25 - 28, but with so much overlap it is safest to state only that a general reducing trend is evident.

Among collections from sympatric sites, female GSI's were significantly higher in weeks 28 and 29, although not significantly higher in week 29 than in weeks 23 and 24. Week 28 includes only a single individual and week 29 only two. The ANOVA for males was just barely significant (Table 18) and the multiple comparison test detected no difference between the highest value in week 28 and the lowest in week 20, although there is a general trend to an increase in male GSI (Fig. 16).

#### b. Manitoba Populations

The two Souris River populations of *N. stramineus* show highly significant differences ( $p < 0.005$ ) in female GSI in weeks 20 and 21. Less pronounced differences ( $0.03 < p < 0.05$ ) occur in both sexes in week 29 and males in week 34 (Fig. 17, Table 20). The two Winnipeg River populations of *N. volucellus*

Table 18. Results of analysis of variance of collections of various populations of *Notropis volucellus* and *N. stramineus*, compared over time.

Site	Source of Variation	SS	DF	MS	F	Prob>F
Allopatric <i>N. volucellus</i>	♀ Groups	113912.287	8	14239.036		
	Error	809997.952	161	5031.043	2.830	0.006
	♂ Groups	569.150	8	71.144		
	Error	1551.552	144	10.775	6.603	<0.0005
Sympatric <i>N. volucellus</i>	♀ Groups	72724.623	7	10389.232		
	Error	52330.570	36	1453.627	7.147	<0.0005
	♂ Groups	567.717	7	81.102		
	Error	662.476	21	31.546	2.571	0.046
Pooled <i>N. volucellus</i>	♀ Groups	69002.285	9	7666.921		
	Error	1125460.306	204	5516.962	1.390	NS
	♂ Groups	811.872	9	90.208		
	Error	3433.611	172	19.963	4.519	<0.0005
Allopatric <i>N. stramineus</i>	♀ Groups	38122.036	8	4765.254		
	Error	231784.660	63	3679.119	1.295	NS
	♂ Groups	181.323	8	22.665		
	Error	1220.952	85	14.364	1.578	NS
Sympatric <i>N. stramineus</i>	♀ Groups	11551.010	6	1925.168		
	Error	64751.408	53	1221.725	1.576	NS
	♂ Groups	156.922	8	19.615		
	Error	322.464	35	9.213	2.129	NS
Pooled <i>N. stramineus</i>	♀ Groups	22508.431	9	2500.937		
	Error	372516.884	122	3053.417	0.819	NS
	♂ Groups	187.749	9	20.861		
	Error	1781.447	128	13.918	1.499	NS
Manitoba <i>N. volucellus</i>	♀ Groups	138679.336	6	23113.223		
	Error	193046.627	87	2218.927	10.416	<0.0005
	♂ Groups	720.498	6	120.083		
	Error	545.928	51	10.704	11.218	<0.0005
Manitoba <i>N. stramineus</i>	♀ Groups	386382.164	11	35125.651		
	Error	258136.286	136	1898.061	18.506	<0.0005
	♂ Groups	573.768	11	52.161		
	Error	472.127	79	5.976	8.728	<0.0005

Table 19. Results of Tukey's multiple comparisons tests on weekly averages of female and male GSI's. Horizontal lines group weeks having means with non-significant differences.

A. *N. volucellus*, Ontario, Allopatric Females

Week	28	27	26	25	23	24	20	19	21
X	43.878	87.302	93.994	105.852	117.396	123.002	131.55	136.673	138.567

B. *N. volucellus*, Ontario, Allopatric Males

Week	28	27	23	26	25	24	21	19	20
X	4.32	4.589	5.429	6.150	6.692	7.757	8.007	9.360	10.753

C. *N. volucellus*, Ontario, Sympatric Females

Week	20	19	21	23	27	24	29	28
X	9.820	18.676	36.471	47.468	51.120	77.760	149.754	224.227

d. *N. volucellus*, Manitoba, Allopatric Females

Week	29	34	21	23	30	28	26
X	5.420	14.356	23.603	45.003	67.136	100.896	114.317

e. *N. volucellus*, Manitoba, Allopatric Males

Week	29	26	30	34	28	21	23
X	1.70	3.006	3.583	4.398	5.096	6.527	12.541

f. *N. s. stramineus*, Manitoba, Allopatric Females

Week	35	34	32	28	29	20	23	22	21
X	13.163	14.282	17.691	23.788	26.563	107.229	118.960	128.441	129.468

g. *N. s. stramineus*, Manitoba, Allopatric Males

Week	29	32	22	34	28	35	21	23	20
X	2.042	2.394	2.619	2.971	3.316	3.417	6.329	7.817	8.199



