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HABITAT USE, DISTRIBUTION, LIFE HISTORY,
AND INTERSPECIFIC ASSOCIATIONS
OF NOTROPIS PHOTOGENIS (SILVER SHINER; OSTEICHTHYES: CYPRINIDAE)
IN CANADA,
WITH COMPARISONS WITH NOTROPIS RUBELLUS (ROSYFACE SHINER)

by

© MARY ELIZABETH BALDWIN, B.Sc.

A thesis submitted to the Faculty of
Graduate Studies and Research in partial fulfillment
of the requirements for the degree of
Master of Science

Department of Biology

Carleton University

Ottawa, Ontario

June 16, 1983

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ABSTRACT

Surveys extended slightly the known Canadian distribution of Notropis photogenis in both the Grand and Thames River watersheds of southwestern Ontario. Univariate and multivariate analyses of 21 habitat variables and nine sampling variables showed that water depth was a good predictor of the presence or absence of both adult and young-of-the-year (YOY; separated by length frequency analysis) of N. photogenis and N. rubellus, all using deep water. The importance of other habitat variables varied between age groups, species, and seasons. Sampling variables were generally unimportant. Both species apparently used sheltered habitats at night, in winter, and during spring floods. Spawning seemed to occur in May and early June in N. photogenis, and from mid-May to late June in N. rubellus, and was observed for N. rubellus. Notropis photogenis adults and YOY were positively associated with N. rubellus, but negatively associated with most of 15 other sympatric species.

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I INTRODUCTION

Notropis photogenis (Cope, 1865), the silver shiner, belongs to the family Cyprinidae (minnows or carps). This family of freshwater fishes has more species - approximately 1600 - than any other, and is the most abundant family in most areas of its range in North America, Africa, and Eurasia (Nelson 1976). The genus Notropis is endemic to North America (Nelson 1976). It is not particularly well-known taxonomically; Nelson stated that it had 101 species and Lee et al. (1980 et seq.) listed 106.

My interest in N. photogenis arose from two directions, the "rare" status of the species in Canada and the lack of information on the species.

In Canada, N. photogenis is restricted to portions of two watersheds in southwestern Ontario (section II). McAllister and Gruchy (1977) considered the species rare in Canada, and Parker and McKee (1980) recommended to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) that the species be classified as rare. COSEWIC defined a rare species as "Any indigenous species of fauna or flora that, because of its biological characteristics, or because it occurs at the fringe of its range, or for some other reason, exists in low numbers or in very restricted areas in Canada but is not a threatened species." (unpublished). Notropis photogenis has a much larger range in the USA (section II). There it was considered rare, defined as "Not under immediate threat of extinction, but occurring in such small numbers and/or in such a restricted or specialized habitat that it could quickly disappear. Requires careful watching." (p. 240), only in Michigan (Miller 1972).

Notropis photogenis was first described in 1865 by E.D. Cope from

Pennsylvania specimens (Gilbert 1971). Since then, little systematic information has been published, and "No comprehensive life history or ecological study exists, and no good summary of miscellaneous information appears to have been published." (Gilbert 1980c). Most publications referring to the species are faunal lists for specific geographic areas and provide little information beyond descriptions and distributions (e.g., Clay 1975). However, Parker and McKee (1980) provided considerable new information on the distribution and biology of N. photogenis in Canada. Much of this information has been published by McKee and Parker (1982), but I used and shall refer throughout the thesis to the more detailed original report.

My major interest in studying N. photogenis was its habitat use. Specifically, I wanted to learn what aspects of its environment (i.e., what habitat variables) were most important in describing habitat use by the species. Such questions have practical applications for a rare species: an understanding of habitat is necessary in order to make useful predictions of the species' future chances for survival or population changes, and in order to undertake any effective conservation measures if they are considered necessary. There are also theoretical reasons, outlined by Rotenberry (1981), for studying habitat: "it is apparent that information ... about habitat is absolutely essential for a full understanding of patterns of life history, adaptation, and evolution of any species" (p. 29). Rotenberry's arguments were developed for studies of bird habitat, but they apply equally well to other organisms including fishes. The most important assumptions were that species' responses to habitat variables are adaptive, and that regular, repeatable patterns exist, and can be studied, between organisms and habitat variables (Rotenberry 1981).

The study of habitat use by N. photogenis can be viewed as part of an attempt to answer the question of why the species is where it is. The types of physical, chemical, and vegetation variables that I studied are only a small proportion of the many factors affecting the distributions of fishes, including geological history, topography, climate, predators, competitors, parasites, and food. The responses of fishes to these extrinsic factors, and therefore the effects of the factors, are mediated by other factors intrinsic to the fishes, such as their genetic makeup, morphology, physiology, and behaviour patterns. The extrinsic factors operate at different scales, from a geographic scale (affecting the species' range) to regional (affecting populations) to the microhabitat scale of my concern, measured in metres, at which these factors affect individuals or groups of individuals. Depending on how it varies, one factor may operate at one or all scales. Many of these factors are further influenced by temporal patterns, diel, seasonal, or over the length of a fish's life cycle. The effects of humans and chance events can also change the relationships of fishes to these factors.

I studied several aspects of the biology of N. photogenis as well as habitat use. These other studies provided necessary background information for the study of habitat use, but also were of interest in themselves as contributions to the understanding of the factors affecting the species' distribution at different scales, and to knowledge of the species' biology. I initially mapped the range of N. photogenis (section II). Because I wanted to describe habitat use by N. photogenis of different ages and at different times, knowledge of its life history -- age, growth, and spawning -- was necessary (section III). Associations of N. photogenis with other fish species were studied at a microhabitat scale (section V), with the aim of

better understanding the factors affecting the species at this scale.

Throughout much of this work, comparisons with Notropis rubellus (Agassiz, 1850), the rosyface shiner, were made. Like N. photogenis, N. rubellus is a stream-dwelling cyprinid occurring in the eastern USA and Canada, although its range in both countries is larger than that of N. photogenis (Gilbert and Burgess 1980, Scott and Crossman 1973). Because of the apparent association of the two species (section IV.1), later confirmed (section V), I was interested in comparing their use of habitat (section IV) as well as their life histories (section III).

The study area for my research consisted of portions of the Grand and Thames River systems of southwestern Ontario. The Grand River drains the largest watershed (6700 km^2) of any river in southwestern Ontario and empties into Lake Erie (Chapman and Putnam 1966). The Thames River flows into Lake St. Clair, draining an area of 5700 km^2 (Chapman and Putnam 1966). Both rivers follow a similar physiographic pattern, with their upstream sections and tributaries flowing mainly in glacial spillways, and the downstream sections having lower gradients and flowing across former lake plains (Chapman and Putnam 1966). These divisions occur at Brantford on the Grand River and London on the Thames River, and coincide quite closely with the downstream ends of the ranges of N. photogenis in both rivers (section II). Both watersheds have been greatly altered by human activities. The major land use by area is agriculture. The Grand River or its tributaries flow through the cities of Guelph, Kitchener, Waterloo, Cambridge, and Brantford; the Thames River flows through London and Chatham, and many smaller towns and cities are located within the two watersheds. However, many patches of forest do remain and these are often located in the stream and

river valleys.

My studies of N. photogenis and N. rubellus were thus done entirely within environments changed by humans, and possibly different in their combinations of conditions from those in which the species have evolved.

II THE DISTRIBUTION OF NOTROPIS PHOTOGENIS IN CANADA

1. INTRODUCTION

Notropis photogenis is endemic to North America and has a wide distribution in the east-central USA. Gilbert (1980c) provided a distribution map, reproduced here as Fig. 1. The species occurs throughout most of the Ohio River watershed and in parts of the Cumberland and Tennessee River basins. Closer to its Canadian range, N. photogenis has been found in several tributaries of Lake Erie in Ohio, Indiana, and Michigan (Gilbert 1980c, Trautman 1981).

The first capture of N. photogenis in Canada was made in the Grand River watershed of southwestern Ontario in 1971 by Gruchy et al. (1973). Since then, the species has also been captured in the Thames River watershed of southwestern Ontario (Ontario Ministry of Natural Resources unpublished data). These Canadian populations are disjunct from USA populations, separated by 130 km from the closest USA populations in Ohio. They are also the most northern populations of the species.

My objective in this part of my study was to supplement existing records of N. photogenis in Canada by doing a survey of the Grand and Thames River watersheds to provide a current distribution map for this species in Canada.

2. METHODS

I gathered existing records of N. photogenis in Canada from several sources. The largest number of records came from unpublished stream surveys conducted by the Ontario Ministry of Natural Resources, in 1974 and 1975 on the Thames River and its tributaries, and in 1976 on the Grand River and many of its tributaries. The Grand River Conservation Authority conducted surveys, also

Fig. 1. Distribution of *Notropis photogenis* in North America (from Gilbert 1980c). Recent Canadian and Ohio records are not included.

unpublished, of the Grand River in 1975. I also used records from the Royal Ontario Museum, those of Gruchy et al. (1973), and existing records and extensive field survey results used by Parker and McKee to compile their report on the status of N. photogenis (Parker and McKee 1980). A search of the fish collection at Wilfrid Laurier University provided some additional records.

Most of my field survey for N. photogenis was conducted in spring and early summer 1981 and spring 1982. Grand River system sites were surveyed from 3 May to 26 June 1981, and 19 May to 27 May 1982, with additional collections in October 1980 and February, March, July, and August 1981. Sites in the Thames River system were surveyed from 5 June to 11 July 1981, and 18 May to 1 June 1982.

The compilation of existing records served as the starting point for my survey. I visited all river sections from which N. photogenis had been reported, and then continued upstream and downstream from them. As well as the Grand and Thames Rivers themselves, I included all major and many smaller tributaries. Survey sites were located at approximately 5-km intervals, but this interval was quite variable. Site location also depended on accessibility of the river, suitability of sampling locations, and presence of features of interest such as tributary mouths. In general, I tried to continue sampling for at least three sites beyond my last capture of N. photogenis on major rivers, but the large deep channel of the lower Grand River prevented sampling below Brantford (site G24; Fig. 2), with the exception of the shallower section between Caledonia and York (sites G25 and G26, 40 and 45 km downstream from Brantford). Similarly, I could not sample the Thames River more than approximately 25 km along the river below the confluence of the North and South Thames Rivers in London, respectively. Usually only one or two sites were sampled on smaller tributaries.

Fig. 2. Distribution of *Notropis photogenis* in the Grand River watershed of Ontario: survey sites and previous records

Eighty-nine sites were sampled. Some sites were visited more than once, in attempts to capture fishes in seasons other than spring and summer (section IV), find spawning individuals (section III), confirm existing records, or test different fish capture techniques.

Most fish-sampling was done by seine. Initially, a seine 1.5 x 3.8 m with 10-mm stretched mesh was used. A bag (1.2 m wide) was added to the centre of this seine in July 1981, giving overall dimensions of 1.5 x 5 m. A smaller seine, 1.25 x 1.7 m with 6-mm stretched mesh, and a hand net were also occasionally used to capture small fishes. Seines have a number of disadvantages in capturing fishes: they cannot be used in deep (over approximately 110 cm) or very fast water and especially combinations of the two, and they are not very effective when large boulders or debris are present, as well as in broad expanses of open water where fishes cannot be "herded" -- all conditions occurring in places in the Grand and Thames River watersheds. In addition, the seine tends to knock scales from captured fishes, particularly smaller individuals and those such as N. photogenis with rather deciduous scales, likely increasing their mortality following release. Therefore, a number of other methods of fish capture were tested during the survey: anglers' minnow traps (baited and unbaited; set on the bottom or on a pole in midwater or near the surface), a larger metal screen minnow trap (80 x 80 x 90 cm), electroshockers, a gill net (2.2 x 7.3 m, 18-mm stretched mesh), and an anglers' dip net. With the exception of two N. photogenis specimens captured in anglers' minnow traps, none of these methods was successful in capturing N. photogenis. The seine was thus retained. The addition of the bag helped to increase its effectiveness in capturing fishes, especially small individuals, and reduced somewhat the injury to them.

At each site, one to five different habitat types were sampled, and one to five seine hauls were made in each habitat type. Generally, sampling effort was greater if N. photogenis was not captured, to reduce the likelihood that it was present but simply missed in sampling.

All fishes captured in one habitat type were pooled. They were identified and counted, and most were released. Voucher specimens and those that could not be identified in the field were killed in 10% formalin or 200 mg/L tricaine methane sulfonate (MS-222, an anaesthetic) and preserved in 10% formalin.

Additional data were collected for each habitat type on colour, clarity, Secchi depth, temperature, dissolved oxygen, pH, conductivity, turbidity, depth, current, substrate, aquatic vegetation, shore vegetation, distance from shore, and stream width. Methods of data collection during the survey were as described in section IV.2.3, with some exceptions. Substrate and aquatic vegetation were described qualitatively only during the survey, and distance from shore and stream width were estimated in the field.

3. RESULTS

Figures 2 and 3 show the distribution of N. photogenis in Canada. Previous records of N. photogenis, as well as the sites surveyed for this study are shown. Two sites surveyed on the Grand River are not shown on Fig. 2. They are G25 (at Caledonia) and G26 (at York), approximately 40 and 45 km downstream from G24 (at Brantford), respectively. Notropis photogenis was not captured at either site. Notropis photogenis was found at 39 of the 89 sites surveyed. It was found almost exclusively in the largest rivers; the Grand River and its tributaries the Conestogo River and Nith River, and the three

Fig. 3. Distribution of *Notropis photogenis* in the Thames River watershed of Ontario: survey sites and previous records

branches of the Thames River. Notropis photogenis was captured in only three smaller rivers or creeks: Whitemans Creek in the Grand watershed, and the Middle Thames and Medway Rivers in the Thames watershed. These small-river captures are discussed in relation to possible spawning movements in section III.4.2.

My survey confirmed the known distribution of N. photogenis in the Grand River watershed, providing only small range extensions of a few kilometres on the Nith River and southward on the Grand River. The record for Whitemans Creek is new for that stream. In the Thames River system, the survey extended the range approximately 10 km along the South Thames River, and approximately 35 km and north of Fanshawe Lake on the North Thames River. Notropis photogenis had not previously been captured in the Middle Thames River.

4. DISCUSSION

Workers from the National Museum of Natural Sciences and the Royal Ontario Museum captured N. photogenis specimens at three locations on the Grand River and one on the Conestogo River in 1971 (Gruchy et al. 1973). Unpublished surveys conducted by the Grand River Conservation Authority in 1975 and the Ontario Ministry of Natural Resources in 1976 added many new locations in the Grand River watershed. The first captures of N. photogenis in the Thames River watershed were made during Ontario Ministry of Natural Resources surveys in 1974. Work by Parker and McKee in 1979 and 1980 (Parker and McKee 1980) added further sites for N. photogenis in both watersheds, and my work has added still more. The recent first discovery of the species in Canada, and the fact that each survey or study finds it in new locations, lead to several questions. Had the species been introduced shortly before the 1971 captures, or had

it been present earlier and simply missed by earlier surveys? Does the pattern of new records indicate real range extensions or population increases, or both, or again, was N. photogenis simply missed at many locations by earlier workers?

Gruchy et al. (1973) discussed the question of the longevity of N. photogenis' presence in Canada. They held the opinion that the Grand River was within the indigenous range of N. photogenis and that the species had not been captured by earlier surveys. They presented several arguments against a recent colonization or introduction: Notropis photogenis is not likely to have recently crossed Lake Erie, because it has never been reported from the lake (Van Meter and Trautman 1970); it is not abundant in USA tributaries of the lake; and its preferred habitat of "deep swift riffles and current of clear streams" (Gruchy et al. 1973, p. 1381) would make it unlikely to enter the lake. Gruchy et al. suggested that an introduction by people was unlikely as well, again because the species is not abundant in USA Lake Erie tributaries, and because it is not hardy and unlikely to survive transfer in a bait bucket.

Although my results (section IV.3) show the habitat of N. photogenis in Canada to be different from that described by Gruchy et al., they do not suggest that a crossing of Lake Erie is likely. Scott (1963) stated that the Lake St. Clair -- Detroit River -- western Lake Erie region was one of four areas usually used by animals moving into Ontario from the south. However, the three species of fishes that he listed as having naturally extended their ranges into Ontario through this route in the 15 years before his paper were all lake- or pond-dwelling (slow-water) catostomids (suckers).

Other more recent data support the conclusions of Gruchy et al. (1973). The occurrence of N. photogenis in the Thames River watershed

as well as the Grand is strong evidence. There is no direct connection between the two watersheds, and although the divide between them is indistinct and some tributaries arise in proximity in wet areas (Chapman and Putnam 1966), all are far from the range of N. photogenis and do not offer likely colonization routes. Thus the occurrence of the species in both watersheds would imply nearly simultaneous recent arrival in both, or that both are part of the species' indigenous range. The latter explanation seems much more likely. The two watersheds also include many dams within the range of N. photogenis. They vary from a metre or two in height to the 23-m-high (Upper Thames River Conservation Authority n.d.) Fanshawe Dam on the North Thames River. Although fishes may be able to survive a fall over the lower dams, most dams appear to be impassable to upstream movement. The Thames River is accessible from Lake St. Clair to London, but the Grand River is dammed at Dunnville, near its mouth and approximately 80 km downstream from the southernmost capture site of N. photogenis.

The absence of connections between the Grand and Thames River watersheds and the extensive damming of both rivers also mean that range expansion by the species since 1971 cannot explain the increasing number of capture locations. Nor are these new locations simply the result of each survey including wider areas: Ontario Ministry of Natural Resources, Grand River Conservation Authority and Parker and McKee (1980) surveyed the two watersheds quite thoroughly.

It does seem possible that population increases by N. photogenis have contributed to the observed increase in its range. Gruchy et al. (1973) suggested that population increases coincident with their collecting may account for their first captures of the species as late

as 1971. They cited similar circumstances in Michigan, where N. photogenis was not captured between 1942 and 1952, but appeared again in surveys after 1952. Trautman (1981) reported captures of N. photogenis during the 1970s in several Lake Erie tributaries in northeastern Ohio. The species had never been captured in these rivers previously, in spite of collecting over many years in one of them. Only one earlier record, from 1900, existed for another northeastern Ohio Lake Erie tributary.

The recent captures of N. photogenis in Canada, including captures at previously surveyed locations, and similar experiences in the USA suggest a population increase by N. photogenis in Canada over the last one or two decades. However, with the type of data available, no firmer conclusions may be drawn.

III LIFE HISTORIES OF NOTROPIS PHOTOGENIS

AND NOTROPIS RUBELLUS

1. INTRODUCTION

The purposes of this work were twofold: to provide necessary background information for the study of habitat use by Notropis photogenis and N. rubellus (section IV), and to contribute to knowledge of the biology of these two species.

I studied age and growth patterns of N. photogenis and N. rubellus to separate adults from young-of-the-year (YOY) for separate descriptions of habitat use by the two age groups. I also hoped to be able to describe spawning dates, habitat, and behaviour.

Age, growth, and spawning of N. rubellus have been studied in the northern USA (Pfeiffer 1955, Reed 1957a and 1957b, Miller 1964), although no study on the biology of Canadian populations has been reported (Scott and Crossman 1973). Parker and McKee (1980), Gruchy et al. (1973), and Trautman (1981) provided some information on age and growth of N. photogenis. There were no reports of observations of spawning by N. photogenis before I began my work; a very brief description by Trautman (1981) has since been published.

2. METHODS

2.1 Age and Growth

Total and standard lengths, as defined by Hubbs and Lagler (1964; SL: the distance from the anterior edge of the snout to the caudal base), were measured on all preserved N. photogenis and N. rubellus specimens. In the field, the maximum and minimum total lengths of N. rubellus captured and released in each distribution survey habitat (section II.2), and of adult N. rubellus captured in each subsite for the habitat use study (section IV.2), were also recorded. Lengths of N. photogenis were

initially measured in the field, but I stopped because of apparent injury to the fishes. Lengths presented in figures in section III.3 are total lengths, to allow inclusion of field data.

I also attempted to age some specimens by looking for annual marks (annuli) on scales, when length frequency analysis did not clearly separate adults from YOY. With the exception of one N. photogenis specimen, this was a problem only for N. rubellus. Pfeiffer (1955) and Reed (1957b) used scales to age N. rubellus, and Parker and McKee (1980) used them to age N. photogenis. The technique has also been successful in aging other species of Notropis (e.g., Marshall 1939, Campbell and MacCrimmon 1970).

Scales were removed from the left side of specimens, above the lateral line and beneath or anterior to the dorsal fin. They were stained with an alizarin red solution and examined under a compound microscope. With large adult and small YOY specimens of both species, the presence or absence of annuli was clear. However, with the intermediate-sized specimens of concern, the presence or absence of an annulus was not clear. Scale-aging was therefore not used further.

2.2 Spawning

Information on spawning by N. rubellus was gathered through the observation of breeding colours (described in detail by Pfeiffer 1955) or distended abdomens in fishes collected during the distribution survey (section II.2) or habitat use studies (section IV.2), examination of the gonads of preserved specimens, and several observations of actual spawning. Notropis photogenis does not develop breeding colours, nor do gravid females show marked swelling of the abdomen. All information was therefore based on the examination of gonads in preserved N. photogenis specimens. Efforts to observe spawning and to capture spawning N. photogenis individuals were intensified

1982, and concentrated at sites where very small YOY were captured in 1981.