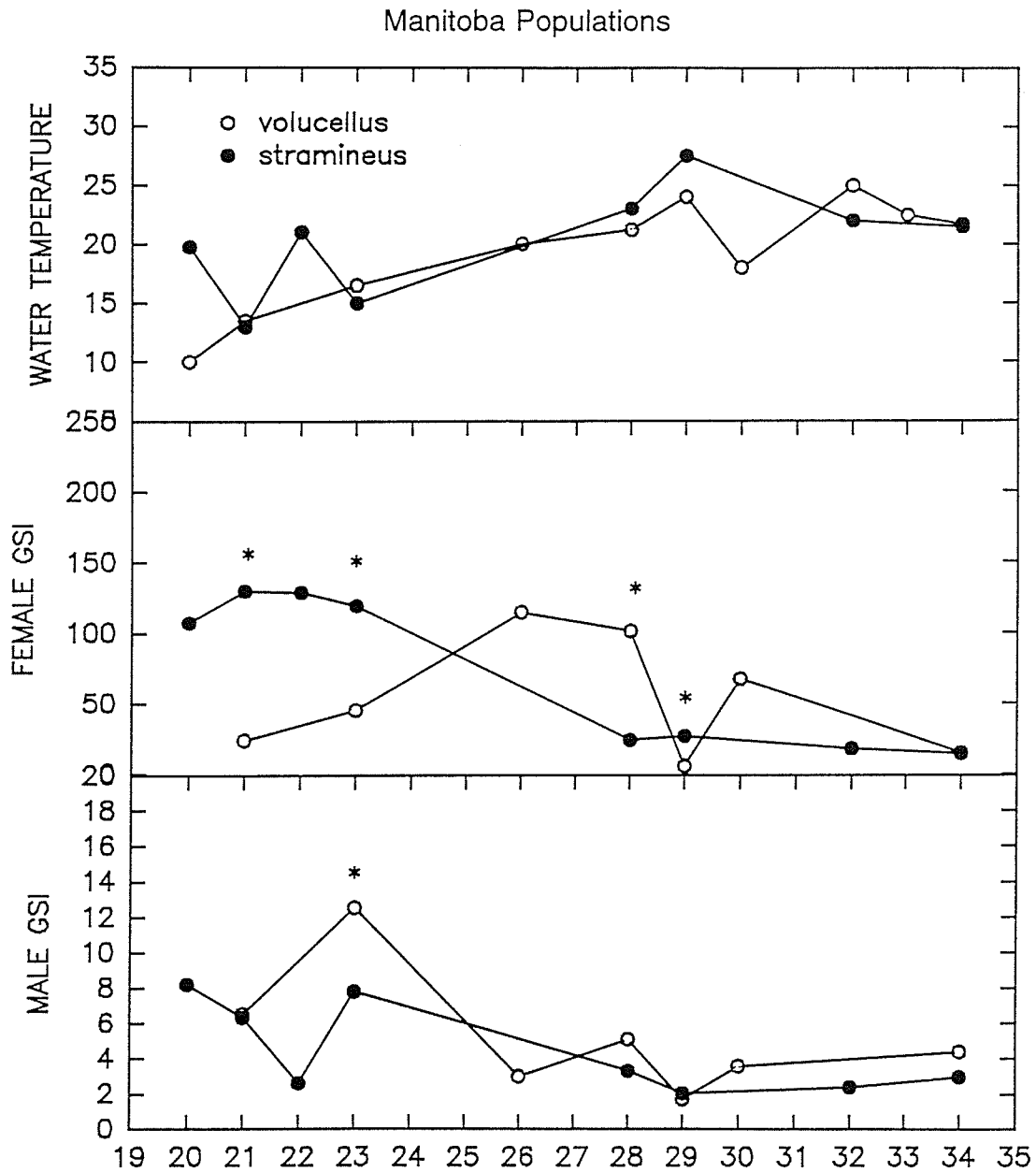


Fig. 17. Weekly averages of water temperature and female and male gonadosomatic indices (GSI) of *Notropis volucellus* and *N. stramineus* in Manitoba. \* indicates significant differences between species for that week.

Table 20. Univariate statistics (means  $\pm$  2 standard deviations) and results of weekly comparisons of gonadosomatic indices of *N. stramineus* from the two Souris River Sites and of *N. volucellus* from Barrier Bay and Dorothy Lake in Manitoba. Souris River data after week 34 are omitted.

Week	Female				Male			
	n	Mean $\pm$ 2s	l <sub>t</sub> l	Prob > t	n	Mean $\pm$ 2s	l <sub>t</sub> l	Prob > t
<i>Notropis stramineus</i>								
20	18	107.229 $\pm$ 106.516	3.097	0.004	20	8.199 $\pm$ 6.059	0.337	NS
21	18	129.468 $\pm$ 114.574	3.145	0.003	8	6.329 $\pm$ 7.761	0.735	NS
22	24	128.441 $\pm$ 135.552	1.063	NS	9	2.619 $\pm$ 4.524	1.610	NS
23	20	118.960 $\pm$ 86.823	0.004	NS	9	7.817 $\pm$ 5.586	0.488	NS
28	13	23.788 $\pm$ 29.097	1.411	NS	13	3.316 $\pm$ 4.016	1.097	NS
29	18	26.563 $\pm$ 42.903	2.045	0.030	7	2.042 $\pm$ 2.220	2.141	0.031
32	11	17.691 $\pm$ 27.207	0.262	NS	5	2.394 $\pm$ 1.359		
34	8	14.282 $\pm$ 3.517			5	2.971 $\pm$ 2.672	2.851	0.035
<i>Notropis volucellus</i>								
21	12	23.603 $\pm$ 21.877	0.156	NS	13	6.527 $\pm$ 8.467	0.001	NS
23	16	45.003 $\pm$ 68.034	1.469	NS	12	12.541 $\pm$ 7.826	0.661	NS
26	7	114.317 $\pm$ 169.471	4.131	0.005	2	3.006 $\pm$ 2.562		
28	20	100.896 $\pm$ 162.307	7.406	<0.0005	7	5.096 $\pm$ 7.340	1.577	NS
29	9	5.420 $\pm$ 4.568	1.819	NS	7	1.700 $\pm$ 2.805	1.438	NS
30	7	67.136 $\pm$ 158.043			3	3.583 $\pm$ 4.304		
34	23	14.356 $\pm$ 59.878	1.793	0.045	14	4.398 $\pm$ 4.256	1.676	NS

show significant differences in female GSI in weeks 26, 28, but no differences between male GSI's.

Comparisons between species demonstrate significant differences between female GSI's in weeks 21, 23, 28 and 29. Males are significantly different in week 23 (Fig. 17, Table 21).

The ANOVA's comparing GSI's over time were highly significant for both sexes for both species (Table 18). Tukey's multiple comparisons test demonstrated that female GSI's of *N. stramineus* formed two mutually exclusive groups, weeks 20 - 23 were significantly higher than weeks 29 - 42. Among males weeks 20, 21 and 23 were equal, forming a distinct group, however week 23, with second highest male GSI, was distinct only from week 42, which had a GSI of 0 (Table 19).

Multiple comparisons among weeks of female GSI's of *N. volucellus* grouped weeks 26, 28, and 30 as equal with week 30 showing no significant difference from any other week. Among males the GSI was significantly highest in week 23. The next highest GSI, in week 21, was significantly different only from the lowest value in week 29.

### c. Interprovincial Comparisons

Direct comparisons of reproductive condition among sympatric and allopatric Ontario populations and Manitoba populations could be made in weeks 21, 23, 26 and 28 for *Notropis volucellus* (Fig. 18), and weeks 20, 21, 23 and 29 for *N. stramineus* (Fig. 19, Table 22).

Table 21. Results of weekly comparisons of gonadosomatic indices of Manitoba populations of *N. stramineus* and *N. volucellus*. |t| absolute value of the *t* statistic.

Week	Female				Male			
	n		t	Prob > t	n		t	Prob > t
	str	vol			str	vol		
21	18	12	6.290	<0.0005	8	13	0.108	NS
23	20	16	5.576	<0.0005	9	12	3.073	0.003
28	13	20	3.373	0.003	13	13	1.352	NS
29	18	9	2.920	0.004	7	7	0.506	NS
34	8	23	0.065	NS	5	14	1.390	NS

Table 22. Results of analysis of variance comparing gonadosomatic indices of Manitoba collections with allopatric and sympatric Ontario collections of *Notropis volucellus* and *N. stramineus* made during the same week.

Week	Source of Variation	SS	DF	MS	F	Prob>F
<i>Notropis stramineus</i>						
20	♀ Groups	50956.640	2	25478.32	12.585	<0.0005
	Error	48587.759	24	2024.490		
	♂ Groups	57.044	2	28.522	3.022	NS
	Error	207.646	22	9.438		
21	♀ Groups	92018.778	2	46009.389	19.556	<0.0005
	Error	112929.548	48	2352.699		
	♂ Groups	11.223	2	5.612	0.295	NS
	Error	532.181	28	19.006		
23	♀ Groups	71637.063	2	35818.532	18.007	<0.0005
	Error	87522.878	44	1989.156		
	♂ Groups	199.282	2	99.641	11.284	<0.0005
	Error	317.898	36	8.830		
29	♀ Groups	7198.628	2	3599.314	1.901	NS
	Error	56793.200	30	1893.107		
	♂ Groups	34.027	5	17.014	1.963	NS
	Error	182.030	21	8.668		
<i>Notropis volucellus</i>						
21	♀ Groups	451752.670	2	225876.335	51.030	<0.0005
	Error	234597.779	53	4426.373		
	♂ Groups	279.993	2	139.997	8.259	0.001
	Error	610.232	36	16.951		
23	♀ Groups	62525.323	2	31212.662	7.373	0.002
	Error	215896.857	51	4233.272		
	♂ Groups	366.730	2	183.365	11.974	<0.0005
	Error	398.167	26	15.314		
26	♀ Groups	1766.842	1	1766.842	0.467	NS
	Error	60569.035	16	3785.565		
	♂ Groups	110.658	2	50.329	10.020	0.001
	Error	110.499	22	5.023		
28	♀ Groups	47710.346	2	23855.173	5.496	0.0009
	Error	138896.740	32	4340.523		
	♂ Groups	386.505	2	193.253	26.152	<0.0005
	Error	125.623	17	7.390		

ANOVA's testing GSI's of *N. volucellus* populations were significant for both sexes for weeks 21, 23 and 28, and for males in week 26. Tukey's multiple comparisons tests demonstrated that differences in female GSI's of Manitoba and sympatric Ontario populations were non-significant in weeks 21, 23 and 28, and in weeks 21 and 28 both were significantly different from values in allopatric populations. In week 23 differences between allopatric and sympatric sites were non-significant (Fig. 13). In weeks 21, 26 and 28 differences in male GSI's of Manitoba and allopatric Ontario populations were non-significant and both were significantly different from sympatric populations. In week 23 differences in male GSI's were non-significant between Manitoba and sympatric Ontario populations, and both were significantly different from the allopatric populations.