Nikolsky (1963) defined ripe gonads as being at maximum mass, but with no running of gametes in response to light pressure on the live fish. During the spawning period, the gametes will run and gonads lose mass rapidly. In a spent fish, the gametes have been extruded, leaving the gonad cavity swollen. I could not determine exactly when gonads reached maximum mass, nor did I make observations on running of gametes in the field. However, by observing maximum ovary and egg sizes reached, it was possible to determine when ovaries were ripe or nearly so.

3. RESULTS

3.1 Age and Growth

Figure 4 presents frequencies of total lengths (TLs) for N. photogenis. A clear separation of YOY and adult fishes is apparent, with the exception of one specimen (TL 7.9, standard length, SL, 6.5 cm) in the 17 - 29 August 1981 period. Young-of-the-year were first captured in June, with TLs of 2.0-3.0 cm (SLs 1.7-2.5 cm). They grew rapidly, so that by October or November their TLs were 5.3-8.6 cm (SLs 4.2-7.1 cm). These fishes were considered adults after 1 January of the following year.

Adult N. photogenis had TLs between 4.9 and 13.1 cm (SLs 3.9-10.7 cm). Their growth rate was somewhat slower than that of YOY. The data for May and June suggest two age classes of adults, but without scale-aging the maximum age for these specimens is uncertain.

Notropis rubellus length frequencies are shown in Fig. 5. Notropis rubellus is a smaller fish than N. photogenis.

Fig. 4. Frequencies of total lengths of *Notropis photogenis* captured in the Grand and Thames River watersheds of Ontario.

Fig. 5. Frequencies of total lengths of *Notropis rubellus* captured in the Grand and Thames River watersheds of Ontario.

Based on May and June data, TLs of adults were 2.9 (SL 2.4 cm) to 9.2 cm (SL approximately 7.6 cm; TL was measured in the field and SL estimated on the basis of data from preserved specimens).

There is no clear separation of YOY from adults, nor are different age classes of adults apparent in Fig. 5. Young-of-the-year were clearly smaller than adults when first captured in July. Total lengths of YOY were then 1.9-3.6 cm (SLs 1.6-3.0 cm), while adult TLs were 5.1-7.8 cm (estimated SLs 4.1-6.4 cm). In the 27 July - 8 August 1981 period, there were separate frequency peaks for YOY and adults, but even the separation of peak frequencies was disappearing by the end of August.

3.2 Spawning

Notropis photogenis specimens with ripe or nearly ripe gonads were captured in the Grand River watershed between 6 and 29 May 1981, and between 5 and 31 May 1982, and in the Thames River watershed between 6 and 18 May 1982. The ovaries were large and eggs were approximately 0.5-1.1 mm in diameter. Eggs approximately 0.8 mm or larger were usually yellow, orange, or pink-orange. Smaller eggs were not always apparent, but when observed were usually paler or white, and more clearly different from the larger coloured eggs at later dates. A combination of small, white eggs and larger, coloured maturing eggs laden with yolk is typical of the ripening ovaries of most fish species (Bagenal 1978). The testes of male N. photogenis were white, opaque, and though not greatly enlarged, noticeably thicker than those of spent fish.

Surface water temperatures at the time of capture of ripe specimens were 10.2-19.0°C. However, water temperatures fluctuated considerably during the day, so that temperatures at capture depended on the time of day of capture. Maximum daily temperatures recorded

for the capture sites (or nearby sites on the same river) were 10.7-23.0°C.

Actual spawning was never observed in N. photogenis. However, specimens at several sites were believed to have been captured during the spawning period. At study sites NT2 on the North Thames River on 5 June 1981, and T1 on the main Thames River (Fig. 3) on 17 May 1982, both ripe and spent females were captured. At survey site C02 on the Conestogo River (Fig. 2) ripe females were captured on 25 and 31 May, and spent females on 9 June 1982; spawning is believed to have started near 31 May. The eggs in these ripe females were as described above; however, the ovaries were usually somewhat smaller than those observed earlier, suggesting that some eggs had been shed. Testes were indistinguishable from those of ripe males described above. Maximum temperatures recorded at or near the sites were: NT2 (5 June 1981) 23.5°C; T1 (17 May 1982) 19.6°C; C02 (31 May 1982) 17.5°C (at 10:00; later temperatures would have been higher).

Spent N. photogenis specimens were first captured on 4 June 1981 and 20 May 1982 in the Grand River watershed, and on 5 June 1981 (the date of first sampling) and 17 May 1982 in the Thames River watershed. Maximum daily temperatures on these dates were 18.1-23.5°C. Ovaries of spent females were small and flattened. They often contained a few eggs, usually small white or slightly translucent eggs approximately 0.4-0.6 mm in diameter, and occasionally a very few larger eggs. This retention of some residual eggs occurs in nearly all fishes (Bagenal 1978). In spent males, the testes remained white and opaque, but were thinner than those of ripe males.

Ripening of gonads starts in the previous year, at least in some fishes. Several female specimens captured in late August and November 1981 contained moderately sized ovaries filled with white or

slightly yellow eggs approximately 0.4-0.5 mm in diameter.

Ripe or spent females as small as 6.9 cm in TL were captured in 1982, indicating that N. photogenis can spawn in its second year (Fig. 4). One of the ripening females captured in November 1981 was a YOY.

~~Notropis~~ rubellus with spawning colours, distended abdomens, or ripe gonads were captured from 6 May to 16 July 1981, and 5 May to 10 June (the end of sampling) 1982 in the Grand River watershed, and 5 (the start of sampling) to 20 June 1981 in the Thames River watershed. Maximum daily temperatures recorded for capture sites during these periods were 13.1-27.1°C. The ovaries of ripe females were very large, greatly distending the abdomen. Eggs had diameters of approximately 0.6-1.1 mm and were usually orange or pink-orange. In some specimens, particularly those apparently very close to spawning (as indicated by ovary size or capture at a site where spawning was observed), two egg types could be distinguished. Larger eggs (0.8 mm or greater diameters) were darker orange; smaller eggs were white or yellow.

Spawning by N. rubellus was observed on four occasions: on 2, 3, and 6 June 1981 at sites S5, I1, and NT5, respectively (Fig. 2 and 3), and on 18 May 1982 at site MT3. All spawning occurred in shallow water (less than approximately 40 cm) over areas or nests of clean gravel. Maximum daily temperatures recorded on these dates at these or nearby sites were 21.3-26.6°C.

With the exception of the group observed at NT5, all N. rubellus spawned with N. cornutus (common shiner) or N. chryscephalus (striped shiner) groups (these two species were not distinguished in this study and will be referred to as N. cornutus group; section V.2). Observations made on 2 June 1981 were considered typical. Ten or fewer N. rubellus

were positioned at the downstream end of each of several much larger aggregations of N. cornutus group. Each spawning group was over an area of cleaned gravel, in current fast enough to require obvious effort by the fishes to maintain their positions. Actual spawning was very difficult to see because of nearly constant aggression between N. cornutus group males, constant shifts in position by all fishes, and the difficulty of distinguishing female N. rubellus from small female N. cornutus group. However, once or twice a male and female N. rubellus appeared to come together briefly, for approximately 1 s, apparently spawning. Several large Cyprinus carpio (carp) were feeding among the spawners, apparently on eggs. Apart from moving aside for the carp, the spawning fishes appeared to show no reaction and continued spawning.

A larger group of approximately 50 N. rubellus was observed at NT5. They appeared to be spawning over a small patch of gravel (approximately 30 cm square) in a small (1-2 m wide) channel of the river. The group frequently moved up the channel and then back to the gravel; it was unclear whether this was due to my disturbance or normal behaviour. Actual spawning was not observed. When the entire group was over the gravel, individual behaviour could not be distinguished. Occasionally two or a few fishes would remain at or return to the gravel without the others; then two fishes, possibly a male and female, showed some parallel swimming and quivering, but whether these were aggressive or spawning behaviours was not known.

4. DISCUSSION

4.1 Age and Growth

Several authors have reported standard lengths for N. photogenis. Gruchy et al. (1973) found juveniles 3.25-5.45 cm and adults 5.70-10.85

cm in July and August in Ontario. In August and September in Ontario, Parker and McKee (1980) captured YOY 3.5-5.9 cm, age 1+ (1-2 years) fishes 5.5-7.7 cm, and age 2+ and 3+ fishes 8.7-9.8 cm. Trautman (1981) reported that YOY in Ohio were 3.8-6.1 cm in October, fishes approximately one year old were 5.1-7.6 cm, and adults were usually 6.9-11 cm (maximum 13 cm).

My data differ slightly from these reports. I captured YOY larger than those of Parker and McKee or Trautman, but I sampled later in the autumn, and, as discussed below, at some sites with particularly rapidly growing fishes. I used a broad definition of adults, to include all fishes that were not YOY. The more standard definition includes only fishes with mature gonads; before maturation they are juveniles (Moyle and Cech 1982). Thus all age categories of other authors except YOY and at least some juveniles fit into my adult category. My range of adult lengths includes smaller fishes than any reported in the literature, but these smaller fishes were all captured in May and June (Fig. 4), earlier than any of the sampling by others. The smallest adults of Gruchy et al. (1973) and Parker and McKee (1980) (SLs 5.7 and 5.5 cm; estimated TLs approximately 6.7-7.2 cm), however, are as small or nearly as small as my largest YOY for July and August. It is possible that some fishes classified as adults by Gruchy et al. were YOY: YOY can spawn the following year and one YOY specimen with ripening eggs was captured in November (section III.3.2). Parker's and McKee's fishes were aged as 1+, however. Thus the separation of age classes may not always be as clearly defined as I found.

The literature contains reports of standard lengths for N. rubellus in the northern United States. Pfeiffer (1955) found immature fishes of 3.0-5.0 cm, one-year-olds 3.9-6.1 cm, two-year-olds 5.6-7.0 cm, and three-year-olds 6.1-7.5 cm in May and June in New

York. Reed (1957b), in Pennsylvania, found YOY from July to October between 2.2 and 3.0 cm. Adults collected throughout the year were 3.8-6.0 cm (one year), 5.0-6.8 cm (two years), and 5.8-7.8 cm (three years). Trautman (1981) reported that YOY in October were 2.5-5.1 cm, fishes approximately one year old 3.3-6.4 cm, and adults usually 4.6-7.6 cm (maximum 8.9 cm) in Ohio. A few of the adults I captured in May were smaller than any reported in the literature, but otherwise my data coincide with these reported ranges. The literature data also show considerable overlap among year classes of adults, and, with the exception of Reed's (1957b) data, between YOY or immature and older fishes. However, both Reed and Pfeiffer (1955) found distinct peaks in length frequency data for each adult age group. Such peaks were not apparent in my data.

Some of the difference between N. photogenis and N. rubellus in the separation of age groups by length is explained by the more prolonged spawning period of N. rubellus (section III.4.2). With a longer period, fishes captured on any one date may vary more in age and therefore in size.

Differences in growth rates among rivers have also contributed to some extent to overlaps in age groups in N. rubellus, and to the widening of size ranges of YOY and adult N. photogenis. Within the Grand River watershed, differences were small, with Conestogo River fishes usually slightly smaller than those from other rivers. The Thames River watershed fishes showed considerable variation: South Thames River fishes were relatively small, while those captured at study site T1 (Fig. 3) on the main Thames River were large relative to fishes from all other sites. There are several possible reasons for these differences. Both the Conestogo River and South Thames River are controlled by dams, which may affect fluctuations in flow as well

as water temperatures. However, other rivers in these watersheds have larger fishes and are also dammed. In addition, the South Thames River was more turbid and apparently more polluted by municipal wastes than most rivers sampled. Site T1 was located just downstream from a small dam, closed in summer only. Increased production of plankton or warming of the water in the small lake created behind the dam may contribute to the growth of fishes downstream.

4.2 Spawning

Notropis photogenis appears to have a shorter and earlier spawning period than N. rubellus in Ontario. Notropis photogenis probably spawned in May or early June in 1981 and 1982, with a spawning period on the order of two weeks long at any one site, at temperatures within a few degrees of 20°C. Notropis rubellus appeared to be spawning from mid-May to late June in 1981 and 1982, and possibly occasionally as late as mid-July (only one ripe specimen was recorded in July). Water temperatures associated with actual spawning observations were greater than 20°C. The presence of eggs of different sizes in both species might suggest long spawning periods, but the data showed a long period only for N. rubellus.

These results are in direct contrast to Trautman's (1981) findings in Ohio that N. photogenis spawned primarily in June and early July and N. rubellus primarily in May. I have no explanation at present for this discrepancy. Based on specimen gonads, Parker and McKee (1980) gave the spawning date and temperatures for N. photogenis in the Grand River in 1980 as mid-June, between 17 and 23°C.

Pfeiffer (1955) reported a short spawning period for N. rubellus of six days in late June in New York. Other reports of longer spawning periods are similar to my results: late May to late June (early June to early July in a cooler year) in Pennsylvania (Reed 1957a),

and early to late June in New York (Miller 1964). Spawning temperatures were also similar to my findings: 24-29°C (Pfeiffer 1955); 20-22°C on the first day of spawning (Reed 1957a); over 21°C (Miller 1964).

The only information in the literature on the spawning habitat of N. photogenis is a statement by Trautman (1981) that it frequently spawns in the same riffles as N. rubellus. However, he stated that N. rubellus also spawned in smaller streams than N. photogenis. Stauffer et al. (1979) suggested that N. photogenis may spawn at least occasionally over Nocomis sp. nests, spawning sites used by other Notropis species, on the basis of their capture of N. chrysocephalus x N. photogenis hybrids. I captured most ripe or spent N. photogenis specimens in pool rather than riffle habitats, but there were always riffles nearby.

My observations of spawning habitat and behaviour of N. rubellus were similar to literature descriptions for the northern United States. Spawning occurred in gravel depressions in very shallow areas (approximately 5-8 cm) in or adjacent to riffles (Pfeiffer 1955, Reed 1957a) or over nests of Nocomis micropogon (river chub), N. biguttatus (hornyhead chub) (both are sympatric with Notropis rubellus in southwestern Ontario) or Exoglossum maxillingua (cutlips minnow) in deeper (20-40 cm), faster water (Reed 1957a, Miller 1964). The size of spawning schools varied from 15-20 (Miller 1964) to 45-60 (Reed 1957a). Pfeiffer (1955) observed that large schools broke into smaller groups of 8-12 during actual spawning. These authors observed N. rubellus spawning alone or with N. cornutus or other cyprinid species. Only Pfeiffer and Miller provided descriptions of actual spawning behaviour, which appeared to vary with spawning habitat. My observations of a male and female apparently coming together briefly fit with Miller's observations of fishes pressing

against one another in spawning, but the parallel swimming I observed was more likely aggressive behaviour (Miller 1964).

Many river fishes, including cyprinids, move upstream to spawn (Hynes 1970). My data provide some suggestion of upstream movements in N. photogenis, although not for movements into small streams. Notropis photogenis from the three smallest rivers in which the species was captured were small YOY (MT2, Fig. 3, width approximately 13 m) or ripe or spent adults (M1, Fig. 3, width approximately 6-7 m; WH1, Fig. 2, width approximately 8 m) suggesting the use of these rivers for spawning. At study site C03 (Fig. 2), the most upstream capture site on the Conestogo River for N. photogenis, YOY were frequently captured, but adults (apparently ripe males) only in May 1981 and 1982. In spring 1982, ripe or spent N. photogenis were captured immediately downstream from dams at sites C02 and G23 (Fig. 2). However, if the dams stopped upstream progress, they did not prevent spawning, and Parker and McKee (1980) also captured N. photogenis at site C02 in August. Thus any upstream movements that N. photogenis may make do not involve long distances or the need for particular upstream spawning sites.

IV HABITAT USE BY NOTROPIS PHOTOGENIS ANDNOTROPIS RUBELLUS1. INTRODUCTION

The purpose of this part of my study was to describe quantitatively habitat use by Notropis photogenis, and also by N. rubellus. The latter was chosen for comparison with N. photogenis because, although it is more widespread than N. photogenis (Scott and Crossman 1973), it is also a stream-dwelling shiner and in preliminary observations appeared to be occupying similar habitats. I found that adults of the two species, although not the young, had strong associations on a microhabitat scale (section V.3). Trautman (1981) also found that the two species were associates throughout the year in Ohio. I observed both to be mid-water species, swimming and feeding in mid-water or near the surface. When a difference was observed, N. photogenis usually appeared to be nearer the surface, and actually to take food from the surface, more often than N. rubellus. These observations have been partially confirmed by diet studies. Parker and McKee (1980) found that insects made up almost all of the identifiable gut contents of N. photogenis, and adult insects over half of this. Trautman (1981) reported N. photogenis jumping into the air to capture flying insects. Insects are also the major food source of N. rubellus (Pfeiffer 1955, Reed 1957b). Pfeiffer found that aquatic insects were 72% of the diet by volume, and terrestrial insects 25%, and observed both bottom and surface feeding by N. rubellus. With these apparent similarities in habitat use, including feeding, I was interested in learning how closely habitat use by the two species actually coincided.

Information on the habitat of N. photogenis in the literature has been based on descriptions of the habitat at which specimens were captured. Trautman (1981) provided the most detailed description (p. 323):

"The silver shiner was abundant in moderate- and large-sized streams which had relatively clear waters throughout most of the year, moderate or high gradients, and clean gravel and boulder-strewn bottoms. In such streams the species was most numerous on the deep, swift riffles and in the swifter eddies and currents of the pools immediately below such riffles. It usually avoided heavily silted bottoms and rooted aquatic vegetation."

In Ontario, Gruchy et al. (1973) captured N. photogenis in habitats similar to those described by Trautman -- deep riffles or flowing pools with depths of 75-100 cm, medium to fast currents, gravelly to stony bottoms, and some submersed vegetation. However, the water was muddy or cloudy, in contrast to Trautman's description.

Parker and McKee (1980) captured N. photogenis in Ontario at sites with widths of 5-100 m, though only two sites had widths less than 30 m, with depths of 20-100 cm. Most sites had alternating pools and riffles. Substrates were usually pebbles or cobbles, with occasional areas of boulders, gravel, sand, and silt. Notropis photogenis was also captured over concrete aprons below dams, so that these authors felt that substrate did not limit the distribution of the species in Ontario. They found no apparent correlation between numbers of N. photogenis captured and abundance of aquatic vegetation. Although clear water and high dissolved oxygen levels (8.5-13 mg/L) were found during their collecting, they pointed out that suspended solids and dissolved oxygen levels are quite variable in southern Ontario streams.

Although other aspects of its biology are better known than those of N. photogenis, habitat information for N. rubellus is also

based only on descriptions of capture locations. Reed (1957b) captured N. rubellus in riffles, usually in the lower (downstream) sections. Miller (1964) found that it usually occurred in riffles or other areas of swift current in summer. Trautman (1981) described N. rubellus habitat as moderate-sized streams, with relatively clear waters, high gradients, and clean bottoms of sandy gravel, gravel, boulders, or bedrock. He found that the species was intolerant to turbid waters and silty bottoms. Scott and Crossman (1973) also considered N. rubellus intolerant to turbidity. They reported that it often occurred in the downstream portions of streams near their mouths in larger rivers, and, especially in such situations, over sand or fine gravel.

Karr (1981) has described three overlapping stages in the development of the study of avian habitats; these stages can be applied to the study of fishes' (or most organisms') habitats. His stages are the "Catalog Stage", usually with cursory and nonquantitative habitat descriptions, the "Natural History Stage", including nonquantitative studies of habitat, and third an "Ecology of Habitat Stage", with increased emphasis on quantitative approaches. Existing information on habitat use by N. photogenis and N. rubellus fits into the second category.

I used a quantitative approach to try to better describe these species' habitat use by studying the relative importance of environmental factors to their use of habitat at a small geographic scale. I used two steps in analysis. The first step was univariate, analysing the importance of individual environmental factors. The second step was multivariate, analysing the environmental factors together. With a relatively large number of interrelated variables under investigation, multivariate analysis appeared to be appropriate. Shugart (1981) pointed out the inherent logic of using multivariate

methods for habitat analysis. He also pointed out, however, that this is a recent approach, and suggested that it followed from several developments before or during the early 1970s: increased availability of high-speed computers, development of multivariate statistical techniques, the hyperspace concept of the niche in theoretical ecology, the recognition of the value of small-spatial-scale studies in understanding interrelationships of animals, and an emphasis on the responses of individual organisms in determining species' distributions.

A quantitative, though not usually multivariate, approach has been used in some other stream-fish habitat studies. In North America, salmonids (salmon and trout) are the best-known group of freshwater fishes, and understanding of the habitats of salmonid species has progressed to the point that specific habitat requirements can be defined for management purposes (e.g., Toews and Brownlee 1981). Quantitative work on other stream fishes has frequently been concerned with faunal or community-level studies, relating habitat factors to such attributes as longitudinal species distribution patterns (e.g., Hocutt and Stauffer 1975) or fish species diversity (e.g., Gorman and Karr 1978). Matthews and Hill (1979a, 1979b) studied the influence of physico-chemical factors on habitat selection by the red shiner (N. lutrensis), including comparisons between adults and juveniles, using univariate techniques. Biëtz (1981) used multivariate analyses to characterize the spawning habitat of longear sunfish (Lepomis megalotis peltastes).

My specific objective was to use univariate and multivariate analyses to determine what environmental factors were important in predicting habitat use by N. photogenis and N. rubellus at a small geographic or microhabitat scale -- a scale measured in metres rather

than hundreds of metres or kilometres. I asked the question separately for adult and young fishes, and also asked how habitat use by these species changed with time, both daily and seasonally.