ANOVA's testing GSI's of *N. stramineus* populations demonstrated no difference in male GSI's for weeks 20, 21 and 29 and no difference in female GSI's in week 29 (Fig. 19). In week 23 differences between Manitoba and allopatric Ontario males were non-significant, and both were significantly different from the sympatric Ontario populations. Differences in allopatric Ontario and Manitoba female GSI's were non-significant in weeks 20 and 23, and both were significantly different from allopatric Ontario populations. In week 21 there was no significant difference between female GSI's in the Ontario populations, which were significantly lower than the values in the Manitoba populations.

d. Effects of Water Temperature

The plots of water temperature and GSI's against time suggest that there is a relationship between them. The allopatric sites in Ontario (Fig. 16) and the Souris River site in Manitoba (Fig. 18) had reached temperatures of 15 - 20°C by the start of the collecting seasons. The sympatric sites in Ontario did not reach and maintain 20°C until week 23 (Fig. 17). Females of both species in the sympatric sites in Ontario show an increase in GSI in the following week. The Winnipeg River sites had reached 20°C by week 26 (Fig. 18), which coincides with the highest female GSI values, however, no collections were made in weeks 24 and 25 so I am unable to state when water temperature actually reached 20°C.

Males from sympatric populations of both species in Ontario show a sharp increase in GSI in week 21, and male *N. volucellus* in the Winnipeg River in week 23 which coincides with water temperatures reaching 15°C.

The ANOVA's comparing the collections across weeks tend to support these observations for the allopatric collections of *N. volucellus*, sympatric females of *N. volucellus*, and both species in Manitoba. *N. stramineus* populations in Ontario did not vary statistically over time.

The line of best fit to describe the relationships of male and female GSI against water temperature for all populations except Ontario *N. stramineus* is a quadratic line (Fig. 20). *r* values were low (0.32 - 0.62) but significant.

*Notropis volucellus*

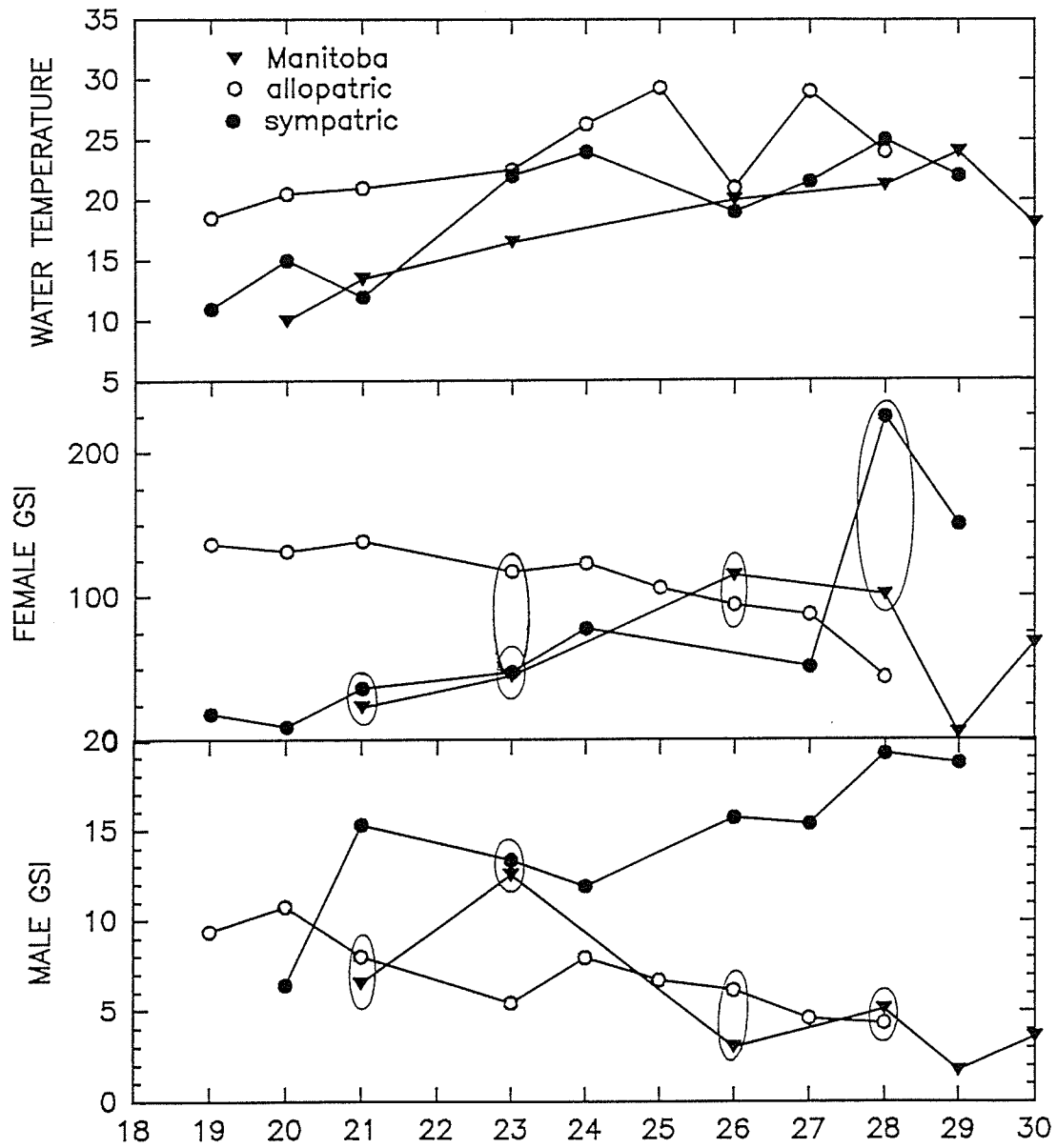


Fig. 18. Weekly comparisons of water temperatures and gonadosomatic indices (GSI) of allopatric and sympatric Ontario populations with Manitoba populations of *Notropis volucellus*. Ellipses enclose pairs with non-significant differences.



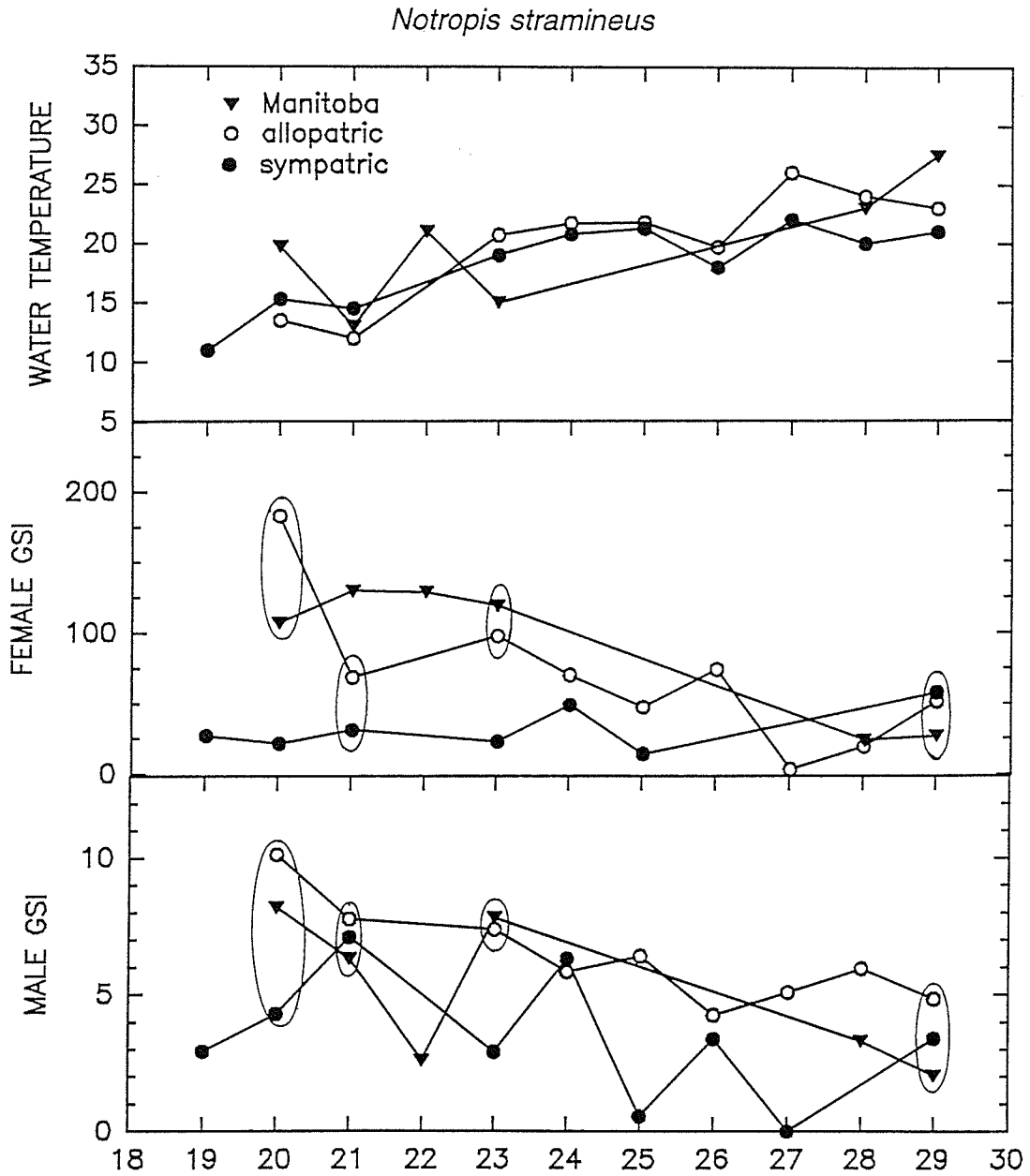


Fig. 19. Weekly comparisons of water temperatures and gonadosomatic indices (GSI) of allopatric and sympatric Ontario populations with Manitoba populations of *Notropis stramineus*. Ellipses enclose groups with non-significant differences.

The parabola of the line is in opposite directions in the two provinces. GSI's of Ontario *N. volucellus* are at their lowest at water temperatures between 15 - 20°C, increasing in value at higher temperatures. In Manitoba, GSI's of male *N. volucellus* peaked at water temperatures between 15 - 17°C, declining sharply thereafter. GSI's of females peaked between 18 - 20 °C. GSI's of both sexes of *N. stramineus* in Manitoba peaked at water temperatures between 17 - 20°C.

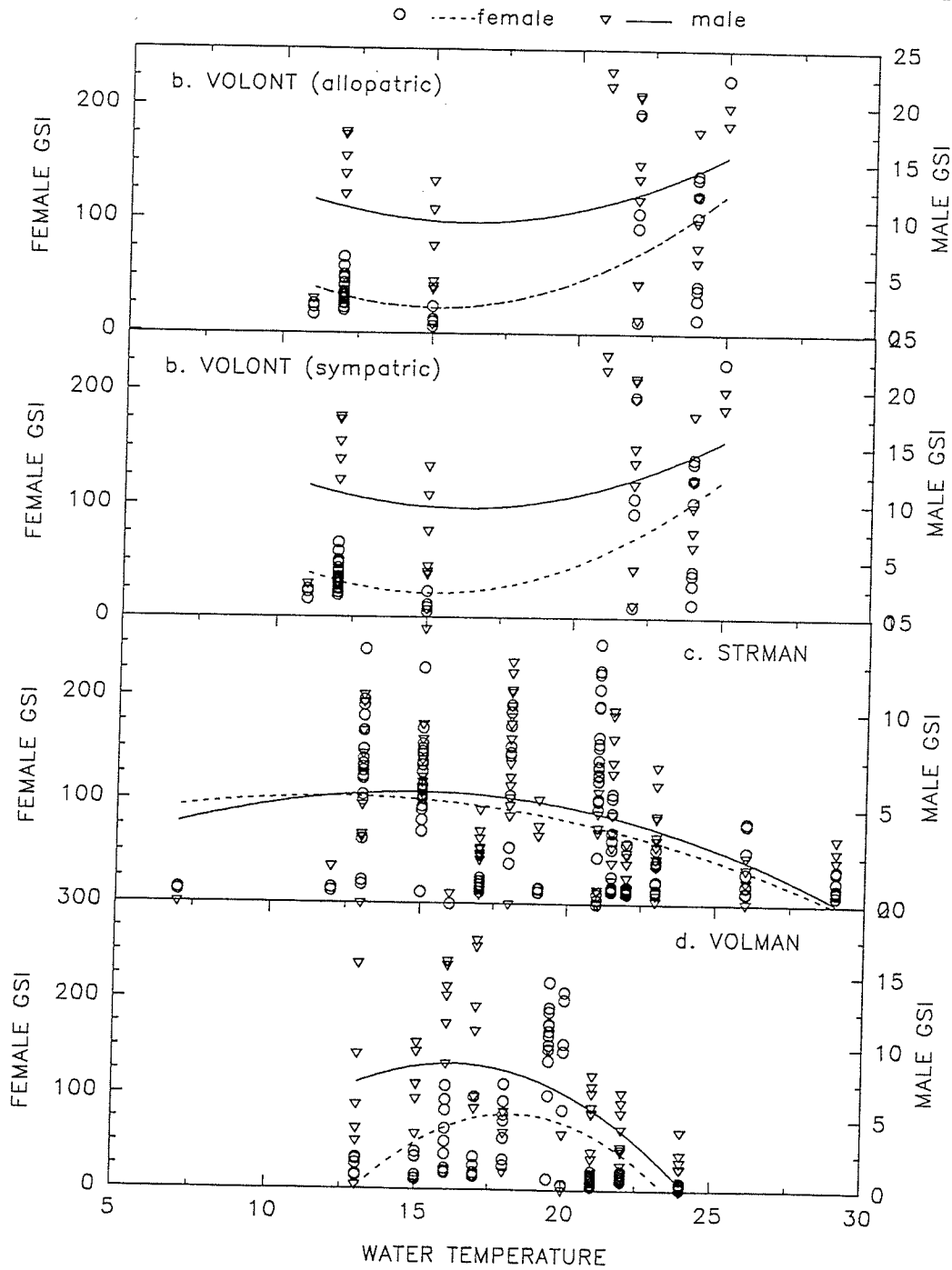


Fig. 20. Gonadosomatic Index (GSI) plotted against water temperature. a. allopatric, b. sympatric populations of *Notropis volucellus* in Ontario (VOLONT), c. *N. stramineus* in Manitoba (STRMAN), d. *N. volucellus* in Manitoba (VOLMAN).