2. METHODS

2.1 Study Sites

Using the data collected while mapping the distribution of N. photogenis (section II), I selected seven study sites (Fig. 2 and 3). One site was chosen on each of five of the six major rivers or tributaries within the range of N. photogenis: Conestogo (CO3), Nith (N2), North Thames (NT2), South Thames (ST1), and main Thames (T1) Rivers. Two sites were chosen on the Grand River (G9, G20) because of the large extent of the range of N. photogenis on the Grand, the change in size of the river, and the apparent changes in the nature of the habitats available within this range. Criteria for selection of sites were that N. photogenis had been captured during my survey, and that the site offered as wide a variety of habitats (as perceived by me) as possible.

At each site, a subsite was established in each visibly different habitat. Sites contained four to eight subsites; a total of 37 subsites was sampled. Each site was mapped in the field, using triangulation from fixed points. Figures 6 to 12 were prepared from these field data and air photos, and show each site and its subsites.

Each site was sampled seven times: four times between 15 July and 29 August 1981, once between 14 and 18 November 1981, once between 3 and 17 May 1982, and once between 2 and 10 June 1982. High water-levels prevented sampling at some subsites in November 1981, and May and June 1982, and at two entire sites (ST1 and T1) in June 1982.

Fig. 6. Study Site G9: Grand River at mouth of Canagagigue Creek, Ontario
a: upstream sub-sites

b: downstream sub-sites
a and b are separated by approximately 100 m

Legend

subsite; arrow indicates direction of seining

riffle

island

Fig. 7. Study site G20:
Grand River
approximately
6 km south of
Cambridge, Ontario

Fig. 8. Study site C03:
Conestogo River
approximately 4
km upstream from
St. Jacobs, Ontario

Fig. 9. Study site N2:
Nith River at
Canning, Ontario

Fig. 10. Study site NT2:
North Thames River
at University of
Western Ontario,
London, Ontario

Legend as Fig. 6

Fig. 11. Study site ST1:
South Thames River
at St. Julien's
Park, London,
Ontario

Fig. 12. Study Site T1:
Thames River at
Springbank Park,
London, Ontario

Legend as Fig. 6

2.2 Fish Sampling

All fishes were captured by seine net. The reasons for the choice of this method of capture were discussed in section II.2. During the first sampling period, a straight seine was used (1.5 x 3.8 m, stretched mesh 10 mm). For the second and all subsequent sampling periods, a bag (1.5 x 1.2 m, stretched mesh 6 mm) was added to the seine giving total dimensions of 1.5 x 5 m. The advantages of the bag seine, for capturing not only small but all fishes, and reducing injury to fishes, were discussed in section II.2.

One sample at a subsite consisted of three seine hauls, at least 10 min apart. The time lapse was to allow the disturbed but uncaptured fishes to resume their positions within the subsite; too long a time may have allowed fishes to move into the subsite from other areas.

Most fishes from each seine haul were identified in the field, counted, and the total lengths of the smallest and largest individuals (except small young-of-the-year) of each species recorded. Notropis photogenis individuals were not measured before release because I found during the earlier surveys that the handling involved greatly increased scale loss in this species. However, counts of adults and young-of-the-year (YOY) were recorded separately. Young-of-the-year are fishes hatched in the year of study; I considered them YOY until the end of the calendar year. Figure 4 shows the lack of overlap in length between adults and YOY, making field separation quite easy. Only one specimen of N. photogenis, captured in August 1981, could not be identified as an adult or YOY in the field or by later scale-aging (sections III.2.1

and III.3.1); it was excluded from data analysis. Adult and YOY N. rubellus were also separated in the field. However, separation of the two age classes by length was not as clear for N. rubellus as for N. photogenis (Fig. 5) and scale-aging was unsuccessful (section III.2.1). I found that, although intermediate-sized fishes were often present, measurements taken in the field or on preserved N. rubellus specimens showed some individuals at most subsites to be clearly adults or YOY. At only a few subsites did I have to consider the data for adults or YOY to be missing.

Most fishes were released alive in the field, into areas of each site that did not allow rapid access into subsites yet to be sampled. Some specimens of N. photogenis and N. rubellus were collected for analysis of age or gonad development, and specimens of other species were kept to confirm identifications. Fishes were killed in 10% formalin during early sampling periods, later in a 200 mg/L solution of the anaesthetic MS-222, and preserved in 10% formalin.

Although numbers of fishes captured were recorded, only the presence or absence of N. photogenis or N. rubellus at a subsite was used in data analysis. I did not believe that the numbers of these species captured were meaningful, both because they are schooling species (Trautman 1981, Reed 1957b, my observations), and because of the different effectiveness of the seine net in different habitats (section II.2). There are also theoretical reasons for the use of presence/absence data. Green (1979) pointed out that "it has been observed many times that the number of species, species identities, and their rank abundances are much less affected by sampling bias and other sources of noise than are quantitative species abundances" (p. 54). Wiens (1977) suggested that density fluctuations in small areas are more likely the result of local or regional redistributions

of individuals than of close tracking by the species of environmental changes. Thus using population density as a measure of habitat suitability or optimality, or prospects of individual success, is suspect.

2.3 Habitat Variables

The selection of variables to test for their influence on habitat use by N. photogenis and N. rubellus was based on existing information on the species' habitats, and on documentation in the literature of effects of environmental variables on fishes.

Variables included in descriptions of N. photogenis or N. rubellus habitats (section IV.1) are stream size or width, water clarity or turbidity, stream gradient, substrate, water depth, current speed, and aquatic vegetation.

Moyle and Cech (1982) stated that four physical factors have been found to be the best predictors of patterns of distribution and abundance of stream fishes, both within and among streams: temperature regime, stream gradient, stream order, and fluctuations in discharge. They had difficulty in finding evidence of strong correlations between water chemistry and stream fish distribution patterns, except under extreme natural or pollution conditions, because streams tend to be well buffered chemically and well oxygenated. Hynes (1970) reviewed the evidence for effects of oxygen, temperature, current speed, fluctuations in discharge, dissolved salts, substrate, and turbidity on stream fishes. He concluded that the most important abiotic factors are temperature (acting both directly and indirectly through its effects on oxygen consumption), current speed, fluctuation in discharge, and the availability of suitable shelter, whereas water chemistry again

seemed to have relatively minor importance. However, fishes do respond to some chemical factors; Matthews and Hill (1979a) briefly reviewed studies showing the effects of pH, salinity, and other physico-chemical factors, as well as temperature and oxygen, on laboratory responses or habitat selection in the field by fishes. Trautman (1981) suggested that increasing pollution and especially turbidity may have been responsible for declining numbers of N. photogenis and N. rubellus in Ohio in this century. Therefore some chemical as well as physical variables were included in this study.

Several of the variables discussed above were not used in this study: stream gradient, stream order, and discharge. Although they have been shown to be important to stream fishes, they vary on a much larger spatial scale -- regional rather than local -- than I was studying. Fluctuations in discharge tend to occur over a longer time period (e.g., annually) than the times separating many of my study periods.

The variables selected and methods of measurement for each are described individually below.

2.3.1 Habitat Type. Each subsite was classified into one of five habitat types. The types were based on the alternating pattern of pools and riffles occurring in most natural, hard-bottomed streams and rivers (Hynes 1970). Riffles are shallower, with larger substrate particles -- boulders, stones, and gravel (Hynes 1970). They have currents faster than those of pools, and the water appears broken (Lagler et al. 1977). Pools tend to be wider, deeper, and slower flowing than riffles, and have smaller substrate particles and smooth surfaces.

I divided pools into three categories: still pools (with no

current), flowing pools, and current edges. The latter contained adjacent areas of very different current speeds, created by riffles just upstream or bank irregularities. The fourth habitat category was used for subsites that included both pool and riffle areas, such as a very small pool surrounded by riffles. The fifth category was riffles. Initially riffles and runs were separated in the field; runs were deeper and smoother-surfaced than riffles but retained their other characteristics. However, later examination of depth and current data showed that the field separations were quite arbitrary, so the distinction was dropped.

The habitat type of a subsite did not usually change between sampling periods. There were some changes, however, between 1981 and 1982 sampling periods as a result of scouring by ice or floods.

2.3.2 Colour. Water colour is caused by the presence of natural metallic ions, humus materials, plankton, aquatic vegetation, and industrial wastes (American Public Health Association et al. 1976). Colour was classified visually as colourless, brown, green-brown, or green.

2.3.3 Clarity. Clarity was classified visually as clear, cloudy, or muddy. Because muddy waters were in fact almost never observed, this category was combined with cloudy for analysis.

2.3.4 Secchi Depth. Secchi depth is a measure of water clarity. A round 20-cm diameter metal disk, painted black and white in alternating quadrants, is lowered into the water and raised again. The average of the depths at which it disappears and reappears is the Secchi depth (Lind 1974).

In practice, the bottom was reached before a Secchi depth could

be measured in over half of my samples. Therefore, Secchi depth was categorized simply as "bottom" or "measurable" for analysis. This variable is similar to clarity. However, whereas visual observations readily separated clear from cloudy water, Secchi depth better distinguished degrees of cloudiness. Therefore both variables were analysed.

2.3.5 Temperature. Water temperature at the surface and bottom of the water column in the deepest part of each subsite were measured with the temperature probe of a Yellow Springs Instrument Co. Inc. (YSI) model 54A or 51B dissolved oxygen meter. Only one measurement was taken in subsites less than 40 cm deep. T-tests of data collected during the 1981 distribution survey for N. photogenis showed that, when different, surface and bottom temperatures were significantly different ($p < 0.01$). Surface temperatures were usually higher than those at the bottom. The mean and range of the two measurements were analysed.

2.3.6 Dissolved Oxygen. Dissolved oxygen was measured in mg/L with the YSI model 54A or 51B dissolved oxygen meter at the surface and bottom of the water column in each subsite. As for temperature, t-tests showed surface and bottom levels to be significantly different ($p < 0.01$) in survey data. The mean and range of surface and bottom values were analysed.

2.3.7 pH. Water samples were collected in the field in plastic bottles for later analysis (usually the same or the following day) for pH, conductivity, and turbidity. Samples were refrigerated until approximately 1-2 h before analysis.

A Fisher Accumet portable pH meter, model 150, was used to

measure pH. I encountered some problems in achieving consistent pH measurements, likely because of probe-aging; in particular the meter showed a tendency to give increasing pH values as operation time increased. No pH values were obtained for the final sampling period (June 1982) because of meter malfunction. In addition, pH can change rapidly between sampling and determination because of such factors as oxidation, hydrolysis, loss of gases, and biological activity (Lind 1974). Although some authorities state that pH may be measured in the laboratory immediately after sample opening (Traversy 1971), others recommend field measurement only because of the potential for rapid changes (American Public Health Association et al. 1976). Therefore, although pH was included in univariate analyses, results are treated with caution, and I excluded this variable from initial multivariate analyses (section IV.2.4).

2.3.8 Conductivity. Conductivity is a measure of the general ionic composition (Wilson 1974) or purity (Midgley and Torrance 1978) of water. It is a measure of the electrical conductivity of a solution; because electricity is carried by the migration of ions in solution, conductivity is related to the total ionic concentration of a solution (Traversy 1971). The unit of electrical conductance is the mho; conductivity is measured in $\mu\text{mho}/\text{cm}$ (American Public Health Association et al. 1976).

I used a YSI model 31 conductivity bridge to measure the conductivity of water samples. Conductivity changes approximately 2% per $^{\circ}\text{C}$ (American Public Health Association et al. 1976, Traversy 1971). In 1981 I did not record sample temperatures consistently, so the adjustment for temperature was estimated in many cases.

Thus conductivity results for 1981 were viewed as approximate, and I did not include them in initial multivariate analyses (section IV.2.4).

2.3.9 Turbidity. Turbidity is a measure of the optical property of a solution causing it to scatter and absorb light, rather than transmit it in straight lines (American Public Health Association et al. 1976). I used a Hach Chemical Company colorimeter, with a turbidity meter scale, to measure turbidity. It measures the light reflected by particles suspended in the sample (Traversy 1971) in Jackson turbidity units (JTU). A JTU is based on the length of the light path through a sample required to make the image of a standard candle disappear (American Public Health Association et al. 1976).

2.3.10 Depth. The maximum and minimum depths in each subsite were measured with a metre-stick. The mean and range of the two depth measurements were analysed.

2.3.11 Current. I measured the time taken for a neutrally balanced floating rubber ball to travel approximately 7.5 m (25 feet) to obtain current measurements. Where current varied within a subsite, maximum and minimum current velocities were measured. For analysis, the mean and range of currents for each subsite were used.

2.3.12 Substrate. In each subsite, I estimated the percentage (within 5 or 10%) of the substrate consisting of bedrock, boulders, stones, pebbles, gravel, sand, mud, clay, or other material (e.g., concrete). Size definitions of substrate particles followed Hynes (1970), although particles were not usually actually measured. Later these data were condensed into five substrate categories: over 50% boulders and stones; 25-50% stones and boulders and 25-50% pebbles and gravel; over 50% pebbles and gravel; 25-50% hard

materials (boulders, stones, pebbles, or gravel) and 25-50% soft (sand, mud, or clay); over 50% sand, mud, or clay.

Substrate estimates were made once during the summer of 1981 for the four summer sampling periods, and once in 1982 for the May and June 1982 sampling periods. No estimates were made in November 1981, and summer 1981 values were not used then because flooding during autumn 1981 changed some substrates.

2.3.13 Aquatic Vegetation. Percentage cover (to 5 or 10%) of the substrate by floating, submersed, and encrusting (e.g., algae) vegetation was estimated for each subsite. These data were used to form four categories for each of two variables, floating and submersed vegetation, and encrusting vegetation: less than 5%, 5-25%, 26-50%, more than 50%.

2.3.14 Shore Vegetation. I categorized the shore vegetation of each subsite as grassy, grassy and bushy, bushy, grassy and forested, bushy and forested, or forested.

2.3.15 Distance from Shore. This was the distance from the centre of each subsite to the nearest shoreline, obtained from Fig. 6 to 12.

2.3.16 Stream Width. The minimum stream width through the centre of each subsite was also obtained from Fig. 6 to 12.

In addition to the habitat variables described above, data were also collected for other variables relevant to sampling that I thought might influence results.

2.3.17 "River". Each of the seven sites was on a different river or section of a river (section IV.2.1). This variable thus had seven categories.

2.3.18 Sampling Information. The day of the year of sampling (starting from 1 January as day 1), the time sampling started, and the total duration of sampling for each subsite, were recorded. Minutes were converted to fractions of an hour for analysis of the two time variables (e.g., 13:30 became 13.5). The standard seine haul distance was 10 m, but in a few subsites increasing depth prevented a full 10 m of seining, so that distance hauled was also recorded.

2.3.19 Weather. Air temperature, cloud cover, wind, and precipitation were recorded. Air temperature was measured with the temperature probe of the YSI model 54A or 51B dissolved oxygen meter. Cloud cover was categorized as less than 10%, 10-50%, 51-90%, or more than 90%; wind as none, light, or moderate; and precipitation as none, haze or fog, or rain.

2.4 Statistical Analysis

Figure 13 summarizes my statistical analysis procedures. The basic aim of all univariate and multivariate procedures was to compare subsites where N. photogenis or N. rubellus was present with subsites where the species was absent, in order to look for differences that might help to explain the species' presence or absence. Data for adults and YOY were analysed separately, so that separate comparisons were made between subsites with and without adults, and between subsites with and without YOY. Data for each sampling period were analysed separately.

All analyses were done using BMDP statistical computer programs (Dixon et al. 1981), with the exception of Kolmogorov-Smirnov tests, which were done with SPSS programs (Hull and Nie 1981).

Fig. 13. Flow chart of statistical methods for analysis of habitat use by Notropis photogenis and Notropis rubellus

The univariate analyses involved studying each habitat (or sampling) variable individually. Data for each variable were initially plotted in histogram format, to allow visual inspection of statistical distribution as well as differences between subsites with and without N. photogenis or N. rubellus. Remaining analyses then differed for continuous and categorical variables.

Normal probability plots of continuous variables were prepared. Although they did often show differences between the two groups of subsites, they were unsatisfactory as an indication of normality, probably as a result of my small sample sizes. Daniel and Wood (1980) plotted actual random normal deviates (taken from random tables) and found that even plots of as many as 64 deviates showed considerable departures from the expected straight lines, especially near the tails. Therefore I used a Kolmogorov-Smirnov one-sample test as a test of normality. This is a test of goodness of fit, based on the vertical distance between an empirical and an hypothesized (here a normal) cumulative frequency distribution (Conover 1971). It has more power than a χ^2 -type goodness of fit test for continuous distributions, especially with small sample sizes (Sokal and Rohlf 1981).

T-tests were used to test for differences between subsites with and without N. photogenis or N. rubellus for normal continuous variables. Levene's test of equality of variances was first computed; when the test was not significant, the usual t-statistic for pooled variances was used, but when Levene's test was significant ($p < 0.10$), the t-statistic for separate variances was used (Dixon et al. 1981). For non-normally distributed variables, i.e., those having a significant ($p < 0.10$) Kolmogorov-Smirnov one-sample test statistic, the nonparametric Mann-Whitney U-test was

used to compare the two groups of subsites. Whereas a t-test compares means of two normal distributions, the Mann-Whitney U-test is used to compare the locations of two populations that may have non-normal distributions. It is based on a comparison of the rank orders of observations of the two samples (Sokal and Rohlf 1981). I also used a third test for continuous variables, the Kolmogorov-Smirnov two-sample test. Its null hypothesis, like that of the Mann-Whitney U-test, is that the two population distributions are identical, but of unknown form, and the test is based on the differences between the two empirical cumulative frequency distributions (Sokal and Rohlf 1981). The t- and Mann-Whitney U-tests measure differences in location, but the Kolmogorov-Smirnov two-sample test is sensitive to other differences as well, such as dispersion and skewness (Sokal and Rohlf 1981). It is thus a more general test, sensitive to a greater range of alternative hypotheses, and more appropriate for some of the non-normal variables with very skewed distributions (such as those measuring the range between maximum and minimum values) where the Mann-Whitney U-test is not very powerful (R. Thomas, pers. comm.). In practice, all three tests were computed for all continuous variables, and their probability values were usually similar, even for non-normal data.

I used χ^2 -tests to test for differences between subsite groups for categorical variables. This is a test of independence of the two variables (Sokal and Rohlf 1981) and is based on a comparison of observed frequencies and the frequencies expected if the two variables were independent. There are other test statistics for contingency tables. I chose χ^2 over G^2 or T^2 on the basis of work by Larntz (1978) showing that the exact levels of χ^2 were closer than G^2 or T^2 levels to nominal levels of α for small expected frequencies of one to four. Because of my small sample sizes, I often

obtained such small expected frequencies. When the minimum expected frequency was less than one, I combined categories to obtain a minimum value greater than one (if possible).

The next analysis step was a multivariate analysis of all habitat variables. The major disadvantage of univariate analyses arises from correlations among the habitat variables. These are expected to be numerous and complex, based on consideration of the variables involved. For example, substrate type is related to current speed; vegetation growth is likely to be affected by substrate and water clarity; greater depths provide more opportunity for greater ranges in temperature and dissolved oxygen. Thus if two variables show significant differences between subsite groups, one cannot necessarily conclude that the fishes are responding in some manner to both variables; only one may be important, and the statistical relationship to the other may simply result from its correlation with the first variable. By permitting the analysis of all variables simultaneously, a multivariate technique should remove some of the correlated variables and provide insight into which variables are the best predictors of habitat use.

I used a logistic regression technique for multivariate analysis. It is analogous to multiple regression in that it is concerned with the relationship between a number of independent variables and one dependent variable. However, multiple regression is designed for normally distributed, continuous variables. Logistic regression uses a binary dependent or outcome variable, and independent variables may be continuous or categorical (Engelman 1980). Both features are obviously suitable for my data. The linear logistic model is:

$$\log \left(\frac{p_i}{1 - p_i} \right) = \beta_0 + \sum_{j=1}^r \beta_j z_{ij}, \quad i=1,2,\dots,N$$

(Fienberg 1977). The right side of this equation resembles a multiple regression equation. The quantities z_{ij} are the values of the r independent variables for the i th observation. The left side of the equation is the logarithm of an odds ratio, where $p_i = p_r(y_i=1)$, (p_i is the probability that $y_i=1$), and y_i is the binary independent variable. Thus, logistic regression is concerned with finding a set of independent variables (the model) that predict a positive outcome ($y_i=1$) of the dependent variable. Here that aim becomes finding the set of habitat variables best predicting the presence of N. photogenis or N. rubellus.

The BMDP logistic regression procedure is stepwise (Dixon et al. 1981), i.e., variables are added to or removed from the model one at a time. At each step, the current coefficient (β) for each of the independent variables is compared to its coefficient if it were entered or removed from the model (Engelman 1980). A χ^2 -test compares these two coefficients; within specified limits, the variable with the least significant χ^2 is removed or the variable with the most significant χ^2 is added.

I am not aware of any published studies using logistic regression to analyse habitat data. Binns and Eiserman (1979) used multiple regression to analyse relationships between a large number of habitat variables and trout standing crop (a continuous variable) in Wyoming streams.

Among multivariate techniques used to analyse habitat, principal components analysis (PCA) and discriminant function analysis are the most popular (Johnson 1981). PCA is often used

to summarize information or reduce the number of variables, by finding a new set of axes (or components, each a compound of the original observations and variables) in the directions of greatest variance in the data (Neff and Marcus 1980). The technique assumes that the data are multivariately normally distributed (implying that the data do not include different groups) (Neff and Marcus), clearly not the case for my data. Although this assumption is not usually made when PCA is just used descriptively, Neff and Marcus pointed out that PCA is also sensitive to the use of categorical variables with very few states. The goal of discriminant analysis is to develop a linear function of variables that will allow the classification (with minimal errors) of subjects into a priori groups (Neff and Marcus 1980). It could thus be appropriate for comparisons of groups of subsites with and without a species, although most studies seem to use it to compare different species (e.g., Baker and Ross 1981). However, for problems of relating a qualitative dependent variable to one or more independent variables, with non-normal data, Press and Wilson (1978) preferred logistic regression to discriminant analysis because of more appropriate underlying assumptions and better statistical properties of the estimators.

For all of my logistic regression runs, all categorical variables were condensed into two classes. In running the program, each continuous variable absorbs one degree of freedom, but each categorical variable absorbs one degree of freedom less than the number of categories (Engelman 1980). Because of my small sample sizes, in cases with small proportions of subsites with N. photogenis or N. rubellus present the program generated statistically uninterpretable results with more than two categories per variable.

Missing data also created some problems. When any data were missing, the entire subsite was dropped by the program. To avoid reducing sample sizes too much, I left any variables with large numbers of missing cases out of the initial run. The analysis was then re-run, including each of these variables one or two at a time, to determine whether they would enter the model. In some sampling periods aquatic vegetation variables were not included in any runs, because they were not only missing for several subsites, but the pattern of missing data was related to water clarity and therefore not random. Problems with pH and conductivity measurements were described in section IV.2.3. Conductivity for sampling periods 1 to 5 and pH for all sampling periods were thus treated in the same manner as variables with missing data and included only in subsequent runs.

For each sampling period habitat variables were analysed initially. A second set of analyses was then run to look for influences of the sampling variables. The habitat variables included in the model in the first run(s) were analysed together with the sampling variables.

All data analysis was conducted for each sampling period separately. Because the same set of subsites was sampled in each period, the results are analogous to repeated sampling on one individual and are not independent from one sampling period to the next. Using these arguments, data for more than one sampling period should not be pooled. However, there were also changes in subsites over time, e.g., changes in water level and temperature, and changes in the presence or absence of N. photogenis and N. rubellus. Small sample sizes made interpretation of logistic regression results difficult for some sampling periods. Pooled

samples for summer 1981 and for 1982 sampling periods were therefore also analysed. Further pooling was not done because expected seasonal differences would have been obscured, and might have confused the results.

3. RESULTS

3.1 Notropis photogenis Adults

The results of data analyses for Notropis photogenis adults are summarized in Table 1 and presented in detail in Appendix I. Data for sampling period 5 (November 1981) are not included. Only 2 of 29 subsites contained N. photogenis adults -- too few data for statistical analysis. Results for this period will be discussed qualitatively in section IV.3.5.

Table 1 shows significance levels for univariate statistics. The actual statistic reported varies with the nature of the variable: χ^2 for categorical variables; t for normal continuous variables; Mann-Whitney U for variables significantly different from normal but without highly skewed distributions; Kolmogorov-Smirnov 2-sample statistic for non-normal continuous variables with skewed distributions. Appendices I.1 and I.2 include p-values for these statistics, as well as means, standard deviations, and results of tests of normality on the data.

Statistically significant differences (p-values less than 0.05) between subsites with N. photogenis adults and those without are shown in Table 1. P-values between 0.05 and 0.15 are also shown, because my major interest lies in looking for trends and comparisons, as opposed to drawing conclusions as to the statistical significance of individual variables in individual sampling periods.

Variables included in the prediction models generated by

TABLE 1. Summary of univariate and multivariate analyses of habitat and sampling variables for presence and absence of *Notropis photogenis* adults

Sampling period	1	2	3	4	1-4	6	7	6-7
Total no. subsites	37	37	37	36	138	30	21	45
No. subsites with <i>N. photogenis</i> present	8	6	5	5	23	11	7	18
Sampling dates	15-28 July 1981	31 July -6 Aug. 1981	7-19 Aug. 1981	22-29 Aug. 1981		3-17 May 1982	2-10 June 1982	
Habitat variables								
habitat type		o	x+		x	o	o	
colour		o				***+	*	
clarity	x					**		
Secchi depth		**				-	-	-
mean temperature		x		o		**	o	x
temperature range								
mean dissolved oxygen				o		o	**	
dissolved oxygen range		*				o		
pH		*	-			**	-	-
conductivity								
turbidity		*						
mean depth		***+	o	* x	x+	**	* x+	
depth range		*			o	x	*	x+
mean current				o		*	*	x
current range								x+
substrata	x			o	x+	x	x	(x)
encrusting vegetation		-	-	-	-	***	-	-
submersed vegetation	o	-	-	-	-	-	-	-
shore vegetation		o x+	o					
stream width	x	x			x+			x+
distance from shore	x						o x+	x+
Sampling variables								
"river"	*	o		o		**	*	+
day	-			o		*	*	
time				+				
duration		o		+			o	+
distance hauled		*				o	*	
air temperature	(+)	+		** +		o +	o	
cloud cover						*		
wind								
precipitation	(+)			*		**		

univariate analysis:

- * $p < 0.05$
 ** $p < 0.01$
 o $0.05 < p < 0.15$

multivariate analysis:

- x included in logistic regression model (habitat variables)
 + included in logistic regression model (habitat and sampling variables)
 () included in model in additional runs
 - not analysed (too few data)

logistic regression analysis are also shown in Table 1. Variables included by analyses using habitat variables only, and habitat as well as sampling variables, are included.

More detailed results of logistic regression analyses are presented in Appendices I.3 and I.4: for each variable included by the program in a model, Appendix I.3 lists the analysis step at which it entered the model, and the p-values of an improvement χ^2 -test and two goodness of fit tests. The improvement χ^2 tests whether the addition (or removal) of the variable at that step significantly improves prediction by the model (a small p-value shows significant improvement) (Dixon et al. 1981). For N. photogenis adults, these values were always less than or equal to 0.1, and usually less than 0.05 (Appendix I.3). The Hosmer-Lemeshow goodness of fit test forms 2 x 10 cells of observed and predicted frequencies, and uses a χ^2 -statistic to compare observed and predicted values (Engelman 1980). The C.C. Brown goodness of fit test compares the fit of the data to the logistic function as opposed to an alternate family of models (Dixon et al. 1981, Engelman 1980). Small p-values for these two tests indicate that the predicted values do not fit the data, or that the logistic model is not appropriate, respectively. These p-values were usually greater than 0.1 for N. photogenis adults (Appendix I.3). The few values below 0.1 were usually associated with cases of perfect prediction, discussed below. Appendix I.3 also lists the regression coefficients, the standard errors of the coefficients, and the ratio of these two values, for each independent variable in the final model (these values change with each step in analysis; only the final values are shown). The ability of these final models to predict the presence or absence of N. photogenis adults is shown graphically in Appendix I.4. Because the model predicts probabilities of N. photogenis adults

being present, with good predictions most of these probabilities would be near 1 for subsites with N. photogenis adults, and near 0 for subsites without them. As discussed below, actual predictions were variable for N. photogenis adults.

In interpreting both univariate and multivariate results, I was interested in variables that were significant or included in prediction models in more than one sampling period during a season. Because of the small sample sizes involved, particularly the small proportion of subsites with N. photogenis adults present (5 of 37 to 11 of 30, Table 1), I did not consider a variable that appears in Table 1 in only one sampling period to be meaningful. This interpretation is confirmed by the results of logistic regression analyses. For sampling periods 2,6,7, and 6 and 7 combined, the set of variables selected by these analyses predicted the presence of N. photogenis perfectly or nearly perfectly (Appendix I.4). However, the standard errors of the coefficients of the selected variables were very high (Appendix I.3). The implication is that the results are unreliable: given more data for the same sampling period, different results might have been obtained. The models for the other sampling periods generally provided only fair or poor predictions of the presence of N. photogenis (Appendix I.4).

Habitat type approached significance in univariate analyses in only one sampling period during summer 1981, but in both periods in spring 1982 (Table 1). However, it was included by logistic regression analysis in prediction models in sampling period 3, and the combined data (sampling periods 1 to 4) for summer 1981. Notropis photogenis adults were usually captured in flowing pools or current edges, less often in still pools, and almost never in habitats including riffles.

Colour appeared to be important in predicting the presence of N. photogenis adults in spring 1982, but not in summer 1981. However, the pattern of colour was not consistent; subsites with N. photogenis adults tended to be green-brown in sampling period 6, but brown or green in period 7.

Water clarity, measured visually or by Secchi depth, and turbidity were not useful predictors of N. photogenis adult presence or absence.

Mean temperature, but not temperature range, appeared to be important, particularly in spring 1982. Notropis photogenis adults were captured in warmer subsites. Dissolved oxygen showed similar patterns to temperature, with mean dissolved oxygen apparently important in spring 1982, when subsites containing N. photogenis had lower dissolved oxygen levels than those without it. However, dissolved oxygen was not included in logistic regression models, indicating that its significance in univariate analysis may have been due to its correlation with some other variable such as temperature.

The presence or absence of N. photogenis adults was unrelated to conductivity. In univariate analyses, pH was significant in both summer 1981 and spring 1982. Subsites with N. photogenis adults had lower pH levels than those without. However, these results can be considered only tentative (section IV.2.3.7).

Mean depth and depth range were important predictors of N. photogenis adult presence or absence, one or both variables being significant in univariate analyses or included by logistic regression analyses in prediction models for all individual and combined sampling periods except period 1. Notropis photogenis adults were present in greater mean depths and, with the exception of sampling

period 3, greater depth ranges, than they were absent from.

Current speed was apparently unimportant to N. photogenis adults in summer 1981, but important in spring 1982. Subsites with N. photogenis adults in spring had slower currents, and in sampling period 6, a lower range of current speeds, than those without.

Substrate emerges as a predictor of N. photogenis adult presence or absence particularly in the logistic regression analyses of combined data sets. Notropis photogenis adults occurred more often than expected over bottoms containing large proportions of sand, mud, or clay.

There were generally too few data to analyse aquatic vegetation. Univariate results showed that subsites with N. photogenis adults had very little submersed plant cover, but encrusting plant cover patterns varied among sampling periods.

Shore vegetation showed some importance in summer 1981, but was included in a logistic regression prediction model only in sampling period 3. Where differences approached significance, N. photogenis adults occurred more often than expected in subsites with grassy or bushy shorelines.

Although stream width never, and distance from shore only once, approached significance in univariate analyses, both emerged as important in logistic regression analyses. Stream width was important in both summer 1981 and spring 1982, but in different directions. In summer 1981 (except for sampling period 4), mean stream widths were narrower at subsites with N. photogenis adults than at those without, whereas in spring 1982 they were wider. Distance from shore was important in spring 1982, but at all times subsites with N. photogenis adults were farther from shore than those without them.

Comparison of the results of logistic regression analyses with and without sampling variables showed that these variables did affect the outcomes (Table 1). However, there are few consistent patterns to indicate the importance of particular sampling variables.

"River" was significant or nearly so in all sampling periods except 3, but was included in the logistic regression model only for periods 6 and 7 together. Notropis photogenis adults were concentrated in Nith and North Thames River subsites, and to a lesser extent in spring 1982, in Upper Grand River and other Thames River watershed subsites.

Day of the year showed significant differences between subsite groups in spring 1982, but did not enter any logistic regression models. Time of sampling was not a good predictor of the presence or absence of N. photogenis adults. Duration of sampling was a somewhat better predictor. Where differences between subsites existed, those with N. photogenis had longer durations. Although distance hauled was significant or nearly significant in univariate analyses in spring 1982, it was not included by logistic regression analysis in prediction models.

Among weather variables, air temperature was the only consistent predictor of N. photogenis presence or absence, primarily in summer 1981. With the exception of sampling period 3, mean air temperatures were higher when N. photogenis adults were present than when they were absent.

3.2 Notropis photogenis Young-of-the-Year

Results of habitat use analysis for N. photogenis young-of-the-year (YOY) are summarized in Table 2 and presented in Appendices II.1 to II.4 in the same manner as described above for N. photogenis

TABLE 2. Summary of univariate and multivariate analyses of habitat and sampling variables for presence and absence of *Notropis photogenis* young-of-the-year

	2	3	4	2-4	5
Sampling period	2	3	4	2-4	5
Total no. subsites	37	37	36	106	29
No. subsites with	18	16	16	49	5
<i>N. photogenis</i> present					
Sampling dates	31 July -6 Aug. 1981	7-19 Aug. 1981	22-29 Aug. 1981		14-18 Nov. 1981
Habitat variables					
habitat type	* x+	**x+	**x+	x+	
colour			o x		o
clarity	o x				
Secchi depth	o	*	*		- -
mean temperature					
temperature range	o	o			
mean dissolved oxygen					- -
dissolved oxygen range	*	o	*		- -
pH		* -	(x)		
conductivity					*
turbidity					*
mean depth	**	**x+	**	x+	o
depth range	*	**	**		**x+
mean current	o	**x+	**	x	*
current range					
substrata					- -
encrusting vegetation	-	-	-	-	o (x)
submersed vegetation	o -	-	o -	-	
shore vegetation	o	o x+		x+	
stream width			x+		
distance from shore					
Sampling variables					
"river"	o	**	*	+	
day	*	*	o		
time		*	o		
duration	o				o +
distance hauled	o	*			
air temperature			*		
cloud cover	o +	o	o +		
wind				+	-
precipitation			o		+

univariate analysis:

- * $p < 0.05$
- ** $p < 0.01$
- o $0.05 < p < 0.01$

multivariate analysis:

- x included in logistic regression model (habitat variables)
- + included in logistic regression model (habitat and sampling variables)
- () included in model in additional runs
- not analysed (too few data)

adults (section IV.3.1).

Results for YOY during summer 1981 (sampling periods 2 to 4) are considered more reliable than those for N. photogenis adults. The proportions of subsites with N. photogenis were much higher, from 16 to 18 of 37 (Table 2). Logistic regression analyses showed no goodness of fit test statistics below 0.1, only two coefficient to standard error ratios less than 1.5 (Appendix II.3), and good predictions of the presence and absence of N. photogenis YOY (Appendix II.4).

In sampling period 5, however, the proportion of subsites with N. photogenis YOY (5 of 29) was similar to those for N. photogenis adults in summer 1981. Logistic regression analysis for period 5 showed problems similar to those encountered with adults: fair to poor predictions, or perfect predictions combined with high standard errors of the coefficients of variables included in the predictive model (Appendices II.3 and II.4). These problems, together with having only one data set for autumn 1981, mean that the results are considered tentative.

The best predictor of the presence or absence of N. photogenis YOY in summer 1981 was habitat type (Table 2). It was significant in all univariate analyses, and was included by logistic regression analyses in all prediction models, for the three sampling periods. Young-of-the-year occurred in pool habitats, and almost never in habitats including riffles.

Colour and clarity showed no consistent pattern over the summer. Secchi depth was significant or nearly so in all three sampling periods. That it never entered any prediction models is likely due to its correlation with other better predictor variable(s).

Water temperature was not a good predictor of the presence or absence of N. photogenis YOY, nor was mean dissolved oxygen. Although subsites with and without YOY showed significantly or nearly significantly greater dissolved oxygen ranges in all three summer 1981 sampling periods, this variable did not enter any of the prediction equations.

pH, conductivity, and turbidity were not good predictors of the presence or absence of N. photogenis YOY.

Mean depth and depth range were significant in all summer 1981 sampling periods. Subsites with N. photogenis YOY were deeper, and had greater depth ranges, than those without YOY. Mean depth appeared to be the better predictor; it was included in both prediction models for sampling period 3, and for the combined summer data.

Mean current speed showed a similar pattern to that of mean depth. Young-of-the-year occurred in subsites with slower currents than subsites without them. Current range was unimportant. Mean current was significant or nearly so in all summer 1981 sampling periods, and was included in logistic regression prediction models for period 3 and the combined data. However, it was dropped from the combined data prediction model by logistic regression analysis when sampling variables were included.

Substrate was not related to the occurrence of N. photogenis YOY in summer 1981, nor was encrusting vegetation cover. Submersed vegetation approached significance in two of the three sampling periods, when subsites with N. photogenis had less vegetation cover than expected by chance. However, there were too many missing data to use either aquatic vegetation variable in multivariate analyses.

Shore vegetation approached significance in two of the three summer 1981 sampling periods, but was included in prediction equations

for period 3 and for the combined data. Subsites containing YOY had grassy or bushy, rather than forested, shorelines.

Stream width and distance from shore were not good predictors of the presence or absence of N. photogenis YOY.

Both "river" and day of the year were significant or approached significance in all summer 1981 sampling periods, but only "river" was included in the prediction equation for the combined data. Subsites with N. photogenis were concentrated in the upper Grand, Nith, and North and South Thames River study sites.

Among other sampling variables, only cloud cover showed a consistent pattern of importance over the summer sampling periods, but wind was selected by logistic regression analysis as a predictor variable for the combined data. Since the direction of differences between subsites with and without N. photogenis -- whether they were more or less cloudy or windy -- varied among sampling periods, the relationships between these weather variables and N. photogenis YOY presence were probably the result of chance, rather than different susceptibility to capture under different weather conditions.

Autumn 1981 results differed from those for the summer. Depth range appeared to be the best predictor of the presence or absence of YOY in both univariate and multivariate analyses. Subsites with YOY had a greater range than those without them. Encrusting plants, with N. photogenis YOY occurring in subsites with very little plant cover, also emerged as a good predictor. Duration of sampling was longer, and rain absent more often, at subsites with N. photogenis.

3.3 Notropis rubellus Adults

Results for Notropis rubellus adults are summarized in Table 3 and presented in Appendices III.1 to III.4. No statistical results

TABLE 3. Summary of univariate and multivariate analyses of habitat and sampling variables for presence and absence of Notropis rubellus adults

Sampling period	1	2	3	4	1-4	6	7	6-7
Total no. subsites	37	37	37	37	139	30	21	49
No. subsites with <u>N. rubellus</u> present	13	15	12	13	51	17	10	26
Sampling dates	15-28 July 1981	31 July -6 Aug. 1981	7-19 Aug. 1981	22-29 Aug. 1981		3-17 May 1982	2-10 June 1982	
Habitat variables								
habitat type							o	
colour	*x+			*x	x+	o		
clarity		o		o	x+	ox+		x
Secchi depth	*			(x)				-
mean temperature	o		o x+			o		
temperature range						x		
mean dissolved oxygen							**x+	
dissolved oxygen range				x				
pH	*(x)		**	**				-
conductivity	(x)		(x)			x+		x
turbidity		o	x+	ox		x		
mean depth		*	o x+	*x	x+		*	
depth range		x+	o		x+	o	*x+	x+
mean current		x+	x	x	x+	o	o	
current range	x+						x+	
substrate	o						**	
encrusting vegetation	x+	-	-	-	-	o-	-	
submersed vegetation	x	-	o -	*-	-	-	o-	-
shore vegetation				o			x+	
stream width			o	x				
distance from shore	*x+	ox+		ox	x+		o	
Sampling variables								
"river"	o	*	o	*				
day	-	*		o +				
time			o	** +				
duration						* +		+
distance hauled		*					o	
air temperature		(*)						
cloud cover				o		o		
wind				o		o		
precipitation		o	+					

univariate analysis:

multivariate analysis:

* $p < 0.05$

x included in logistic regression model (habitat variables)

** $p < 0.01$

+ included in logistic regression model (habitat and sampling variables)

o $0.05 < p < 0.15$

() included in model in additional runs

- not analysed (too few data)

for sampling period 5 are included, because N. rubellus adults were captured at only 2 of 29 subsites. Habitats at this season are discussed in section IV.3.5.

The proportions of subsites containing N. rubellus adults were relatively high, from 12 of 37 to 17 of 30 (Table 3). In sampling periods 4 and 7, logistic regression analyses made near-perfect predictions of N. rubellus presence and absence (Appendix III.4), and these were accompanied by very low coefficient to standard error ratios (less than 0.2) for the predictor variables (Appendix III.3). The other logistic regression analyses, however, produced fair to good predictions (Appendix III.4), coefficient to standard error ratios greater than 1.5 (with one exception), and few significant goodness of fit statistics (Appendix III.3).

Habitat type did not predict N. rubellus adult presence or absence (Table 3).

Water colour appeared to be important in summer 1981, but not in spring 1982. Notropis rubellus adults occurred primarily in green-brown or green water.

Water clarity did not emerge as an important predictor of the presence of N. rubellus adults in any individual sampling periods except 6, but was included in prediction equations for combined data for both summer 1981 and spring 1982. With the exception of one sampling period, adults were captured more often than expected in cloudy or muddy water. Secchi depth, however, showed no consistent pattern for summer 1981.

Neither mean water temperature nor temperature range were good predictors of N. rubellus adult presence. Although mean temperature approached significance in univariate analysis in several sampling periods, it was included by logistic regression analysis in only one

prediction model, and the data showed adults in subsites with higher temperatures in some sampling periods and lower temperatures in others.

The mean and range of dissolved oxygen were also unimportant. Although mean dissolved oxygen appeared to be important in sampling period 7, this did not extend to the whole spring 1982 season.

pH showed some importance in summer 1981, and conductivity in both summer 1981 and spring 1982. However, whether subsites with N. rubellus adults had higher or lower conductivity was inconsistent, so this variable was considered a poor predictor. Subsites with adults had lower pH values than those without them. Turbidity also showed some importance in summer 1981, but again opposing trends in the data make interpretation difficult. Turbidity was included by logistic regression analysis in prediction models in two sampling periods; in period 3, subsites containing N. rubellus had lower turbidity, but in period 4 (and all other sampling periods), they had higher turbidity than those without N. rubellus.