## DISCUSSION

### A. Morphometric Comparisons

#### a. Discrimination of Living Specimens in Sympatry

Although the comparisons of the pooled populations of these species demonstrates a separation between them, it also emphasizes their similarities, at least on a superficial level. The relative positions of the dorsal and pelvic fins and head shape, although statistically significant, are usually described in very similar terms for both species (Scott & Crossman 1973) and are not useful to the field biologist as discriminators of living fish. Differences in anal ray count and lateral line scale count although consistent in all populations, are also difficult to determine in living fish. The pattern of tuberculation on the pectoral fins could be determined using a magnifying lens, but is useful only to discriminate males close to and during breeding season. Height of the anterior lateral line scales can be determined in confined fish and could be a useful field discriminator where habitat permits. However, in the absence of any studies which might demonstrate behavioural or microhabitat differences it is very unlikely that it is possible for a human observer to distinguish between these species in a living, mixed school.

#### b. Allopatric and Sympatric Populations in Ontario

The apparent morphological convergence of the species in sympatric sites in Ontario was not unexpected because hybridization is at least theoretically possible, and both species have access to the same habitats and resources. All the sympatric sites are in or immediately adjacent to Lakes Erie, Huron or St. Clair (Fig. 4). The apparent convergence of the species in the allopatric habitats is more difficult to explain because the allopatric habitats of

*N. volucellus* in Ontario differ more from the sympatric habitats than do those of *N. s. stramineus* (Figs. 4,7, Appendix A). However the allopatric habitats of both are primarily stream as opposed to lacustrine habitats.

Characters which apparently converge in sympatry, relative to their values for either species in allopatry are summarized in Table 23. Most of the convergence is the result of overall reduction in head and mouth size in *N. volucellus*, although the ratio HWHL increases resulting in a relatively broader head in sympatric populations.

Most of the characters which diverge in sympatry do so as the result of changes in both species. Changes to the snout length, and chin and angular widths reinforce differences in head and mouth shape, which is longer snouted with a narrower mouth in *N. volucellus*. However, characters which diverge in sympatry converge in allopatry, and in both species the result is a proportionately narrower head and more streamlined shape in the stream dwelling allopatric populations.

I believe that the sympatric populations demonstrate ecological adaptations of both species to a lacustrine habitat and that these represent retained conservative characters of populations which originally invaded the Great Lakes from the Mississippi Refugium following the Wisconsinan glacial period (see below). Characters which converge in allopatry are the result of adaptations to a stream habitat. *N. volucellus* differs more than *N. s. stramineus* between habitats because its allopatric habitat differs more from the sympatric habitat. Other apparently ecologically neutral characters which

Table 23. Summary of character state adjustments between sympatric and allopatric populations of *Notropis s. stramineus* and *N. volucellus* in Ontario. SYM - sympatric, ALL - allopatric, symbols refer to direction of change between the two site types for each species. (UJ upper jaw length, HW head width, HL head length, CW chin width, SH scale height, SW scale width, DS dorsal stripe, AW angular width, SN snout length, LL lateral line scales, P1 pectoral fin rays, AP anal pigment)

Character	<i>N. s. stramineus</i>		<i>N. volucellus</i>		Result in Sympatry
	SYM	ALL	SYM	ALL	
UJ	=		<		CONVERGE
HW	=		<		
HL	=		<		
HW/HL	=		>		
CW	<		=		
CW/HW	<		>		
SH	>		<		
SW/SH	<		>		
DS	<		>		
AW	=		<		DIVERGE
AW/CW	>		<		
SN	<		>		
UJ/SN	>		<		
SN/HL	<		>		
LL	>		>		NEUTRAL
P1	>		>		
AP	>		>		

converge in sympatry (SH, SWSH, DS) may be evidence of some degree of hybridization. The higher lateral line scale counts and pectoral fin ray counts in sympatric populations of both species are probably the result of living in generally lower water temperatures, which is known to result in an increase in most meristic character values (Lindsey 1988).

### c. Interprovincial Differences

The greater discrimination of the two species in Manitoba, and in particular the greater discrimination of Manitoba and Ontario populations of *N. s. stramineus*, raises questions about the historical relationships of these populations. One possible explanation of these differences could be that the two species invaded Manitoba from different sources following the last glacial recession.

During the Wisconsinan glacial advances, fauna of the northern part of the mid-continent were forced south into the Mississippi refugium (Cross et al. 1986, Crossman & McAllister 1986, Stewart & Lindsey 1983). As the Laurentide ice sheet receded ( $\approx$  13,000 years ago) the meltwater formed several large periglacial lakes. Lakes roughly analogous to Lakes Erie, Huron and Michigan were continuous with one another with a common outlet into the Mississippi Drainage. To the west, a lake analogous to Lake Superior emptied into the Mississippi Drainage, as did Lake Agassiz which covered parts of northeastern North Dakota and northwestern Minnesota (Crossman & McAllister 1986, Clayton 1983, Teller & Thorleifson 1983). This permitted the invasion of all these systems by the species in the refugium (Bailey & Smith 1981, Stewart & Lindsey 1983). As the ice sheet continued to recede northward Lake Agassiz

lost its connection with the Mississippi Drainage  $\approx$  9500 years ago (Clayton 1983, Teller & Thorleifson 1983). It retained its connections with the periglacial system of lakes and spillways which were connected with Lake Superior until  $\approx$  8700 years ago (Bailey & Smith 1981). The Great Lakes lost their last connections with both the Mississippi Drainage and the Hudson Bay Drainage systems  $\approx$  6000 years ago (Bailey & Smith 1981).

In this scenario it seems possible that *N. s. stramineus* invaded Manitoba from the northwestern portion of the Mississippi Refugium prior to the loss of its connection with Lake Agassiz, whereas *N. volucellus* could have dispersed northeastward from the more easterly portions of the Mississippi Refugium and then dispersed westward via the series of periglacial lakes and their spillways.

Two lines of evidence lend some support to this contention. Prepleistocene fossils of *N. s. stramineus* have been described from Nebraska (Bennett 1979) which shows that this species was resident in the drainage system prior to the onset of glaciation and presumably was available to disperse north following deglaciation. In addition, characters included in this study appear to conform to those associated with western and central forms of *N. s. stramineus* by Tanyolac (1973). This is particularly striking in lateral line scale counts which closely conform to Tanyolac's (1973) central population with lowest scale counts. Lateral line scale counts in Manitoba populations, which are all from populations north of 49° 25' north latitude, were lower than those from Ontario where the most northerly collections were from 45° 37'. There is a tendency for an increase in the values of meristic variables of ectotherms at higher latitudes, which is associated with cooler temperature régimes during



development (Lindsey 1988). If *N. s. stramineus* in Manitoba was more closely related to eastern populations I would have expected the average lateral line scale count to be higher than for eastern populations, as it is for Manitoba populations of *N. volucellus*.

Modern *N. volucellus* extends much further north than *N. s. stramineus* (Fig. 3) which suggests a greater tolerance to colder water, which would almost certainly have been necessary for dispersal via the periglacial lakes, suggesting that this avenue of dispersal was available only to *N. volucellus*.