Mean depth, the range of depth, and mean current speed all emerged as good predictors of the presence or absence of N. rubellus adults in summer 1981 prediction models, although less consistently so in univariate analyses. Depth range was also a good predictor in spring 1982. Notropis rubellus adults occurred in subsites deeper, with greater depth ranges and (in summer 1981) faster currents than subsites without them.

Substrate type and shore vegetation were not good predictors of N. rubellus adult occurrence in either season. There were usually too few data to use aquatic vegetation variables in multivariate analyses, but both entered the prediction equation for sampling period 1. Subsites with N. rubellus adults usually had less than

5% cover by submersed vegetation at all times. In sampling period 1, most of these subsites had 26-50% encrusting vegetation cover, but percentages varied in other periods.

Stream width was unimportant, but distance from shore was important in predicting the occurrence of N. rubellus adults in summer 1981. These fishes occurred in subsites farther than average from shore.

Sampling variables had relatively little influence on results for N. rubellus adults. "River" was significant or approached significance for all summer 1981 sampling periods, but did not enter any logistic regression prediction models. Day of the year and time of sampling formed an entire prediction model for sampling period 4, but this is considered a chance occurrence because neither variable showed consistent importance over summer 1981. Duration of sampling was important in spring 1982, when sampling was longer in subsites with than without N. rubellus.

3.4 Notropis rubellus Young-of-the-Year

Table 4 and Appendices IV.1 to IV.4 show results for Notropis rubellus young-of-the-year (YOY).

The proportions of subsites containing N. rubellus YOY were relatively high for summer 1981 (12 to 14 of 35), but low for autumn 1981 (4 of 29, Table 4). With just one sampling period, autumn 1981 results are considered tentative. Logistic regression results for sampling period 5, with near-perfect predictions (Appendix IV.4) but high standard errors of the predictor variables (Appendix IV.3) confirm the tentative nature of the results. Logistic regression analyses for sampling period 3 showed similar problems, but the other analyses did not (Appendices IV.3 and IV.4).

TABLE 4. Summary of univariate and multivariate analyses of habitat and sampling variables for presence and absence of *Notropis rubellus* young-of-the-year

Sampling period	2	3	4	2-4	5
Total no. subsites	37	35	35	101	29
No. subsites with <i>N. rubellus</i> present	14	12	14	36	4
Sampling dates	31 July -6 Aug. 1981	7-19 Aug. 1981	22-29 Aug. 1981		14-18 Nov. 1981
Habitat variables					
habitat type	0	x			0x
colour	**x+	*	**x+	x+	0
clarity	*	*	**		
Secchi depth	*	**		x+	—
mean temperature		0 x	0 x+		0
temperature range		0			x
mean dissolved oxygen	*	**			—
dissolved oxygen range					—
pH	0	0 -	**		
conductivity		0	(x)		
turbidity	*	*	0		*x
mean depth	*	**			
depth range	**x+	**x+	*	x+	**x(x)
mean current		*			
current range		*			
substrate	**	0			—
encrusting vegetation	-	0 -	-	-	—
submersed vegetation	0 -	-	x -	-	(x)
shore vegetation				x+	
stream width		x			
distance from shore					x+
Sampling variables					
"river"	*	*	*		0 +
day	*	0	*		*
time				+	
duration		* +			** +
distance hauled		*	+		
air temperature		0	0 +		+
cloud cover			0 +		+
wind		+	0 +		** -
precipitation					

univariate analysis:

- * $p < 0.05$
- ** $p < 0.01$
- 0 $0.05 < p < 0.01$

multivariate analysis:

- x included in logistic regression model (habitat variables)
- + included in logistic regression model (habitat and sampling variables)
- () included in model in additional runs
- not analysed (too few data)

Habitat type was not a consistent predictor of the occurrence of N. rubellus YOY in summer 1981 (Table 4).

Water colour was one of the best predictors of N. rubellus YOY presence or absence in summer 1981, in both univariate and multivariate analyses. Young-of-the-year were captured most often in green water, and also relatively frequently in green-brown subsites.

Both water clarity and secchi depth appeared important in univariate analyses, but only Secchi depth entered the logistic regression prediction model for combined summer 1981 data. Notropis rubellus YOY occurred more often than expected in subsites with a measurable Secchi depth (i.e., cloudy water).

Mean water temperature showed some importance, but temperature range, mean dissolved oxygen, and dissolved oxygen range were not good predictors of presence or absence of N. rubellus YOY in summer 1981. The data for mean temperature were not consistent, however; subsites with YOY had higher temperatures than those without YOY in sampling periods 2 and 4, but lower temperatures in period 3.

Turbidity and pH were significant or nearly significant in all summer 1981 sampling periods. They were not included by logistic regression analysis in any prediction equations, likely because of correlations with better predictor variables. Conductivity was included in one prediction equation but was not a consistent predictor of N. rubellus YOY occurrence in summer 1981.

Depth range was one of the best predictors of the presence or absence of N. rubellus YOY in summer 1981. Subsites with YOY had greater ranges than those without. Mean depth, and the mean and range of current speed, were relatively poor predictors.

Substrate type was also a relatively poor predictor of the occurrence of YOY. There were too few data to use

aquatic vegetation variables in logistic regression analyses. However, submersed vegetation was significant or nearly so in all summer 1981 sampling periods. Notropis rubellus YOY were concentrated in subsites with less than 5% of the substrate covered by submersed plants. Neither the data nor univariate analysis results showed consistent patterns for encrusting plant cover.

Although shore vegetation was not important in any individual summer 1981 sampling periods, it was selected as a predictor variable by logistic regression analysis of the combined data. Young-of-the-year were captured more often than expected in subsites with at least partially forested shores..

Stream width and distance from shore were not good predictors of N. rubellus YOY occurrence in summer 1981.

Among sampling variables, "river" and day of the year showed the most consistent results for univariate analyses, but neither entered any logistic regression prediction equations for summer 1981.

Time and duration of sampling, air temperature, cloud cover, and wind all entered at least one summer 1981 prediction equation. However, the data for those variables entering the equations for more than one sampling period (air temperature and wind) or for the combined data (time) showed that the differences between subsite groups varied in direction among sampling periods. Thus these variables did not show consistent relationships to the presence or absence of YOY.

Based on both univariate and multivariate results, the best predictor variables of the presence or absence of N. rubellus YOY in autumn 1981 appeared to be habitat type, turbidity, and depth range. Young-of-the-year were captured only in pool habitats, and in subsites with lower turbidity and greater ranges in depth than

those without YOY. Water temperature range, submersed vegetation cover, and distance from shore were also included by logistic regression analysis in the initial equation, but only distance from shore was retained when sampling variables were also used in the analysis. Subsites with YOY were farther from shore than those without YOY.

"River", duration of sampling, and cloud cover were the sampling variables selected as predictors of N. rubellus YOY presence in autumn 1981 by logistic regression. The first two were also significant or nearly significant in univariate analyses. Notropis rubellus YOY were captured primarily in Thames River watershed study sites with relatively long sampling durations.

3.5 Habitat Use at Night and in Other Seasons

I made or attempted to make some observations of habitat use by N. photogenis and N. rubellus at night, and during the seasons not discussed in sections IV.3.1 to IV.3.4: autumn (for adults), winter, spring floods, and spawning. Spawning habitat is discussed in section III.

One set of samples was taken at study site N2 (Fig. 2) at night (21:00-23:30) on 24 August 1981. The five subsites at this site included all five habitat types. Three N. photogenis adults were captured in a flowing pool (N2C; Fig. 9), and five in a still pool (N2E). One N. rubellus adult was captured in a combined riffle/pool subsite (N2D), and eight were captured in N2E. All YOY of both species, 46 N. photogenis and six N. rubellus, were captured in N2E. In fact N2E contained most of the fishes captured, 371 fishes of 11 species, whereas only 43 individuals of nine species were captured in the other four subsites. There were small decreases in water

temperature and dissolved oxygen levels over the evening. There was very little difference in pH or conductivity among subsites, but turbidity varied from 11 (at N2E) to 19 JTU. Mean depths varied from 17.5 to 40.5 cm; those at subsites with N. photogenis or N. rubellus were 40.5 cm (N2C), 29.5 cm (N2D), and 24.5 cm (N2E).

In the autumn 1981 sampling period, N. photogenis adults were captured at only two subsites: the still pool at study site N2 (N2E) and a current edge subsite at study site T1 (T1A; Fig. 3 and 12). Notropis rubellus adults were also captured at two subsites, T1A and a current edge subsite at study site ST1 (ST1A; Fig. 3 and 11). Subsites with N. photogenis adults differed from those without them in several ways: mean water temperature was higher (6.5°C with N. photogenis, 5.8°C without), turbidity was lower (12 , 16 JTU), mean depth was less (38 , 43 cm) but depth range greater (50 , 42 cm), mean current speed slower (0.24 , 0.48 m/s) but current range greater (0.48 , 0.31 m/s), encrusting plant cover was less (less than 5%, most other subsites had more than 50%), and stream width was greater (56 , 43 m). Subsites with N. rubellus adults differed from those without them in several ways, many of them similar to differences for N. photogenis: mean temperature was higher with N. rubellus (7.2 , 5.8°C), turbidity was lower (10 , 17 JTU), mean depth differed little but depth range was greater (64 , 41 cm), mean current speed was slower (0.40 , 0.47 m/s) but current range greater (0.80 , 0.29 m/s), stream width was greater (54 , 43 m), and distance from shore was less (4.0 , 6.2 m).

As in the single night sample, all fishes captured in autumn 1981 tended to be concentrated in a few subsites. In total, 297 fishes were captured in the three subsites with N. photogenis or N. rubellus adults. Two other subsites, a current edge at study site

C03 (C03A; Fig. 2 and 8) and a still pool at ST1 (ST1D; Fig. 3 and 11) contained over 550 fishes, most of them YOY. Only 78 fishes were captured at the remaining 24 subsites sampled.

In December 1981 and February 1982 I set gill nets adjacent to or under the ice in pools at study sites NT2, N2, and C03. No fish was captured.

Maximum flows during spring floods usually occur in March and April in the Grand and Thames River watersheds (Chapman and Putnam 1966), although they may begin earlier as in 1981. Flooding can also occur in autumn. Fluctuations are great; unpublished data from the Grand River Conservation Authority for 1981 showed an approximate 50-fold difference between the maximum daily flow of the Grand River at Doon (site G17, Fig. 2) of $337 \text{ m}^3/\text{s}$ (February 1981) and minimum of $6.66 \text{ m}^3/\text{s}$ (March 1981). Differences can be even greater on unregulated rivers. On the Nith River near study site N2 there was a 194-fold difference between the maximum daily flow of $165 \text{ m}^3/\text{s}$ (February 1981) and the minimum of $0.85 \text{ m}^3/\text{s}$ (August 1981).

I used minnow traps, a small seine, and a gill net (described in section II.2) to capture fishes along flooded margins of the rivers at survey sites G6, G17, and C02 (Fig. 2) in February 1981, and at N2 and C03 in late March and early April 1982. Two N. photogenis and three N. rubellus specimens were captured in 1981, with 115 specimens of 14 other species. In 1982 no N. photogenis or N. rubellus and only six other fishes were captured.

Evidence of the use of margins of flooded rivers was provided by the capture of 7 N. photogenis, 45 N. rubellus, and 262 fishes of 10 other species in a floodplain pond at study site N2 on 5 May 1982. The pond could have been connected to the Nith River only at high flood levels, such as those observed in late March 1982, and appeared

to be receding when sampled. The Wilfrid Laurier University collection also contains N. photogenis specimens captured on 17 May 1981 in a flood-plain pond at Bridgeport (near survey site G14, Fig. 2). This pond exists all year, but is connected to the Grand River only during spring floods (E. Kott, pers. comm.).

4. DISCUSSION

4.1 Habitat Use by Notropis photogenis

The most important habitat variable for predicting the presence or absence of Notropis photogenis adults appeared to be depth (both mean and range). Data analyses also suggested that substrate and stream width had some predictive value in spring and summer. Mean temperature, dissolved oxygen, current, and distance from shore in spring, and habitat type and shore vegetation in summer, appeared to have some importance.

For N. photogenis young-of-the-year (YOY), the best indicator of summer habitat use was habitat type. Because habitat type itself can be regarded as representing several other variables, such as depth, current, and substrate, I repeated logistic regression analyses for the summer sampling periods with habitat type excluded. The other variables selected as predictors differed little from those selected when habitat type was used; no additional variables were selected consistently by the program. The other good predictors of presence or absence of N. photogenis YOY were mean depth, and to a lesser extent depth range, mean current, and shore vegetation. Secchi depth and dissolved oxygen range appeared to have some importance in univariate analyses. In autumn, depth range appeared to be the best predictor, with encrusting plants also useful.

"River" was important for adults in spring and YOY in summer, and possibly for adults in summer. This variable was used in

analysis because I suspected that other factors, such as physiographic ones, and some of the variables I measured, such as colour, pH, conductivity, or other aspects of water chemistry, tended to vary and therefore to influence fishes on a broader geographic scale than I used. The inclusion of "river" in some prediction models suggested that some larger-scale influences were present. However, they did not seem to obscure small-scale patterns, in that the inclusion of "river" by logistic regression analysis in prediction models resulted in few other variables being dropped (Tables 1 and 2).

Other sampling variables did not consistently influence results for adult or YOY N. photogenis. Air temperature was likely a predictor of adult occurrence at times because of its influence on water temperature. I found in the field that for any one river or stretch of river, water temperature changes followed air temperature changes quite closely in time. The relationship between precipitation and YOY occurrence in autumn was probably due to chance, rather than an effect of precipitation on fish activity and therefore susceptibility to capture, as this variable was not important at other times. The longer sampling durations in autumn when N. photogenis was captured were the result of the concentration of all fishes into a few subsites at this season (section IV.3.5).

Some similarities and differences between age groups, and between seasons, are suggested by the data analysis results for N. photogenis. Water depth emerged as the single most important predictor for all seasons and both age groups. Habitat type was the most important predictor for YOY in summer, and also showed some importance for adults at this time. It is not surprising that a mid-water, largely surface-feeding (section IV.1) fish should select deeper pools over shallower riffles. The importance of depth range,

as well as mean depth, may be related to the use of pool habitats bordering on riffles. Riffles generally contain more benthic invertebrates (both species and biomass) than pools (Hynes 1970); thus by inhabiting pools near riffles a fish could take advantage of the food drifting from the riffle while avoiding its turbulence and current. Mendelson (1975), however, in a study of four coexisting species of Notropis in a Wisconsin stream, found that spatial preferences appeared to largely determine diet, rather than vice versa. Greater depths may also provide some cover from predators, but there are virtually no data on predation on N. photogenis.

Current velocity was a predictor of summer YOY and spring adult, but not summer adult, occurrence. The YOY were likely simply less able to cope with fast currents than adults because of their smaller size. In spring, a large part of the adult population consists of the previous year's YOY (section II.3.1); these fishes too may still be small enough to have to avoid strong currents.

Shore vegetation was a predictor of the presence or absence of N. photogenis YOY, and to some extent of adults, in summer. Shore vegetation can affect habitat available to fishes by influencing water temperature through shading, by preventing erosion and providing cover through the stabilization of stream banks, by preventing sediment from reaching the water, and by affecting the food supply both directly and indirectly through shading and providing organic detritus and insects (Meehan et al. 1977). The grassy or bushy shores usually associated with N. photogenis occurrence would provide minimum shade and thus increased water temperatures. Adults showed some tendency to occur in subsites warmer than subsites without them, but YOY did not. In sampling

periods 2 to 4, mean water temperatures differed very little (maximum 0.7°C) between subsites with adults and those with YOY, and neither age group consistently occurred in higher temperatures than the other. Adults did occur in warmer subsites than those without them in spring. Water temperatures were rising rapidly during this time, especially in sampling period 6. That a species at or near the northern limit of its range should occur in warmer areas is not surprising.

These results differ in several ways from existing descriptions of N. photogenis habitat (section IV.1). Gruchy et al. (1973) found that N. photogenis occurred in deep riffles or flowing pools with moderate to fast currents, and Trautman (1981) found them most abundant in deep swift riffles and the faster currents of pools below the riffles. My results confirm the species' occurrence in deeper water, also noted by Parker and McKee (1980). However, I did not find it in faster currents; when current speed was a predictor of presence or absence, N. photogenis occurred in slower currents. Nor did I capture N. photogenis in riffles, with very few exceptions, and habitat type was a good predictor of their occurrence because of this near-exclusive use of pools.

Substrates described in the literature were all hard, with particles varying from gravel to boulders, although Parker and McKee (1980) considered substrate unimportant. I found that substrate appeared to have some importance for adults because they occurred more often than expected over soft or small-particle substrates (sand, mud, and clay). The few data I had for submersed vegetation tended to show both adults and YOY occurring in subsites with little or none, confirming Trautman's (1981) observation that N. photogenis avoided rooted aquatic vegetation.

Trautman (1981) found N. photogenis in moderate to large streams, and the capture locations of Gruchy et al. (1973) and Parker and McKee (1980) tended to be wide. My distribution data confirmed that N. photogenis occurs in the larger rivers within its Ontario range (section II.3). However, within those rivers, stream width was a predictor of occurrence only for adults, and then operated in opposite directions in spring and summer.

The preference for clear water and apparent sensitivity to turbidity noted by Trautman (1981) were not found here. Of the variables related to clarity, clarity itself, Secchi depth, and turbidity, only secchi depth had some predictive value, for N. photogenis YOY in summer. As discussed below for N. rubellus, turbidity levels encountered during my study may not have been high enough to show sensitivity by N. photogenis.

4.2 Habitat Use by Notropis rubellus

For Notropis rubellus adults in summer, colour, mean depth, mean current, and distance from shore were the best predictors of presence or absence. Clarity and depth range were also good predictors, and pH possibly had some predictive value. In spring, only clarity and depth range seemed to be consistent predictors among the habitat variables. Results varied considerably between sampling periods 6 and 7. Sampling period 7 overlapped part of the spawning period of N. rubellus (section III.4.2), and sampling period 6 overlapped or just preceded spawning. Changes in habitat use for spawning may help to explain why conclusions for spring 1982 were not clear.

Colour and depth range were the most important variables in predicting the occurrence of N. rubellus YOY in summer. Secchi depth and shore vegetation also had some predictive value. Clarity, pH, and

turbidity appeared to be important in univariate analyses. Autumn data were few, but habitat type, turbidity and depth range appeared to be the best predictors. Temperature range, submersed vegetation, and distance from shore had less importance.

"River" appeared to have some importance to adults in summer, and to YOY in summer and autumn. As discussed for N. photogenis, this could indicate the influence of factors operating at a larger geographic scale. However, because "river" was never included by logistic regression analyses in prediction models, these factors do not appear to have obscured localized patterns. Sampling duration was the only other important sampling variable for N. rubellus, for adults in spring and YOY in autumn. As for N. photogenis, this result for YOY was caused by the concentration of all fishes into a few subsites. This concentration was also observed to a lesser extent in sampling period 6, accounting for the longer durations when adults were captured. Other sampling variables apparently did not affect captures of N. rubellus.

There were no pronounced differences in N. rubellus habitat use between age groups, or between seasons for adults. The greatest differences existed between YOY habitat use in summer and autumn, but because of the small autumn sample size, these differences may not be meaningful. The lack of greater differences between adults and YOY is somewhat surprising in the light of Reed's (1957b) finding of considerable differences in the proportions of diet components between the two age groups. Differences in mouth size and swimming speed between adults and YOY may account for differences in diet, even when they feed in the same habitat.

Depth range was the best overall predictor of N. rubellus occurrence, for both age groups in each season analysed. Clarity

or Secchi depth were also common to both age groups. Only for YOY in autumn was neither variable a predictor, but the related variable, turbidity, was. However, in spring and summer, N. rubellus were usually captured more often than expected in cloudy water, while in autumn, YOY occurred in subsites with lower turbidity.

Mean current and distance from shore were important for adults during summer, whereas shore vegetation was important to YOY. Adults were present in relatively fast currents. Young-of-the-year, and adults in spring, were present in subsites with slower than average currents, as expected for smaller fishes, but the differences were not great enough to be significant.

Water temperature was not a good predictor of habitat use by adults or YOY, nor was either age group found in warmer subsites than the other (maximum difference 0.3°C for sampling periods 2 to 4).

These results for N. rubellus differ from the published descriptions of its habitat (section IV.1). Reed (1957b) found N. rubellus in riffles. Although I never captured adults in still pools in summer, they were captured in all other habitat types; adults in spring and YOY in summer were captured in all habitat types; and habitat type was not a predictor for any of these groups. Only for YOY in autumn was habitat type a predictor, when the species did not occur in riffles at all. However, my finding that current speed was important to adults does agree with Miller's (1964) observations of N. rubellus in riffles and other faster areas.

Trautman's (1981) finding of N. rubellus in moderate-sized streams was neither confirmed nor rejected by this study. Stream width was not a good predictor of N. rubellus presence or absence, but distance from shore was important for adults in summer (they occurred farther from shore than average) and YOY in autumn (they

were closer to shore). Both Trautman (1981) and Scott and Crossman (1973) described substrates over which N. rubellus occurred, but substrate was not important in this study.

The intolerance to turbidity also reported by Trautman and Scott and Crossman was not found. Possibly the levels of turbidity were not high enough in my study sites to approach the species' tolerance levels.

4.3 Comparisons of Habitat Use by Notropis photogenis, Notropis rubellus, and Other Stream Fishes

Water depth was one of the most important predictors of habitat use for both N. photogenis and N. rubellus. Mean depth and depth range were predictors for adults of both species in summer, but in general depth range appeared to be more important for N. rubellus and mean depth for N. photogenis. This suggests more use by N. rubellus of habitats including both shallow and deep areas, such as edges of the river or edges between riffles and pools. Although subsites with adults or YOY of either species always had greater depths and depth ranges than subsites without them, there were some differences between species in the actual depths used. With the exception of one and two sampling periods, respectively, mean depths (38-58 cm) and depth ranges (36-61 cm) of subsites with adult N. photogenis were greater than those with adult N. rubellus (40-45 cm; 38-46 cm). For YOY, mean depths were greater in subsites with N. photogenis (45-54 cm) than with N. rubellus (40-54 cm) in three of four sampling periods, but depth ranges were greater with N. rubellus (52-76 cm) than with N. photogenis (45-71 cm) in three of four sampling periods.

Beyond the similarity in the importance of depths, habitat use

by the two species was different. Their relationships with current speed were opposite. Whereas N. photogenis adults in spring and YOY in summer occurred in areas of relatively slow current, current speed was a good predictor of habitat use by N. rubellus only for adults in summer using relatively fast currents. Notropis photogenis clearly used pool rather than riffle habitat types, especially the YOY. This was not the case for N. rubellus, with the exception of YOY in autumn. Notropis photogenis adults occurred more frequently than expected over fine-grained substrates, but no use of particular substrates was found for N. rubellus. These three variables, habitat type, current, and substrate type, are related to each other (as well as to depth). Pool habitats have slower currents and finer-grained substrates, so the findings that N. photogenis tended to occur in pool habitats, slower currents, and over fine-grained substrates were not surprising. Which variable "caused" the responses by the fishes was not clear, although the strength of habitat type as a predictor for YOY suggested that it was particularly important to them. In reality, the fishes may respond to a combination of the variables. Notropis rubellus, especially adults, occurred in riffles as well as pools, providing the faster currents used by adults, and a wider variety of substrate types that would preclude a relationship to just fine- or coarse-grained particles.

Shore vegetation was a predictor of habitat use for YOY of both species and of slight importance to N. photogenis adults. However, N. photogenis tended to occur in areas with grassy or bushy shorelines, whereas N. rubellus tended to be found with shorelines including bushy or forested areas. It was suggested above (section IV.4.1) that the occurrence of N. photogenis in subsites with low vegetation may be related to a tendency of adults to occur in higher

temperatures. However, temperature was not a good predictor of habitat use by YOY of either species, so that their different relationships to shoreline vegetation type may be related to some other aspect of the vegetation, such as terrestrial arthropod food provided, rather than shading.

Both adult and YOY N. rubellus were concentrated in green and green-brown water in summer, but N. photogenis showed no patterns related to water colour. Again with the exception of YOY in autumn, N. rubellus tended to be found in cloudy water; only the YOY of N. photogenis showed a similar but weaker tendency in summer. These differences in colour and clarity may be related to distribution patterns of the species during the study. Both species tended to be concentrated at the Nith River (N2) and Thames River watershed (NT2, ST1, T1) study sites, especially NT2. The Thames and Nith Rivers characteristically had green or green-brown, cloudy water. Notropis photogenis, however, was also captured frequently at the upper Grand River study site (G9). This section of the river was usually clear and brown.

Results for sampling periods 6 and 7 for N. photogenis and especially N. rubellus adults tended to be inconsistent, making general patterns of spring habitat use difficult to interpret. These inconsistencies were probably at least partially the result of the overlapping of the spring sampling and spawning periods (section III.4.2); the longer spawning period of N. rubellus may be related to its greater differences in habitat use between sampling periods. In addition, fishes showed some tendency to be concentrated in some sites or subsites in sampling period 6. Though much less pronounced than the concentrations of November 1981 (sampling period 5), they suggested that the fishes may still have been in the process of

2

moving from winter habitats.

Habitat use patterns of N. photogenis and N. rubellus agree with the conclusions of Hynes (1970) and Moyle and Cech (1982) that physical factors are more important to stream fishes than chemical factors (section IV.2.3). Colour was the only chemical variable clearly related to habitat use by either species; pH may have had some importance, but the data were inadequate to draw conclusions. The physical variables considered most important by Hynes and Moyle and Cech, and included in this study, were temperature and current speed (section IV.2.3). Temperature was found to be of some importance only to N. photogenis adults in spring, and of minor importance to them in summer and to N. rubellus YOY in autumn. However, temperature probably influences these species on a much broader geographic scale than that studied here, acting more to limit their ranges rather than to influence their habitat use within those ranges. As discussed above, current speed was important to habitat use by both species, although in different ways.

Hynes (1970) also listed another physical variable of major importance -- availability of suitable shelter (section IV.2.3) -- which I studied only indirectly. What constitutes shelter or cover for fishes varies among species and its definition requires detailed knowledge of a species' behaviour and ecology. For example, Binns and Eiserman (1979) took from the literature the following criteria for cover for trout in the Rocky Mountains: deep water, surface turbulence, loose substrate, large rocks and other submersed objects, undercut banks, aquatic vegetation, overhanging terrestrial vegetation, snags or debris, etc.; and still needed subjective judgement to measure cover. Several of the variables that I measured could thus provide cover. Substrate was important only for N. photogenis adults, but

they did not tend to use bouldery substrates. Data were few, but both species tended to occur in areas with few submersed plants. The use by both species of deep water, however, may have provided them with some cover.

The results of other quantitative habitat studies of cyprinids, or including cyprinids, that have used a small scale similar to mine offer more direct comparisons. Most such studies have been concerned with community-level analyses or resource partitioning between at least two species, rather than individual species. These studies still offer information as to important habitat variables, although they tend to emphasize only variables that separate species rather than all those that describe habitat use by any one species. Gorman and Karr (1978) found that fish species diversity in Indiana streams was significantly correlated with habitat diversity, as measured by depth, current, and substrate. Fish species diversity was related to depth and current diversity alone as well as in combinations with the other habitat variables, but to substrate diversity only in combinations with the others. Baker and Ross (1981) studied eight species of cyprinids in a Mississippi stream, using multiple discriminant analysis to identify habitat variables most important in spatial separation of the species at a microhabitat level. They measured current, mean and maximum depth, substrate, litter, aquatic vegetation, other cover, and water column position, and found that water column (or vertical) position and aquatic vegetation were the most important factors separating species. Mendelson (1975) studied spatial relationships of four species of Notropis in pools of a Wisconsin stream along vertical and longitudinal axes. Both axes, the second apparently reflecting primarily depth changes, separated species. Of the habitat variables they measured, habitat type (pool,

channel, or riffle), vertical water column position, and current speed, Surat et al. (1982) found that only vertical position provided any ecological separation among three species of Notropis in the Roanoke River, Virginia. Gee and Northcote (1963) found that current speed separated two species of dace (Rhinichthys) in British Columbia. While recently emerged dace occupied slow current areas, older fish of one species showed definite preferences for faster currents. Adults of the two species were also captured in different depths, but current was apparently more important in differentiating their habitats.

Matthews and Hill (1979a) studied the effects of temperature, dissolved oxygen, pH, total dissolved solids, and turbidity on habitat selection by Notropis lutrensis (red shiner) in the laboratory and the field in Oklahoma, as well as the effects of current speed, water depth, shelter, shade, and substrate in the field. Temperature, current speed, and depth were most important in influencing habitat selection; when varying, total dissolved solids and pH could be important; dissolved oxygen, turbidity, shelter, shade, and substrate appeared less important. No differences between adults and juveniles were found in mid-winter (December - January), but in some or all of four other study periods throughout the year adults and juveniles differed in their distributions over every habitat factor except current speed (Matthews and Hill 1979b).

These studies confirm the importance of physical factors at a microhabitat level, as well as at a wider scale. Current speed and depth appear particularly important to habitat use by cyprinids, although they do not consistently separate species. Notropis photogenis and N. rubellus thus fit this pattern quite well, although depth was the more important variable to both species. In other

studies, substrate was not consistent in its importance, and aquatic vegetation and vertical position could be important. Because I used a seine to capture fishes, I was unable to measure vertical position. However, observations suggested that there might be minor differences between N. photogenis and N. rubellus, with N. photogenis usually seen slightly closer to the surface (section IV.1). The importance of habitat type to N. photogenis differed from the findings of Surat et al. (1982). The importance of temperature, total dissolved solids, and pH found by Matthews and Hill (1979a) may have been due to the rigorous and highly variable environment of the Oklahoma river in which they worked. Although I found clarity, Secchi depth, or turbidity to be important to N. rubellus, Matthews and Hill found that turbidity was unimportant to N. lutrensis. However, they stated that N. lutrensis has wide physico-chemical tolerances. The other variables that I found to be important in predicting habitat use by N. photogenis or N. rubellus, colour, shore vegetation, and distance from shore, were not included in these studies. Stream width was considered at the macrohabitat level only by Baker and Ross (1981).

4.4 Diel and Seasonal Changes in Habitat Use

Diel rhythms do exist in stream fishes, and many species are more active at night or twilight than during the day (Hynes 1970). However, more fishes are active by day than at night (Helfman 1978). Helfman stated that timing of activity is generally a family characteristic, and classified Cyprinidae among those in which most species studied are diurnal. My daytime observations of N. photogenis and N. rubellus indicated that they were active then. The night sample results suggested that they moved to different habitats at night, with slower or no current, but did not demonstrate inactivity.

Emery (1978) found that most species of Cyprinidae, Centrarchidae (sunfishes), Percidae (perches), and Salmonidae (salmon and trout) dominating shallow water (0-4 m) in small boreal Canadian lakes rested on the bottom or in the cover of plants at night in summer. Gee and Northcote (1963) found movements to areas of different depth in the Fraser River at night in juvenile Rhinichthys falcatus (leopard dace) and R. cataractae (longnose dace), and adult R. falcatus, but not in adult R. cataractae. In his study of four Notropis species in pools, Mendelson (1975) reset traps at dawn and dusk. He found that two species were captured more frequently at night, and one more frequently during the day, but that all species tended to be captured in shallow water or near the surface at night. However, he also found in aquarium observations that all four species rested on the bottom at night, and suggested that night captures may have represented crepuscular rather than night activity.

My observations of the presence of N. photogenis and N. rubellus in different night habitats on one occasion thus appear typical of many stream fishes. It seems likely that they are inactive at night, and that the use of habitats with little or no current would permit resting.

The concentrations of all fishes in relatively few subsites in November 1981 may have indicated a movement to overwintering areas. Many stream fishes move into deeper water for the winter (Hynes 1970). Hynes suggested that this is probably a general behaviour pattern related to reduced activity in cold water.

Costanzo and Driver (1971) reported that N. photogenis was known to aggregate at the mouths of several small tributaries in spring and autumn, but was present in the deeper water of their Ohio study

stream in late summer and winter. Notropis rubellus overwintered in the deeper riffles and pools of the larger streams in Ohio (Trautman 1981). In New York, Miller (1964) found a decrease in fish activity and movement out of fast water as temperatures dropped in November. During winter, fishes congregated in deeper pools, backwaters, or other areas sheltered from the current. Some larger individuals overwintered in larger rivers, especially in severe winters. Among the seven cyprinid species studied, N. rubellus appeared to show the greatest tendency to move downstream and thus the largest spring upstream migration.

There are many other reports of autumn movements of cyprinids, and of captures in pools in autumn and winter. Mendelson (1975) observed upstream migrations in autumn and spring into his study creek from the nearby Wisconsin River by the four Notropis species he studied; the numbers remaining through the winter were variable. Noble (1965) found Rhinichthys atratulus (blacknose dace) apparently moving from his study streams into the Des Moines River for the winter, while others overwintered in large pools in the streams. Starrett (1951) captured large numbers of minnows in pools in the Des Moines River, Iowa, from mid-October through November. Three species of Notropis studied by Surat et al. (1982) showed marked changes in habitat use in winter (February and March) in the Roanoke River, being absent from localities where they were previously common and captured only in a few deep pools. Semotilus atromaculatus (creek chub) of all sizes were captured only in slow deep channels, deep pools, and sheltered deep pools (as opposed to fast or slow shallow channels, or shallow or moderately deep pools) in October by Moshenko and Gee (1973). In an unusual report of under-ice capture, Moshenko and Gee captured Semotilus only in sheltered deep

pools in December.

Thus it seems likely that N. photogenis and N. rubellus use different habitats in winter in Ontario from those used at other times of year; these habitats are probably deep pools. These species, and most others, were captured in pool habitats in November 1981. Depth and the absence of current are emphasized by most authors in winter habitat descriptions, but results of my November sampling show that other factors may also be important to the fishes. Given the prevalence of movements by cyprinids during autumn, however, these November habitats may not have been final overwintering areas.

Levels of activity during winter may be very low. All N. rubellus captured by Reed (1957b) in November, February, and March in Pennsylvania had empty stomachs. Under the ice in Ontario lakes, Emery (1978) found cyprinids remaining in relatively shallow water (1-5 m) but in the substrate: in crevices in rocks and logs, in mats of twigs, or as much as 0.5 m below the surface of gravel substrates. Similar behaviour in rivers could explain the absence of fishes in my gill nets set under ice. However, in New York streams, Miller (1964) found that although many species moved under stones, leaves, or other debris in winter, N. rubellus did not do so in any numbers.

Captures of N. photogenis and N. rubellus in floodplain ponds suggest that they also use different habitats during periodic spring flooding. Starrett (1951) found that minnows and other fishes used the shallow temporary backwaters created by May and June floods on the Des Moines River, and that large numbers of minnows could be fatally isolated by the receding waters. By using traps as well as seining, Ross and Baker (1983) were able to capture fishes on the floodplain and in the channel of a Mississippi stream during floods.

They found that some species, including all cyprinids captured during flooding, tended to use the floodplain ("flood-exploitative species"), while others remained in the channel. Notropis photogenis and N. rubellus would appear to fit into Ross's and Baker's flood-exploitative category. They suggested that this behaviour may benefit fishes: by using the seasonally abundant resources of the floodplain before spawning, energy for reproduction and therefore population sizes may be increased. These benefits are obviously gained at the risk of entrapment in pools. Starrett (1951), however, suggested that high population densities may lead to unsuccessful spawning by limiting available space, and that floods were thus beneficial because they "thinned" populations.

V ASSOCIATIONS OF NOTROPIS PHOTOGENIS WITH OTHER FISH SPECIES

1. INTRODUCTION

The question addressed in this section is: what is the nature of associations of Notropis photogenis with sympatric fish species on a microhabitat scale? As discussed in section I, the environmental variables analysed in the study of habitat use by N. photogenis (and N. rubellus; section IV) can be considered to make up only one category of factors among several influencing the small-scale distribution of the species. The presence or absence of other fish species may also be important.

Hubert (1969:5-6) defined association as "the tendency of species to occur together more (or less) often than is to be expected on the basis of chance". Associations between species are usually interpreted as the result of interactions between species, either direct or through modifications of the environment; or the result of the two species having identical or overlapping tolerances for some independent environmental factors (Pielou 1977). Interpretations of associations of N. photogenis will therefore be made not only in terms of the influence of other fish species, but also (and in fact primarily) in terms of similarities or differences in habitat use. Associations between N. photogenis and N. rubellus are thus of particular interest in light of the studies of their habitat use (section IV).

2. METHODS

Data collected during habitat-use studies were used to determine associations. Study sites and subsites, fish-sampling methods, and sampling dates were described in sections IV.2.1 and IV.2.2.

In addition to N. photogenis, 36 species of fishes were captured during habitat-use studies. However, many were captured infrequently. If both species in a pair being analysed are rare (absent from most samples), as may occur if many samples from habitats outside the environmental ranges of both species are included in analysis, an inflated level of positive association may be found (Southwood 1978). Pielou (1977), however, pointed out that such a positive association may provide valuable information on the tolerance ranges of the two species, in that neither tolerated the environmental conditions of most samples. I therefore attempted to compromise in selecting species for analysis, excluding only those that appeared to be so rare in my samples as to offer no information on associations with N. photogenis. Because many species varied considerably in their frequency of capture between the Grand and Thames River watersheds, some occurring in only one watershed, I selected species separately for each watershed. To be included in analysis, a species had to be captured in at least 10% of all sub-sites sampled in a watershed over the seven sampling periods.

There were sufficient data to include the following six species for both watersheds: Nocomis spp. (chubs), Notropis cornutus group (common shiner), N. photogenis, N. rubellus, Pimephales notatus (bluntnose minnow), and Micropterus dolomieu (smallmouth bass). Thames River watershed data only were analysed for five species: Dorosoma cepedianum (gizzard shad), Notropis spilopterus (spotfin shiner), N. volucellus (mimic shiner), Ambloplites rupestris (rock bass), and Etheostoma blennioides (greenside darter). Data from the Grand River watershed only were analysed for six species: Rhinichthys cataractae (longnose dace), Semotilus atromaculatus (creek chub), Catostomus commersoni (white sucker), Hypentelium nigricans (northern

hog sucker), Etheostoma caeruleum (rainbow darter), and E. nigrum (johnny darter).

Adults and young-of-the-year (YOY) were analysed separately for Notropis photogenis and N. rubellus. Although adults and YOY of other species were often separated in the field, these designations were not confirmed by the type of length frequency analysis done for N. photogenis and N. rubellus (section III), so age groups were combined. However, the seine net tended to select smaller fishes. As their maximum total length (TL) was 11.7 cm, based on comparisons with lengths given by Scott and Crossman (1973) all Micropterus captured were YOY. All Dorosoma (maximum TL approximately 5 cm) were also YOY. Most individuals of the larger-growing suckers, Catostomus and Hypentelium, were small (less than 10 cm TL); maximum TLs were 19.5 and 23.0 cm, respectively. Total lengths of Ambloplites, the only other relatively large fishes included in analysis, were 3.7-17.2 cm.

Two of the "species" listed above are actually pairs of species. I was not able to distinguish Nocomis micropogon (river chub) from N. biguttatus (hornyhead chub) in the field, so these fishes were recorded as Nocomis spp. There is current uncertainty as to whether Notropis cornutus (common shiner) and N. chrysocephalus (striped shiner) are species or subspecies. Gilbert (1961) presented evidence for considering them separate species; Buth (1979:77) concluded that they were "probably best described as semispecies" pending further studies. Many specimens that I captured had definite characteristics of one "species" or the other, but some were intermediate. I therefore combined them as N. cornutus group for analysis.

Fishes were counted in the field, but only their presence or absence in each subsite was analysed. Reasons for analysing presence

or absence of Notropis photogenis and N. rubellus were discussed in section IV.2.2. In addition, Hurlbert (1969) showed the advantages of presence-absence data for the calculation of coefficients of association: two competing species that are positively associated in space because of similar habitat preferences, and therefore have a positive coefficient of association based on presence-absence data, would have a negative coefficient based on abundance data because of their negative effects on each others' populations. Measures using abundance data are also affected by the species frequencies (although this is a problem for some coefficients based on presence-absence data) and by the amount of within-quadrat environmental heterogeneity (Hurlbert 1969).

Data for each of the seven sampling periods, four in summer 1981, one in November 1981, and two in spring 1982, were analysed separately. The numbers of subsites for which fish data were available differed among sampling periods, because not all subsites could be sampled in the last three periods (section IV.2.1), and among fish species, depending on the watershed of analysis. Of the total 37 subsites, 23 were in the Grand River watershed and 14 in the Thames River watershed. Numbers of subsites used in analysis of each species in each sampling period are included in Appendices V.1 and V.2.

Statistical analysis of associations was done in three steps. Initially, whether an association was positive or negative was determined by inspection of the 2x2 contingency table of presence and absence of adult or YOY N. photogenis tabulated with presence and absence of each other fish species. A χ^2 -test (described in section IV.2.4) was carried out on each contingency table using a BMDP computer program (Dixon et al. 1981) to determine whether or not the occurrences of the two species were independent.

When the χ^2 -statistic was statistically significant ($p < 0.05$), a coefficient of association was calculated. However, because I was interested in looking for trends in results among sampling periods, and not simply in the statistical significance of associations in single sampling periods, I also calculated coefficients when p-values of χ^2 -statistics were between 0.05 and 0.15. I used Hurlbert's (1969) coefficient of interspecific association, C8. This coefficient provides a quantitative measure of the degree of association, ranges from -1 (maximum negative association) to +1 (maximum positive association), and is independent of sample size and the species' frequencies (Hurlbert 1969). A value of +1 indicates complete association as defined by Pielou (1977) (one species is never found in the absence of the other) not absolute association (neither species occurs without the other).

3. RESULTS

Tables 5 and 6 summarize results for N. photogenis adults and YOY, respectively. The coefficient of association and its significance, as measured by a χ^2 -test, are presented for each N. photogenis - other species pair when the χ^2 -statistic had a p-value of less than 0.15. When the p-value was greater than 0.15 only the direction of association, positive or negative, is shown. Exact p-values are presented in Appendices V.1 and V.2.