Under these circumstances *N. s. stramineus* would have had to enter the Hudson Bay drainage system prior to its separation from the Mississippi drainage system and may have been isolated from other populations of conspecifics for 9500 years, whereas *N. volucellus* could have invaded Manitoba from 8500 - 7500 years ago and could have maintained some degree of genetic exchange with the parent population since that time. In the east both species had access to the Great Lakes from the Mississippi refugium, until 6000 years ago, and more recently as a result of construction of navigation canals (Bailey & Smith 1981). There is clearly more opportunity for gene flow among populations of both species in this region.

This raises a further question. If the populations of *N. s. stramineus* in Manitoba have been isolated for 9500 years, do they represent a conservative relict of the parental population, or do they represent a more derived population? This question could probably be most effectively addressed by

comparing the DNA's of *N. s. stramineus* from Manitoba with populations from different parts of the total range of the species, and with *N. s. missuriensis*.

It is generally accepted that fish described as *N. volucellus* actually represent a species complex (Etnier 1989, pers. comm.), including both recognized and cryptic subspecies. The diversity of its habitats (Figs. 5,7) and habits (Black 1945, Hanych et al. 1983, Moyle 1973) tend to support this view, although the morphological similarity I found between the two widely separated populations in Manitoba and Ontario may dispute this. It is clear that morphometric analysis is unlikely to resolve questions about the interrelationships of these populations and that the answers will have to wait until genetic analyses have been done.

## **B. Reproductive Biology**

The data clearly demonstrate a relationship between water temperature (TW) and gonadosomatic index (GSI) of both sexes of both species. This relationship appears to be different in southern Ontario than in Manitoba (Fig. 20). My data from Ontario are biased by the fact that my field seasons began after the onset of the breeding season, and finished before it was over (see below). In both site types in Ontario GSI of both sexes of *N. volucellus* is lowest at TW 15°C and rises on either side of this TW. Comparing this result with plots of TW against time it becomes clear that 15°C is the threshold temperature for testis maturation. Females appear to peak at 20°C and GSI of both sexes declines once active spawning has begun. Many of the Ontario sites were very shallow and TW varied directly and rapidly with air temperature. Water temperatures were 6°C cooler during the first two weeks of the 1988

season, but GSI's were higher during those weeks. Presumably the cool temperatures prevented spawning and resulted in the apparent anomaly of higher GSI's at lower temperatures. Fish continued to come into spawning condition as TW varied above 15°C.

The relationship between TW and GSI is particularly clear in the Manitoba collections of *N. volucellus* and the sympatric collections of both species in Ontario, which were the only collections which began prior to the onset of the breeding season. It is apparent that 15°C is the minimum TW for male maturation but that spawning will not occur until temperatures reach ≈18°C.

Allopatric populations of both species in Ontario were in full reproductive condition at the start of my collecting seasons. Ovaries of all females were large, with yolk laden eggs. Males were fully tuberculate. Although there was a slow, steady decline in GSI's over time, no pronounced differences occurred until weeks 27 (7 July 1988) in *N. s. stramineus* and 28 (15 July 1988) in *N. volucellus*. The evidence suggests that these populations spawned over a prolonged period which agrees with Tanyolaç (1973) and Black (1945). The apparent rebound of male and female GSI's of *N. s. stramineus* in weeks 27 - 29 (Fig. 14) suggest that this population may be a multiple spawner, a phenomenon that has been observed in other *Notropis* species (Heins & Rabito 1986). Sympatric populations of both species reached breeding condition just prior to my departure so I have no information about duration of breeding season of these populations.

*N. s. stramineus* in Manitoba occupies habitat similar to allopatric populations in Ontario but its reproductive patterns appear to differ. Water temperatures had reached 20°C and GSI's were high at the onset of the collecting season and remained so until week 23 (8 June 1989). It is unfortunate that there was an hiatus in collections between weeks 23 and 28 (13 July 1989) because there had been a significant drop in GSI's in both sexes by week 28. Ovaries were clearly spent, testes were regressing and tubercles were waning. There was no evidence of rebound of any reproductive characters after this date. The data point overwhelmingly to a single, relatively brief spawning period between mid-June and mid-July, which I obviously missed.

*N. volucellus* in Manitoba follows reproductive patterns more similar to that of sympatric *N. volucellus* populations in Ontario. This is not surprising because their habitat in Manitoba is much more similar to sympatric sites in Ontario. Water temperatures did not rise as quickly, as a consequence sexual maturity was delayed. GSI's of males peaked when water temperature reached 15°C in week 23, and females peaked when water temperatures reached 20°C in week 26 and declined after week 30 (31 July 1991). This suggests a single, rather truncated spawning period.

The morphometric convergence of the two species in sympatric sites raises questions about their degree of reproductive isolation. There is no information available about the breeding habits or habitats of either species to help answer this question. My data suggest that they may be allochronic in both occurrence and maturation in sympatric sites (Tables 12,14,17). In

addition the large differences in abundance between the two species in sympatry may also reduce the probability of interspecific matings (Appen. A5-A7).

One scenario that I was unable to study and which might be illuminating would be to make extensive night collections in some of these sites. Black (1945) has suggested that *N. volucellus* is a night spawner, and I have evidence that in a similar habitat in Manitoba, it moves inshore at night. If the sympatric populations in Ontario behave the same way it could be that there is a diurnal as well as a seasonal allochryony in habitat use by these two species.

In summary, it is evident that populations of *N. s. stramineus* in Manitoba differ more from conspecifics in southern Ontario than they do from populations in the American Midwest, to which they are probably more closely related. There is less distinction between populations of *N. volucellus* which is known to be morphologically and behaviourally plastic throughout its range. Some degree of hybridization may be occurring between these two species in zones of sympatry in southern Ontario, but they are largely allochronic in these areas. Temporal differences in habitat use could be an important reproductive isolating mechanism because both species in both provinces appear to require a minimum TW of 15°C for maturation of testes and 18-20°C for spawning to occur.

Allopatric populations of both species have prolonged spawning periods in southern Ontario and it is possible that *N. s. stramineus* may be a multiple spawner. Fish had just reached spawning condition in sympatric sites at the

end of my field seasons so I have no information about the duration of the spawning period in sympatric sites. Both species in Manitoba appear to have a single, relatively short spawning period, in June or early July for *N. s. stramineus*, and late July early August for *N. volucellus*.

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Appendix A. Collection Notes

Appendix A1. Collection notes for Barrier Bay and Dorothy Lake, MB. *Notropis volucellus* sites.