No results are presented for some species pairs in Tables 5 and 6. In a few cases, no data were collected, e.g., no YOY (as I defined them; section III.3.1) of N. photogenis or N. rubellus could be captured in spring 1982. In most cases, however, there were too few data to present results: when the minimum expected value in a contingency table, calculated for a χ^2 -test, was less than 0.5, I considered the data too few to provide reliable information even on the direction of association. Lack of data was a problem for results

TABLE 5. Coefficients of association ^a ($p < 0.15$) and directions of association ^b ($p > 0.15$) of Notropis photogenis adults with other fish species

Species	Watershed analysed	Sampling period					
		1 15-28 July 1981	2 31 July -6 Aug. 1981	3 7-19 Aug. 1981	4 22-29 Aug. 1981	6 3-17 May 1982	7 2-10 June 1982
<u>Dorosoma cepedianum</u>	Thames		+				
<u>Nocomis</u> spp.	both	-0.67	-1.00	-1.00	-1.00	-	-
<u>Notropis cornutus</u> group	both	-	-	-0.28	-	0.61	1.00
<u>N. photogenis</u> YOY	both		0.68	+	+		
<u>N. rubellus</u> adults	both	0.42	1.00**	0.70*	+	0.56*	1.00**
<u>N. rubellus</u> YOY	both		0.43	+	0.61		
<u>N. spilopterus</u>	Thames	-	-1.00		+		
<u>N. volucellus</u>	Thames		+			+	
<u>Pimephales notatus</u>	both	-1.00	-	-	-	0.64**	o
<u>Rhinichthys cataractae</u>	Grand	-		-			
<u>Semotilus atromaculatus</u>	Grand	-		-			
<u>Catostomus commersoni</u>	Grand	-1.00		-			
<u>Hypentelium nigricans</u>	Grand						
<u>Ambloplites rupestris</u>	Thames	-	-				
<u>Micropterus dolomieu</u>	both	-	-1.00	-	+		
<u>Etheostoma biennioides</u>	Thames		-1.00*		-		
<u>E. caeruleum</u>	Grand	-		-		-	-
<u>E. nigrum</u>	Grand			-			

* $p < 0.05$

** $p < 0.01$

^b + positive
- negative
o no direction

TABLE 6. Coefficients of association ^a ($p < 0.15$) and directions of association ^b ($p > 0.15$) of Notropis photogenis young-of-the-year with other fish species

Species	Watershed analysed	Sampling period			
		2 31 July -6 Aug. 1981	3 7-19 Aug. 1981	4 22-29 Aug. 1981	5 14-18 Nov. 1981
<u>Dorosoma cepedianum</u>	Thames	-	-1.00**	.	
<u>Nocomis</u> spp.	both	-	-	-0.62*	-
<u>Notropis cornutus</u> group	both	-1.00*	+	+	1.00**
<u>N. photogenis</u> adults	both	0.68	+	+	
<u>N. rubellus</u> adults	both	+	+	+	
<u>N. rubellus</u> YOY	both	+	0.38	+	0.70**
<u>N. spilopterus</u>	Thames	-0.55	-	-0.60*	
<u>N. volucellus</u>	Thames	+			
<u>Pimephales notatus</u>	both	+	-1.00*	-	0.72**
<u>Rhinichthys cataractae</u>	Grand	-	-1.00	-	
<u>Semotilus atromaculatus</u>	Grand	-1.00	-	-	
<u>Catostomus commersoni</u>	Grand	-1.00	-1.00	-1.00	
<u>Hypentelium nigricans</u>	Grand	-1.00	-	+	
<u>Ambloplites rupestris</u>	Thames	-	-		
<u>Micropterus dolomieu</u>	both	-	-	0.40	
<u>Etheostoma blennioides</u>	Thames	-0.40	-1.00**	-0.69**	-
<u>E. caeruleum</u>	Grand	-	-1.00	+	+
<u>E. nigrum</u>	Grand	-	-	-	

^a * $p < 0.05$
 ** $p < 0.01$

^b + positive
 - negative

for N. photogenis adults more often than for YOY because adults were captured less frequently (in 5 of 36 to 11 of 30 subsites for sampling periods 1-4 and 6-7; section IV.3.1) than YOY (5 of 29 to 18 of 37 subsites; section IV.3.2). No results are presented for N. photogenis adults in sampling period 5. Adults were captured in two of 29 subsites; the minimum expected value was greater than 0.5 only for Notropis cornutus group. Notropis photogenis and N. cornutus group were positively associated, with a coefficient of association of 1.00 ($0.05 < p < 0.15$).

The strongest association of N. photogenis adults was with N. rubellus adults: they were positively associated in summer 1981 and spring 1982, with significant coefficients of association in four of six sampling periods (Table 5). Notropis photogenis adults were also positively associated with YOY of their own species and of N. rubellus but these associations were weaker than that with N. rubellus adults.

With both N. cornutus group and Pimephales, adults had consistently negative associations through summer 1981, but positive associations in spring 1982. Associations with Dorosoma and N. volucellus were positive, but data were adequate for too few sampling periods to draw firm conclusions. Notropis photogenis adults were negatively associated with all remaining fish species in Table 5 (with the exception of one sampling period for two species). Associations with Nocomis spp. approached significance in all summer 1981 sampling periods, but in general negative associations were weak.

Like the adults, N. photogenis YOY showed positive associations with the other age group of its species and with both age groups of N. rubellus (Table 6). However, these associations were generally weak, with the exception of a significant coefficient of association

with N. rubellus YOY in autumn 1981.

Associations of N. photogenis YOY with N. cornutus group, Pimephales, Micropterus, and Etheostoma caeruleum were inconsistent, being positive in some sampling periods and negative in others. Young-of-the-year were positively associated with N. volucellus but there were enough data for analysis in only one sampling period. Associations with all other species were negative, including strong negative associations with N. spilopterus, Catostomus, and E. blennioides.

4. DISCUSSION

It is emphasized that the spatial associations discussed here occurred at a microhabitat scale -- at a larger scale different patterns of interspecific associations could occur. Both Hurlbert (1969), and Pielou (1977) pointed out the importance of scale ("quadrat size") in determining the nature of associations found.

Information on habitats of species other than N. photogenis and N. rubellus was taken from Scott and Crossman (1973), Trautman (1981); or my own field observations, unless otherwise noted.

Notropis photogenis and N. rubellus were strongly positively associated in spite of the differences in microhabitat use between them (section IV.4.3). Both N. photogenis and N. rubellus were captured in deep pool habitats, and this is reflected in the strong positive association. However, N. rubellus adults were captured in more subsites (12 of 37 to 17 of 30 subsites; section IV.3.3) than N. photogenis (section V.3). Thus N. photogenis was usually captured with N. rubellus (giving a strong positive association) but because of the different environments in the additional subsites also occupied by N. rubellus, the environmental variables found to be the

best predictors of habitat use by each species were often different. The strong positive association of N. photogenis and N. rubellus adults suggests positive interactions between them. In fact, associations among Notropis species, including multispecies schools, are common (Mendelson 1975).

Other summer 1981 N. photogenis - N. rubellus associations were positive but not strong. These results reflect the results of habitat use studies: both age groups of both species were basically inhabitants of relatively deep stream sections, but differed in the other variables best describing their use of habitat (section IV.4).

Notropis photogenis YOY were, however, strongly positively associated with N. rubellus YOY in autumn 1981. This was the result of the concentration of most fishes into a few subsites in pools at this time (section IV.3.5). This concentration also explains the large proportion (four of six; three of the four significant; Table 6) of positive associations of YOY with other species in autumn, including two species (Pimephales notatus and Etheostoma caeruleum) with which YOY were usually negatively associated in summer 1981. Notropis photogenis adults showed a somewhat similar tendency in spring 1982. Associations with four of six species were positive (Table 5), including associations with N. cornutus group and Pimephales notatus which had been negative in summer 1981. There was some concentration of fishes in some subsites in sampling period 6, but this was much less marked than in autumn 1981. The positive spring 1982 associations may reflect seasonal changes in habitat use, including changes for spawning.

Individuals of Notropis cornutus group were the most common fishes captured during my studies -- their occurrence in most subsites accounts for the generally non-significant coefficients of association

with N. photogenis. Notropis cornutus group is characteristic of small to medium-sized streams, without submersed vegetation and usually clear, with alternating pools and riffles, moderate to fast currents, and sand, gravel, boulder, or bedrock substrates (Gilbert 1980a and 1980b, Scott and Crossman 1973, Trautman 1981). Notropis chrysocephalus occurs in larger, warmer, and often more turbid streams, with more silted substrates, than N. cornutus sensu stricto (Gilbert 1980a, Trautman 1981). These macrohabitat descriptions provide little information for microhabitat comparisons with N. photogenis, but the preference of N. cornutus for pools over riffles (Gilbert 1980b) suggests similarities with N. photogenis habitat use, while the substrates described for N. cornutus group differ from the small-particle substrates more often used by N. photogenis (section IV.3.1). As small-stream inhabitants, members of N. cornutus group are likely to use many of the shallower habitats not used by N. photogenis. In summer 1981, in spite of their frequent occurrence with N. photogenis adults, their use of a wide variety of other habitats resulted in negative associations with the adults. There is no apparent explanation for the change from a significant negative association with N. photogenis YOY in sampling period 2 to positive associations for the remaining summer sampling periods.

Pimephales, Catostomus, and Etheostoma nigrum, like N. cornutus group, also have generalized habitat requirements, and all showed negative associations with N. photogenis in summer. Small Catostomus, which comprised most of my samples (section V.2), tended to occur in slow areas with aquatic vegetation not occupied by N. photogenis.

Positive associations between N. volucellus and N. photogenis were likely the result of preferences of the former for areas of no or slow current in moderate to large streams. Although adults also

occurred in faster currents, slow habitats were used by both adult and YOY N. photogenis (sections IV.3.1 and IV.3.2).

All of the remaining species usually had negative associations with both adult and YOY N. photogenis. Four of these taxa, Rhinichthys, Hypentelium, Etheostoma blennioides, and E. caeruleum, are riffle-dwellers and thus clearly different in microhabitat use from N. photogenis.

Like members of N. cornutus group, Semotilus is characteristic of smaller streams with moderate to high gradients. It differs from N. photogenis in that, whereas older fishes usually occur in deeper channels or pools, younger fishes also occur in fast and slow shallow habitats (Moshenko and Gee 1973) not used by N. photogenis.

Young Dorosoma and N. spilopterus are both characteristic of larger rivers, and in Ontario overlap only the downstream portions of the range of N. photogenis. Both species are associated with aquatic vegetation, unlike N. photogenis. Notropis spilopterus often occurs in turbid water; N. photogenis showed no habitat use patterns in relation to turbidity. I observed large schools of Dorosoma YOY in very shallow areas unused by N. photogenis. The positive association of Dorosoma with N. photogenis adults is unexplained; however, this non-significant result for one sampling period is not considered very meaningful.

Habitat use differences that would explain negative associations with N. photogenis are less clear for Nocomis spp. Nocomis biguttatus prefers small to medium streams with slow to moderate currents, sand or gravel bottoms, usually with aquatic vegetation (Scott and Crossman 1973, Trautman 1981), where it inhabits pools and slow to moderate runs, and is occasionally associated with submersed vegetation (Jenkins and Lachner 1980a). Nocomis micropogon,

however, prefers larger streams or rivers with moderate to high gradients, larger substrate particles, and little aquatic vegetation (Scott and Crossman 1973, Trautman 1981), inhabiting swift currents and pools (Jenkins and Lachner 1980b). Microhabitat use by N. biguttatus, with the exception of its occasional association with submersed vegetation, thus appears more similar to that of Notropis photogenis than does Nocomis micropogon habitat use. The negative associations and preference of N. micropogon for larger streams suggest that most of my Nocomis spp. were micropogon, but without further data neither the species nor the reasons for the negative associations can be conclusively identified.

Both Ambloplites and Micropterus are potential predators on Notropis photogenis. Many of the Ambloplites captured were large enough (section V.2) to prey on at least YOY, so that the negative associations could represent an avoidance of a predator by N. photogenis. However, Ambloplites usually occurs in habitats with bouldery or bedrock substrates unlike those of N. photogenis. Micropterus captured, with the possible exception of the largest YOY captured at the end of summer 1981, were too small (section V.2) to prey on N. photogenis. Descriptions of adult Micropterus habitat -- streams with moderate temperatures, low to moderate gradients, riffles with gravel to boulder substrates, and flowing pools over 1 m deep -- are not unlike N. photogenis macrohabitat. However, I observed YOY Micropterus in shallow habitats not used by N. photogenis. It is possible that the change to positive associations with both adult and YOY N. photogenis in sampling period 4 may have resulted from a movement by larger YOY Micropterus to less sheltered habitats more like those of the older fishes.

In most cases, associations of N. photogenis with other species appeared to be related to similarities or differences in microhabitat use. The strong positive association between adult N. photogenis and N. rubellus, however, appeared greater than could be explained on the basis of habitat use alone. For many of the species other than N. photogenis and N. rubellus, limited microhabitat data prevented definite conclusions that habitat use similarities or differences accounted for the nature of associations, and for N. cornutus group and Nocomis spp., combinations of species confused interpretation. Had habitat differences been rejected as an explanation for negative associations, competition would have provided an alternative hypothesis (section V.1). The proof of competition, though, would require far more than these data, e.g., the demonstration that resource use by a species differed when its competitor was present or absent. In fact, competition could have been occurring and have contributed to differences in microhabitat use between N. photogenis and its negative associates, but again these data cannot prove or disprove this hypothesis. Neither should it be assumed that N. photogenis used a set of habitats unexploited by the negatively associated species. Rather, some of the more common or generalized species were negatively associated with N. photogenis because they used a variety of habitats only some of which were shared with N. photogenis.

VI DISCUSSION AND CONCLUSIONS

1. DISCUSSION

Habitat use by Notropis photogenis and N. rubellus differs, and changes occur over time, with the age of the fishes and with season. Some of these differences and changes can be related to other aspects of these fishes' biology.

In summer, many fewer adult N. photogenis were captured than young-of-the-year (YOY; section III.3.1). Differences in habitat use or susceptibility to capture as well as high mortality may have contributed to the scarcity of adults, but the data are not adequate to identify the true cause or causes. The captures of adults in relatively few of the subsites sampled reduced the reliability of the results of analysis relative to YOY and N. rubellus (section IV.3). However, one habitat variable, water depth, emerged consistently from my analyses: adult N. photogenis used the deeper parts of the study sites. These tended to be pool habitats with fine-grained substrates.

During the summer, N. photogenis YOY and N. rubellus adults and YOY also used the deeper habitats sampled (section IV.3). Adult and YOY N. photogenis were positively associated with each other, and both age groups were positively associated with adults and YOY of N. rubellus (section V.3). Associations with almost all other fish species were negative at this time, usually as a result of differences in habitat use or use of a broader range of habitats by other species (section V.4). The particularly strong association between N. photogenis and N. rubellus adults appeared to transcend similarities in habitat use, however; these were limited to

similarities in depths used (section IV.4.3). Their association may be an example of the multispecific aggregations or schools common among Notropis species (Mendelson 1975). I did observe these species together in the field, and in fact also sometimes observed individuals of N. cornutus group with them. However, the occurrence of N. cornutus group in most subsites, as well as with N. photogenis adults, led to weak negative associations (section V.4). Multispecific aggregations may provide increased protection from predation, but do not prevent member species from showing some spatial and food differences (Mendelson 1975). Differences in food do appear to exist between N. photogenis and N. rubellus adults, with N. photogenis doing more surface-feeding on terrestrial-insects (section IV.1).

Food differences may also be related to differences between N. photogenis and N. rubellus in their relationships to current speed and habitat type. Adults of N. photogenis showed no tendency to occur in slower or faster currents, but N. rubellus tended to occur in faster currents, and in riffles as well as pools (sections IV.3.1 and IV.3.3). Feeding on benthic invertebrates is possible in riffles, but such habitats are clearly unsuitable for the surface-feeding apparently characteristic of N. photogenis because floating or flying insects would be much harder to detect through the broken surface film.

Notropis photogenis and N. rubellus showed parallel patterns of changes in current use with age. Young-of-the-year N. photogenis occurred in slow water, but N. photogenis adults showed no pattern. Notropis rubellus YOY also showed no pattern, occurring in currents of different speeds, but adults used faster currents. These changes were attributed to the ability of the larger adults to swim in

stronger currents (sections IV.4.1 and IV.4.2). However, the adults of the smaller species, N. rubellus, (section III.3.1) occurred in the faster currents. This is not considered contradictory; while body size affects ability to resist current, so does body shape. Both N. photogenis and N. rubellus have oval cross-sections, approaching the round body cross-section that best resists current (Hynes 1970), but N. rubellus is more streamlined.

All of this discussion of summer habitat use applies to the day-time only. A night sample (section IV.3.5) and the limited literature available (section IV.4.4) suggest that N. photogenis, N. rubellus, and most sympatric species retreat to areas of slow or no current and are inactive at night. From the large eye sizes of N. photogenis and N. rubellus and my observations of feeding, vision appears to be their major means of prey detection, so that absence of feeding at night would not be surprising.

Notropis photogenis, N. rubellus, and most other species were probably also inactive during the winter. Most November captures were made in a few of the deeper subsites (section IV.3.5). These were all pools, including still and flowing pools, and current edges. At this time, depth range was the best or one of the best predictors of the presence or absence of both N. photogenis and N. rubellus YOY (sections IV.3.2 and IV.3.4). This suggests their use of pools bordering on riffles or other shallow areas. The November habitats may not have represented final overwintering sites, as autumn movements are commonly made by many fishes (section IV.4.4). The smaller tributaries and much of the main Grand and Thames Rivers are ice-covered in winter, although areas of faster current remain open. Under ice cover, N. photogenis, N. rubellus, or other fishes may not only be inactive, but may rest in or on the substrate (section

IV.4.4).

Break-up of the ice cover in these rivers often coincides with or is followed quickly by spring floods, when flows may be many times greater than those at other times (section IV.3.5). Captures along flooded river edges and in floodplain ponds suggested that N. photogenis and N. rubellus, as well as many other sympatric species, retreat to the slower-flowing edges of the flooded rivers (section IV.3.5). Mortality due to stranding may result, but Ross and Baker (1983) suggested that the floodplain habitats may also offer additional food sources (section IV.4.4). However, flood waters in the Grand and Thames River watersheds are usually very turbid: I recorded turbidities over 500 JTU during spring floods at study site N2 (Fig. 2) in spring 1982 (compared to non-flood levels of 7-28 JTU during sampling periods 1-7). In such turbid water, it would appear to be difficult for such probable sight-feeders as N. photogenis and N. rubellus to find many prey.

Later in the spring, May and June samples showed that habitat use by adults was generally similar to that of the previous summer for both N. photogenis and N. rubellus (sections IV.3.1 and IV.3.3). However, adults of both species showed patterns of current use similar to those of the YOY in the previous summer, probably because the largest part of both species' spring adult populations consisted of the previous year's YOY (section III.3.1) which were still small enough to be required to avoid strong currents (sections IV.4.1 and IV.4.2.).

Spring habitat use patterns were complicated by other factors, making results of the two spring sampling periods differ from each other (especially for N. rubellus; sections IV.3.1 and IV.3.3) and general interpretations difficult. Water temperatures were rising

rapidly during sampling period 6; the slight tendency for fishes to be concentrated in some subsites and study sites was probably a result of fishes seeking warmer temperatures. Notropis photogenis adults were positively associated with most other fish species tested at this season, including previously negatively-associated species (section V.3). These associations may have resulted to some extent from the concentration of fishes, and may also have been related to habitat-use changes related to spawning. Notropis photogenis apparently spawned in May or early June, and N. rubellus from mid-May to the end of June (or possibly later) (section III.4.2). Part or all of the spawning periods of all species tested for associations with N. photogenis (section V.2) also occurred in May and June (my observations of spawning, spawning colours, or gravid females; Scott and Crossman 1973). Although most of my spring 1982 samples did not include individuals actually spawning at the time of capture, I expect that habitat use during the spawning period would be influenced by spawning activities. Movements to spawning areas and the possible existence of pre-spawning or courtship behaviour (e.g., as described by Pfeiffer 1955 for N. rubellus) may result in different habitat-use patterns than those found at other times of year. Spring movements by N. rubellus (and many other stream species) have been observed, and my data suggested possible movements by N. photogenis (section III.4.2). The actual spawning habitat of N. rubellus is shallow gravel areas, in or near riffles, and often over Nocomis nests (sections III.3.2 and III.4.2). I did not observe spawning by Notropis photogenis but it may use similar sites (section III.4.2).

Mortality of N. photogenis adults appeared to be high during spring and summer but trends for N. rubellus were less evident

(section III.3.1). Young-of-the-year of both species grew rapidly (section III.3.1). Summer habitat use by YOY as discussed above and in section IV refers only to YOY whose total lengths were larger than 3.5 cm (N. photogenis) or 2.0 cm (N. rubellus) when they were large enough to begin to be captured by my seine. Smaller YOY of these (and other) species were observed earlier in very shallow shoreline or backwater habitats with warm temperatures and no current.

The results of my studies of habitat use by N. photogenis and N. rubellus showed some rather disturbing inconsistencies among sampling periods in the variables best predicting the presence or absence of these species (Tables 1-4, section IV.3). However, such inconsistencies may not be unusual. Matthews and Hill (1979a), in their study of the effects of 10 variables on habitat selection by N. lutrensis (section IV.4.3), found that its distribution differed significantly from that expected for every factor, at each of five times of year, with the exception of a non-significant result for only one factor at one time of year. However, they were then able to show that some variables were more important than others. They also found inconsistencies between field and laboratory responses for several variables. Felley and Hill (1983) studied the environmental preferences of 10 cyprinid species in the four seasons over two years in Oklahoma. They used principal components analysis to identify sets of covarying variables among 13 environmental variables and three variables describing gut contents. Among the eight sampling periods, there was considerable variation in which variables were highly correlated with the first two or three components. However, Felley and Hill were able to identify three recurring sets of variables -- describing longitudinal

(upstream - downstream), current speed, and food differences -- that were related to habitat partitioning among the species.