SITE	DATE	Week	WATER			CLAR	CURRENT	HABITAT	NOTES	
			STR	VOL	TEMP					DEPTH
BB8901	17/05/89	20			10.0	64	64	0	sand, sparse non-emergent vegetation near shore	
BB8902	23/05/89	21			12.5	56	56	0	sand, sparse non-emergent vegetation near shore	
BB8903	12/07/89	28	111		21.0	36	36	0	sand, sparse non-emergent vegetation near shore	
BB8904	19/07/89	29	40		24.0	73	73	0	sand, sparse non-emergent vegetation near shore	threw almost all catch away did not count releases, recorded as 0; all but <u>volucellus</u> discarded after identification
BB8905	09/08/89	32			25.0	67	60	0	sand, sparse non-emergent vegetation near shore	
BB8906	16/08/89	33			23.0	60	50	0	sand, sparse non-emergent vegetation near shore	
BB8907	23/08/89	34	78		22.0	100	100	0	sand, sparse non-emergent vegetation near shore	two hauls, one each side of dock K.W.Stewart, B. McCulloch, D. Tyson all cooperated for night haul. Discarded <u>Cu-</u> <u>laea</u> and <u>N. hudsonius</u> . Releases not id'd or counted
BB9101	22/05/91	21	66		13.0			0	sand and concrete ramp	too dark for depth or secchi measure
BB9102	05/06/91	23	60		17.0			0	sand, concrete boat ramp, emergent vegetation	too dark for depth and secchi readings
BB9103	26/06/91	26	38		20.0			0	sand, concrete boat ramp, emergent vegetation	coll: Bruce McCulloch, Gavin Hanke, Lisa Sawka; 3 hauls
BB9104	10/07/91	28	73		19.5			0	sand, concrete ramp, some vegetation	Ray and Sue Kenny helped
BB9105	31/07/91	30	19		18.0			0	sand, concrete ramp, some weed	Gavin Hanke helped, MOSQUITOES!
BB9106	21/08/91	34	13		22.0			0	sand, concrete ramp, some weed	Bruce McCulloch and Gavin Hanke Col- lected; three hauls
DL8901	19/07/89	29	3		24.0	80	80	0	sand and boat launch grid	
DL8902	09/08/89	32						0	sand and boat launch grid	water skiers operating from the boat ramp, did not seine
DL8903	16/08/89	33			22.0	90	90	0	sand and boat launch grid	
DL8904	23/08/89	34	88		21.0	113	113	0	sand and boat launch grid	K.W.Stewart, B. McCulloch, D. Tyson assisted with night haul
DL9101	22/05/91	21	56		15.0			0	sand and ramp, some weed	Bruce McCulloch helped
DL9102	05/06/91	23	44		16.0			0	sand and ramp, some weed	Bruce McCulloch, Lisa Sawka assisted
DL9103	27/06/91	26	7		20.0			0	sand and ramp, some weed	Bruce McCulloch, Gavin Hanke, Lisa Sawka collected
DL9104	10/07/91	28			23.0			0	sand, concrete ramp, some vegetation	Ray and Sue Kenny helped, I got my waders full

Appendix A2. Collection notes for Souris River Sites (SR10 = between old and new Hwy 10 bridges, south of Brandon MB, SRMB = at Mckellar Bridge on PTR 346). *Notropis stramineus* sites.

SITE	DATE	Week	STR	VOL	WATER TEMP	DEPTH	CLAR	CURRENT	HABITAT	NOTES
SR1001	18/05/89	20	225		18.0	108	108	4	sand, a little vegetation near shore	
SR1002	25/05/89	21	20		13.0				sand, a little vegetation near shore	too cold to get depth, current and clarity data
SR1003	31/05/89	22	21		21.0	90	90	0	sand, a little vegetation near shore	
SR1004	08/06/89	23	25		15.0	81	81	0	sand, a little vegetation near shore	
SR1005	13/07/89	28	23		23.0	90	90	0	sand, a little vegetation near shore	many fry in shallow water near shore; released too many <u>cornutus</u> to count, hence 0; discarded the 3 that were kept
SR1006	20/07/89	29	25		26.0	97	97	0	sand, a little vegetation near shore	released young, not <u>stramineus</u>
SR1007	10/08/89	32	3		22.0	105	90	0	sand, a little vegetation near shore	assisted by Ebba Marrington did not sort, impending thunderstorm; lots of filamentous green algae;
SR1008	23/08/89	34	3		21.5	105	105	0	sand, a little vegetation near shore	released mostly <u>cornutus</u>
SR1009	31/08/89	35	6		17.0	92	92	0	sand, a little vegetation near shore	
SR1010	17/09/89	38	9		16.0	92	92	0	sand, a little vegetation near shore	
SR1011	01/10/89	41			12.0				sand, a little vegetation near shore	
SR1012	15/10/89	42			7.0				sand, a little vegetation near shore	water up onto sand bar where I normally seine. No sign of life in accessible depths, did not seine.
SRMB01	18/05/89	20	42		21.5	55	55	17	sand, some vegetation	
SRMB02	25/05/89	21	39		13.0	49	49	21	sand, some vegetation	
SRMB03	31/05/89	22	48		21.0	55	55	36	shale	changed collection locale for ease of working
SRMB04	08/06/89	23	23		15.0	60	60	11	shale	many fry in shallows near shore
SRMB05	13/07/89	28	55		23.0	40	40	7	shale	released many young of year
SRMB06	20/07/89	29	30		29.0	30	30	4	shale	water dropping, discarded unid'd larvae (2)
SRMB07	10/08/89	32	60		22.0	45	45	0	shale	riffle blocked by small dam formed of branches, apparently a small beaver dam kept, and discarded, some of all released, no counts made
SRMB08	23/08/89	34	35		21.5	40	40	25	shale	
SRMB09	31/08/89	35	11		19.0	53	53	22	shale	
SRMB10	17/09/89	38	20		17.0	45	45	0	shale	
SRMB11	01/10/89	40	9		12.0	47	47		shale	
SRMB12	15/10/89	42	12		07.0	29	29	19	shale	no stramineus at usual spot, collection made near shore; only <u>stramineus</u> kept after counting

Appendix A3. Collection notes for Welland River site. Allopatric *Notropis volucellus* site.

SITE	DATE	Week	STR	WATER		CLAR	CURRENT	HABITAT	NOTES	
				VOL	TEMP					
WR8701	12/05/87	19		20	22.0	70	turbid mod	boulders & silt, pools approx 1 m. separated by riffles, filamentous algae on rocks, some grasses near shore.		
WR8702	23/05/87	20		22	23.0	50	turbid slow			
WR8703	28/05/87	21		29	24.0	70	turbid slow	vegetation increasing on bottom with some emergent		
WR8704	08/06/87	23		41	23.0	60	15 cm mod	sand and isolated rocks, some veg near shore		
WR8705	17/06/87	24		5	27.5	50	turbid slow	sand and some boulders - grassy patches widely dispersed		
WR8706	25/06/87	25		37	29.5	50	turbid slow			
WR8707	30/06/87	26		8	23.0		10 mod			
WR8801	13/05/88	19		29	15.0	40	15	16	sand & rocks, some vegetation near shore	
WR8802	20/05/88	20		14	18.0	28	18	48	as before	
WR8803	27/05/88	21		11	18.0	40	17	7	as before;	kid said something about a die-off this week, sheepshead? and mudpuppies; also mentioned something about a dump near Binbrook
WR8804	10/06/88	23		43	22.0	39	29	13	as before	water levels seem down; heard bullfrog; less obvious violet overtones to <u>volucellus</u> , turbid water perhaps?
WR8805	17/06/88	24		69	25.0	49	25	7	as before	threw about half back, <u>volucellus</u> so dominant
WR8806	24/06/88	25		17	29.0	33	33	0	as before	many fry; dumped about half catch without sorting
WR8807	29/06/88	26		105	19.0	35	30	11	as before	
WR8808	08/07/88	27		31	29.0	50	45	7	as before	
WR8809	15/07/88	28		42	24.0	43	35	7	as before	appears to be a fine oil slick on the water

Appendix A4. Collection notes for Duffin Creek (DC) and Little Rouge River (LR) sites. Allopatric *Notropis stramineus* sites.

SITE	DATE	Week	STR	VOL	WATER		CLAR	CURRENT	HABITAT	NOTES
					TEMP	DEPTH				
DC8701	27/05/87	21	11			70	70	strong	sand and gravel, no vegetation	Collected with Crossman, Holm, et al. of ROM; rain and THUNDER showers INTO waders! No temps taken fell in because of current minnow, large, with tubercles, red fins, terminal mouth ( <u>cornutus</u> ).
DC8702	12/06/87	23	4	24.0	120	120		strong	sand	
DC8703	19/06/87	24	10	24.0	110	110		mod	sand	
DC8704	26/06/87	25	7	24.0	120	turbid		strong	sand	
DC8705	03/07/87	26	27	20.0	100	100		mod	sand, scoured out hole	
DC8801	20/05/88	20							sand	
DC8802	26/05/88	21	21	12.0	70	70		31	sand	water high, current very fast, not safe to try to cross river to collect water very clear; seined with the current
DC8803	09/06/88	23	25	16.0	72	72		23	sand	
DC8804	16/06/88	24	13	20.0	65	65		19	sand	
DC8805	23/06/88	25	3	21.0	60	18		67	sand	
DC8806	30/06/88	26	11	20.0	80	80		56	sand	water levels up and silty from rain; 3 hauls; larger suckers, approx 20 cm. released, had large scales, <u>Moxostoma</u> or <u>Hypentelium</u> ?
DC8807	07/07/88	27	1	23.0	60	60		31	sand	
DC8807	07/07/88	27	3	26.0	20	20		9	sand, a little silt at shore	salmonids; approx 13 circles along side, speckled back and dorsal fin, adipose edged in black, paired and anal fins rose pink with white leading edge
DC8808	14/07/88	28	9	24.0	47	47		11	sand	
DC8808	14/07/88	28		24.0	20	20			sand and some silt	
DC8809	20/07/88	29	16	23.0	79	79		11	sand	didn't count or sort carefully; no salmonids current measured in main channel 0.37 m/s; in pool's counter current as recorded above
LR8701	19/05/87	20	2	13.5	120	120		mod	sand, some silt to shore, lge boulders embedded in bottom, some algae	
LR8702	12/06/87	23	1	22.0	120	120		mod	water level dropped	
LR8703	19/06/87	24		21.0	100	100		mod	sand and boulders	
LR8704	26/06/87	25	3	20.5	100	100		mod	sand and scattered boulders	
LR8705	03/07/87	26	2	19.0	130	130		mod	sand with scattered boulders	



Appendix A5. Collection notes for Bowen Creek Site. Sympatric Site

SITE	DATE	Week	WATER		DEPTH	CLAR	CURRENT	HABITAT	NOTES	
			STR	VOL						
BC8801	24/05/88	21	2	159	12.0	62	50	0	sand, some soft silt, a few weeds near shore	
BC8802	07/06/88	23	2	4	22.0	30	30	16	pebbles and sand	huge haul; emptied half of net right back without attempting to sort
BC8802	07/06/88	23		1	22.0	60	60	0	sand, shallow scour hole at end of culvert	
BC8803	14/06/88	24		1	17.5	32	32	0	as before	
BC8803	14/06/88	24			17.5	80	75	0	as before	
BC8804	21/06/88	25			17.0	27	27	0	as before	lake boats draw water out of creek, then it washes back in
BC8804	21/06/88	25			23.0	85	25	0	sand away from shore, emergent vegetation near shore	
BC8805	28/06/88	26	1		18.0	33	33	13	as before	
BC8805	28/06/88	26			18.0	58	35	0	as before	
BC8806	05/07/88	27			23.0	70	35	0	as before	
BC8807	12/07/88	28			20.0	65	65	0	as before	2nd haul in river skunked, no data
BC8807	12/07/88	28	1		20.0	30	30	0	as before	
BC8808	19/07/88	29			23.0	25	25	0	as before	photograph
BC8808	19/07/88	29			25.0	45	37	0	as before	photographed haul site photographed creek mouth

Appendix A6. Collection notes for Indian Brook Site. Sympatric site

SITE	DATE	Week	STR	VOL	WATER		CLAR	CURRENT	HABITAT	NOTES
					TEMP	DEPTH				
IB8801	16/05/88	20	8		14.0	93	93	33	sand	
IB8802	25/05/88	21	44		17.0	100	100	8	boulders and sand with algae on rocks	
IB8803	06/06/88	23	27		16.0	98	98	5	sand and boulders, pool partially shaded	
IB8804	13/06/88	24			23.0	98	98	5	pool in shade,	
IB8805	20/06/88	25	1		22.0	90	93	33	sand	
IB8805	20/06/88	25			24.0	50	50	5	sand	
IB8805	20/06/88	25			20.0	17	17	11	sand	water temp in lake 14.0 C., gave one of two sculpins to a local kid for his fish tank
IB8805	20/06/88	25			20.0	82	82	6	sand, some large boulders, through scour hole	
IB8806	27/06/88	26			21.0			6	sand	
IB8806	27/06/88	26			20.0	75	75	0	sand and boulders	
IB8806	27/06/88	26			19.5	50	50	0	sand, silt	
IB8807	04/07/88	27	1	3	22.0	69	69	0	sand	
IB8807	04/07/88	27			18.0	80	80	0	sand and boulders	photographed fish
IB8808	11/07/88	28			27.0	47	47	0	sand	water somewhat silted following overnight
IB8808	11/07/88	28			25.0	70	70	5	rain, filamentous green algae building up sand and some boulders; filamentous green algae for first time rain; far fewer fish than usual	water somewhat silted following overnight
IB8809	18/07/88	29			22.0	59	59	0	sand	
IB8809	18/07/88	29			20.5	83	83	0	sand and boulders	
IB9001	18/07/90	29	17		21.0	100	clear	0	gravel, some boulders	
IB9001	18/07/90	29	17		21.0		clear	slow	pool on east side	lots of fry and yearlings; chub in deeper
									sand	photographed site

Appendix A7. Collection notes for South Otter Creek (OC), Wardell's Creek (WC), Young's Creek at bridge in Port Ryerse (PR), and Pelée Island (PI). Sympatric sites

SITE	DATE	Week	STR	VOL	WATER		CLAR	CURRENT	HABITAT	NOTES
					TEMP	DEPTH				
OC8701	21/05/87	20	2		17.0	100	turbid	mod	sand, a little silt near shore	
OC8702	28/05/87	21			20.5	100	20 cm	slow	sand and a little silt near shore, some sort of algae near shore in places	
OC8801	17/05/88	20			15.0	40	25	15	sand, some silt	
OC8802	24/05/88	21			18.0	40	20	78	as before	water much lower than last year; appears to be more debris on beach
OC8803	07/06/88	23			18.0	40	19	45	drift	windy, current readings exaggerated by wind
OC8804	14/06/88	24							as before	
OC8805	21/06/88	25	1		20.5	28	22	24	as before;	did not do - feeling unwell, heat bothering me
OC8806	28/06/88	26		1	19.0	22	21	18	as before	current was appreciable into lake, by the time I came to measure it, it reversed. It reversed again so I measured again
OC8806	28/06/88	26			18.5	53	21	7	ooze and weed bed	
OC8807	05/07/88	27		2	21.0	17	17	13	as before	
OC8808	12/07/88	28		3	25.0	21	21	19	as before	
OC8809	19/07/88	29		6	22.0	32	20	52	as before	
WC8801	13/05/88	19	4	3	11.0	60	47	16	sandy	it has rained, water levels are up; catfish came from slightly quieter water above riffle
PR8701	21/05/87	20	11	278	15.0	70	70	mod	sand, with soft silt near shore, sand bars interspersed with current scoured holes	
PI8701	15/06/87	24	24	188	24.0	50	50	neg	sand with some gravel, haul 4 sand with some algae	saw 2 <u>Lepisosteus osseus</u> , and 3 water snakes