Thus variability in the responses of stream fishes to habitat variables should perhaps be expected. In reality, fishes must always respond to combinations of variables. Although analysis methods such as mine may indicate which variables appear to be most important, and multivariate analysis in particular gives information on the effects of variables together (section IV.2.4), the real environment of the fishes will always be much more complex than its representation by a subset of variables.

Environmental variation on a seasonal or much longer scale may also affect results of habitat-use studies. Wiens (1977) suggested that selection pressure on resource utilization patterns by a species may vary with such environmental fluctuations, so that during "ecological crunches" a population would use a relatively narrow range of resources, but during "benign" periods its use of resources would expand. I do not have data to judge whether environmental conditions were difficult or benign for N. photogenis during 1981-82. If, however, conditions were benign, as the possibility of recent population increases of N. photogenis (section II.4) would suggest, then habitat-use patterns may have been less clear and included a broader range of habitats than would be expected under more severe conditions.

The question remains as to whether the microhabitat-use patterns of N. photogenis offer any insight into the reasons for its restricted range in Canada (section II). The importance of the variable "river" at some times in predicting the presence or absence of N. photogenis (sections IV.3.1 and IV.3.2) suggested that larger-scale factors were influencing the outcome of my analysis to some

extent, and it is factors operating at a geographic scale that would be expected to affect the range of the species (section I). Temperature is obviously a possible limit for a species at the northern limit of its range (section IV.4.1), and water chemistry variables that were generally unimportant to habitat use patterns of N. photogenis may have been more important (if important at all) at a larger scale. For N. rubellus, the importance of colour and clarity in predicting habitat use appeared to be related more to differences among rivers (i.e., to large-scale differences) than among subsites (section IV.4.3). The coincidence of the downstream ends of the range of N. photogenis and physiographic changes in the Grand and Thames Rivers (section I) suggests that gradient or other factors related to it or to the soil types of the watershed limit the species' distribution. Parker and McKee (1980) felt that gradient was a limiting factor. My results may offer some explanation of upstream limits, however. For both adults and YOY, depth was the most important variable in describing habitat use; the deeper habitats used by both age groups would decrease in frequency and eventually disappear as stream size decreased.

The habitats occupied by N. photogenis have been altered by human activities (section I). However, there is no evidence in my results that these changes are currently detrimental to N. photogenis. The water chemistry and turbidity variables that are often most obviously changed by humans were, within the ranges encountered, not important in describing habitat use by the species (sections IV.3.1 and IV.3.2). The basic physical character of these rivers, of alternating pools and riffles, has not likely been greatly changed by human settlement, although clearing of riparian forests in some areas may have allowed bank erosion and thus widened

channels and decreased average depth, resulting in fewer deep pool habitats.

In spite of any human influences, present habitat availability appears adequate to maintain populations of N. photogenis. In the future, continued maintenance of the physical characteristics of the Grand and Thames Rivers appears to be important to provide the microhabitats suitable for Notropis photogenis populations in Canada.

2. CONCLUSIONS

1. The distribution of Notropis photogenis in Canada is slightly larger than was previously known. My new records extended it approximately 10 km up the South Thames River and approximately 35 km up the North Thames River, and included the first records of N. photogenis in Whitemans Creek (Grand River watershed) and the Middle Thames River, less than 1 and 2 km from the mouths, respectively.
2. All young-of-the-year (YOY) and adult N. photogenis except one could be separated by differences in total length (TL). The YOY grew rapidly from first capture at 2.0-3.0 cm TL in June 1981 to 5.3-8.6 cm TL in November 1981. Adults had TLs of 4.9-13.1 cm in 1981 and 1982. Differences in length between adults and YOY N. rubellus were not clear. When first captured in July 1981, YOY had TLs of 1.9-3.6 cm. In May and June 1981 and 1982 adults had TLs of 2.9-9.2 cm.
3. Ripe or nearly ripe N. photogenis were captured from 6-29 May 1981 and 5-31 May 1982. Spent individuals were first captured on 4 June 1981 and 17 May 1982. Ripe individuals included fishes in their second year. Ripe or nearly ripe N. rubellus were captured from 6 May to 16 July 1981, and spawning was observed on 2, 3, and 6 June 1981 and 18 May 1982.

Spawning occurred over gravel in water less than 40 cm deep, and, on three of the four occasions observed, with members of N. cornutus group.

4. Logistic regression analysis provided a useful means of studying habitat use by analysing simultaneously the effects of 21 habitat and nine sampling variables on the presence or absence of adult of YOY N. photogenis or N. rubellus. Interpretations were limited however by small sample sizes.
5. Water depth was the best predictor of the presence or absence of N. photogenis adults in summer 1981 and spring 1982. Subsites with adults had greater mean depths and depth ranges than those without them. The next best predictors of adult presence or absence in summer were habitat type, substrate, and stream width. Adults usually occurred in pools, over small-particle substrates, with relatively narrow stream widths. In spring the next best predictors were water temperature, current speed, substrate, stream width, distance from shore, and "river", with adult N. photogenis found more often than expected in warmer subsites with slow currents, small-particle substrates, and relatively great widths and distances from shore, and were concentrated in some of the sampled rivers.
6. For N. photogenis YOY, the best predictor of presence or absence in summer 1981 was habitat type. Young-of-the-year occurred in pool habitats. Other variables most useful in predictions were water depth, current speed, shore vegetation, and "river". Subsites with YOY were deeper and slower than those without YOY, had grassy or bushy shorelines, and were concentrated in some rivers.

7. In summer 1981, the habitat variables best predicting the presence or absence of N. rubellus adults were colour, clarity, water depth, current speed, and distance from shore. In spring 1982 the best predictors were clarity and water depth range. Adults usually occurred in cloudy, green-brown or green water, in relatively deep and fast water, and subsites far from shore.
8. Among habitat variables, colour and depth range were the best predictors of the presence or absence of N. rubellus YOY in summer 1981. Subsites with YOY had greater depth ranges than those without YOY, and were usually green or green-brown. Other good predictor variables were Secchi depth and shore vegetation: YOY usually occurred in subsites with cloudy water and at least partially forested shorelines.
9. Notropis photogenis, N. rubellus, and most other species captured in November 1981 were concentrated in a few of the deeper pool subsites. Both N. photogenis and N. rubellus were captured along the edges of flooded rivers in spring 1981, and in a floodplain pond in 1982. A night sample in summer 1981 showed both species in different habitats at night than during the day.
10. Notropis photogenis and N. rubellus were positively associated, with a strong positive association between adults of the two species. In summer 1981, N. photogenis adults and YOY were each negatively associated with all but two of the 15 other species tested. In autumn 1981 and spring 1982, associations of YOY

and adults, respectively, with other species were positive
in four of six cases.

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APPENDIX I.1
RESULTS OF UNIVARIATE ANALYSIS
OF CONTINUOUS HABITAT AND SAMPLING VARIABLES
FOR NOTROPIS PHOTOGENIS ADULTS

The following abbreviations are used:

N.p.	<u>Notropis photogenis</u>
S.D.	standard deviation
K-S 1	Kolmogorov-Smirnov one-sample test
(s)	skewed distribution
Levene	Levene's test for equality of variances
t(sep.)	t-test for separate variances
t(pool.)	t-test for pooled variances
M-W U	Mann-Whitney U-test
K-S 2	Kolmogorov-Smirnov two-sample test

APPENDIX I.I.I. Results of univariate analysis of continuous habitat and sampling variables for *Notropis photogenis* adults in sampling period 1

variable	mean, subsites without & with N.p.	S.D., subsites without & with N.p.	K-S 1: p-value	Levene: p-value	t (sep.): p-value	t (pool.): p-value	M-W U: p-value	K-S 2: p-value
mean temperature (°C)	22.9	1.709	.742	.476		.657	.970	.978
temperature range (°C)	23.2	2.065						
	.06	.086	.000(s)	.546		.990	.951	1.000
mean dissolved oxygen	10.9	1.656	.993	.017	.618		.568	.292
dissolved oxygen range	11.4	2.473						
	.32	.444	.043(s)	.161		.523	.861	.891
pH	.45	.609						
	8.1	.201	.157	.171		.324	.321	.911
conductivity ($\mu\text{mho/cm}$)	8.0	.292						
	6.7×10^2	200	.028(u)	.299		.520	.566	.959
turbidity (JTU)	7.4×10^2	296						
	17	7.78	.766	.688		.638	.782	.942
mean depth (cm)	16	6.30						
	37	14.2	.572	.272		.962	.790	.832
depth range (cm)	38	11.9						
	35	21.5	.173(s)	.726		.967	.834	1.000
mean current (m/s)	36	19.6						
	.38	.266	.429	.079	.251	.317	.346	.618
current range (m/s)	.28	.200						
	.20	.263	.005(s)	.238		.356	.299	.654
stream width (m)	.31	.314						
	51	34.3	.465	.014	.388		.970	.445
distance from shore (m)	44	13.8						
	6.9	5.08	.520(s)	.365		.612	.237	.398
time	7.8	3.23						
	12.4	2.697	.473	.973		.961	.941	.999
duration (h)	12.4	2.788						
	.56	.157	.004	.363		.229	.199	.873
air temperature (°C)	.49	.083						
	22.4	2.876	.684	.687		.417	.629	.833
	23.5	2.889						

APPENDIX I.1.2. Results of univariate analysis of continuous habitat and sampling variables for *Notropis photogenis* adults in sampling period 2

variable	mean, subsites without & with N.p.	S.D., subsites without & with N.p.	K-S 1: p-value	Levene: p-value	t(sep.): p-value	t(pool.): p-value	M-W U: p-value	K-S 2: p-value
mean temperature (°C)	23.8	1.744	.628	.432		.186	.201	.475
temperature range (°C)	24.8	1.263	.001(a)	.052	.289	.502	.119	.269
	.06	.089						
	.08	.041						
mean dissolved oxygen (mg/L)	10.7	1.951	.268	.285		.622	.656	.759
dissolved oxygen range	10.2	2.544	.001(a)	.492		.483	.006	.023
	.22	.494						
	.37	.197						
pH	8.2	.231	.175	.448		.049	.081	.210
	8.0	.281						
conductivity (µmho/cm)	6.3x10 ²	144	.037	.464		.564	.966	.948
	6.0x10 ²	85						
turbidity (JTU)	18	6.08	.333	.145		.044	.030	.046
	24	3.93						
mean depth (cm)	34	12.5	.361(a)	.770		.000	.003	.020
	58	14.3						
depth range (cm)	34	21.0	.049(a)	.874		.016	.011	.046
	57	19.2						
mean current (m/s)	.36	.271	.444	.553		.884	.804	.960
	.37	.212						
current range (m/s)	.25	.286	.001(a)	.971		.874	.894	1.000
	.27	.327						
stream width (m)	50	31.1	.465	.210		.681	.902	.791
	45	17.6						
distance from shore (m)	7.0	4.61	.520(a)	.826		.834	.934	.918
	7.4	5.62						
time	13.5	2.650	.809	.721		.959	.984	1.000
	13.4	2.615						
duration (h)	.56	.192	.015	.614		.276	.142	.400
	.65	.164						
air temperature (°C)	23.7	2.243	.182	.532		.244	.155	.162
	25.0	2.813						

APPENDIX I.1.3. Results of univariate analysis of continuous habitat and sampling variables for *Notropis photogenis* adults in sampling period 3

variable	mean, subsites without & with N.P.	S.D., subsites without & with N.P.	K-S 1: p-value	Levene: p-value	t(sep.): p-value	t(pool.): p-value	M-W U: p-value	K-S 2: p-value
mean temperature (°C)	21.6	1.508	.739	.156		.194	.328	.599
temperature range (°C)	20.5	2.361	.000(s)	.032	.507		.626	.708
	.05	.084						
mean dissolved oxygen (mg/L)	10.6	1.438	.421	.281		.702	.807	.730
dissolved oxygen range (mg/L)	10.9	2.329	.055(s)	.071	.161	.028	.034	.230
	.18	.238						
pH	8.2	.365	.681	.370		.023	.025	.155
	.46	.128						
conductivity (µmho/cm)	8.0	.058	.247	.753		.559	.624	.986
	6.2x10 ²	145						
turbidity (JTU)	17	142	.838	.406		.272	.221	.230
	13	7.02						
mean depth (cm)	36	6.02	.378	.743		.093	.091	.068
depth range (cm)	49	15.7	.200	.005	.663		.398	.329
	38	25.0						
mean current (m/s)	36	6.5	.848	.437		.741	.615	.948
	.39	.264						
current range (m/s)	.43	.217	.090(s)	.234		.650	.981	.995
	.26	.272						
stream width (m)	.33	.453	.465	.064	.215	.477	.672	.792
	51	32.8						
distance from shore (m)	40	13.3	.520(s)	.970		.237	.205	.256
	6.7	4.58						
time	9.4	5.46	.727	.984		.234	.205	.362
	12.7	2.409						
duration (h)	11.3	2.546	.013(s)	.166		.505	.624	.686
	53	.157						
air temperature (°C)	.48	.045	.661(s)	.002	.460		.657	.599
	20.9	2.496						
	18.9	5.259						

APPENDIX 1.1.4. Results of univariate analysis of continuous habitat and sampling variables for *Notropis photogenis* adults in sampling period 4

variable	mean, subsites without & with N.p.	S.D., subsites without & with N.p.	K-S 1: p-value	Levene: p-value	t(aep.): p-value	t(pool.): p-value	M-W U: p-value	K-S 2: p-value
mean temperature ($^{\circ}$ C)	20.8	.733	.237	.025	.113		.583	.435
temperature range ($^{\circ}$ C)	21.1	.237						
	.06	.102	.005(a)	.841		.750	.463	.990
	.08	.084						
mean dissolved oxygen (mg/L)	10.0	1.575	.671	.564		.090	.131	.131
dissolved oxygen range	8.6	1.831						
	.16	.224	.025(a)	.878		.480	.296	.867
	.24	.230						
pH	7.9	.363	.574	.230		.261	.290	.361
	7.7	.288						
conductivity (μ mho/cm)	6.7x10 ²	210	.071	.172		.467	.358	.361
	6.0x10 ²	.72						
turbidity (JTU)	18	5.81	.706	.653		.281	.251	.361
	22	7.44						
mean depth (cm)	33	14.9	.476	.472		.015	.021	.060
depth range (cm)	52	13.8						
	37	22.7	.311(a)	.136		.051	.038	.226
	61	33.9						
mean current (m/s)	.39	.267	.324	.169		.139	.192	.561
	.20	.200						
current range (m/s)	.29	.300	.052(a)	.226		.375	.509	.937
	.16	.206						
stream width (m)	47	32.5	.465	.160		.377	.109	.150
	60	16.2						
distance from shore (m)	6.9	5.08	.520(a)	.255		.834	.325	.266
	7.4	2.30						
time	12.0	2.362	.518	.089	.154	.295	.410	.539
	10.9	1.363						
duration (h)	.48	.132	.021(a)	.189		.359	.092	.202
	.54	.055						
air temperature ($^{\circ}$ C)	20.2	1.728	.575	.297		.006	.014	.044
	22.6	1.195						

APPENDIX I.1.5. Results of univariate analysis of continuous habitat and sampling variables for *Notropis photogenis* adults in sampling period 6

variable	mean, subsites without & with N.p.	S.D., subsites without & with N.p.	K-S 1: p-value	Levene: p-value	t(sep.): p-value	t(pool.): p-value	M-W U: p-value	K-S 2: p-value
mean temperature (°C)	15.3	2.610	.521	.025	.003		.008	.014
temperature range (°C)	17.8	1.274	.000(s)	.050	.311		.215	.973
mean dissolved oxygen (mg/L)	13.1	2.960	.777	.213		.079	.213	.341
dissolved oxygen range	11.2	2.179	.074(s)	.778		.097	.014	.090
pH	8.4	.121	.223	.002	.000		.000	.002
conductivity (µmho/cm)	8.0	.317	.552	.000	.626		.914	.169
turbidity (JTU)	16	216	.781	.794		.842	.880	.917
mean depth (cm)	16	6.49	.471	.129		.000	.001	.009
depth range (cm)	31	10.7	.109	.077	.003	.001	.002	.027
mean current (m/s)	50	17.1	.685	.314		.020	.021	.119
current range (m/s)	20	22.6	.018(s)	.117		.363	.286	.497
stream width (m)	50	.246	.716	.124		.866	.698	.720
distance from shore (m)	52	21.7	.232(s)	.865		.206	.043	.169
time	5.9	5.03	.555	.271		.911	.914	.975
duration (h)	12.8	4.54	.069(s)	.049	.094		.067	.286
air temperature (°C)	19.0	2.00	.377	.769		.062	.057	.154

APPENDIX I.1.6. Results of univariate analysis of continuous habitat and sampling variables for *Metropis photogenis* adults in sampling period 7

variable	mean, subsites without & with N.p.	S.D., subsites without & with N.p.	K-S 1: p-value	Levene: p-value	t(sep.): p-value	t(pool.): p-value	M-W U: p-value	K-S 2: p-value
mean temperature (°C)	15.6	1.691	.405	.496		.053	.052	.095
temperature range (°C)	17.3	2.097	.000(s)	.001	.136		.044	.591
mean dissolved oxygen (mg/L)	12.0	1.792	.578	.255		.008	.016	.045
dissolved oxygen range (mg/L)	9.5	1.263	.007(s)	.384		.695	.692	1.000
pH	.05	.084						
conductivity (µmho/cm)	6.0x10 ²	233	.447(s)	.165		.681	.177	.194
turbidity (JTU)	6.4x10 ²	130	.780	.253		.230	.274	.694
mean depth (cm)	14	3.87	.663(s)	.070	.034	.005	.012	.042
depth range (cm)	17	6.53	.744(s)	.130		.021	.052	.095
mean current (m/s)	49	16.2	.615	.021	.018		.041	.296
current range (m/s)	26	12.3	.243	.434		.934	.965	1.000
stream width (m)	45	21.9	.990	.121		.549	.502	.591
distance from shore (m)	36	25.2	.519(s)	.096	.087	.029	.048	.194
time	43	13.9	.778	.168		.636	.602	.591
duration (h)	4.9	2.67	.195	.709		.071	.037	.194
air temperature (°C)	8.8	1.796	.681(s)	.261		.138	.191	.358
	12.2	2.264						
	11.8	1.135						
	.49	.115						
	.60	3.162						
	16.5	4.040						
	19.0							

APPENDIX I.2. Results of X^2 tests (p-values) of categorical habitat and sampling variables for Notropis photogenis adults

variable	sampling period					
	1	2	3	4	6	7
habitat type	.352	.144	.250	.175	.080	.117
colour	.476	.142	.923	.189	.000	.034
clarity	.218	.160	.283	.898	.002	.743
secchi depth	.343	.003	.805	.382	-	-
substrate	.154	.344	.689	.150	.028	.016
encrusting vegetation	.717	-	.249	-	.000	.375
submersed vegetation	.091	-	.037	-	-	.290
shore vegetation	.594	.065	.104	.606	.517	.718
river	.048	.140	.672	.105	.002	.012
day	.416	.210	.584	.114	.045	.047
distance hauled	.445	.013	.295	.496	.136	.036
cloud cover	.879	.807	.609	.581	.042	.910
wind	.384	.346	.808	.173	.710	.513
precipitation	.303	.187	.475	.042	.000	.186

APPENDIX I.3
RESULTS OF LOGISTIC REGRESSION ANALYSIS
OF HABITAT AND SAMPLING VARIABLES
FOR NOTROPIS PHOTOGENIS ADULTS

The following abbreviations are used:

N.p.	<u>Notropis photogenis</u>
p	p-value
improve.	improvement X^2 -test
Hosmer	Hosmer-Lemeshow goodness of fit test
Brown	C.C. Brown goodness of fit test
coeff.	regression coefficient
S.E.	standard error of regression coefficient

APPENDIX I.3.1. Results of logistic regression analysis of habitat (H) and sampling (HS) variables for *Notropis photogenis* adults in sampling periods 1 to 4

samping period	total no. sub- sites	no. sub- sites with N.p.	variable	step no.	variable entered			final model		
					im- prove.: p	Hos- mer: p	Brown: p	coeff.	S.E.	coeff S.E.
1(H)	34	8	clarity	2	.030	1.000	1.000	-4.22	1.91	-2.21
			substrate	1	.097	-	1.000	5.94	2.82	2.11
			distance from shore	4	.004	.601	.567	.615	.276	2.22
			stream width	3	.025	.251	.801	-.201	.118	-1.70
			constant					6.36	5.10	1.25
1(HS)	37	8	constant					-1.29	.399	-1.22
2(H)	35	6	mean temperature	3	.049	.805	.574	17.0	41.8	.40
			mean depth	1	.000	.504	.392	4.30	10.4	.41
			shore vegetation	2	.015	.393	.395	-39.6	262	-.15
			stream width	4	.003	-	.000	-2.17	5.47	-.39
			constant					-578	1405	-.41
2(HS)	35	6	mean depth	1	.000	.635	.392	1.49	6.11	.24
			shore vegetation	2	.006	.648	.414	-17.6	2541	-.00
			air temperature	3	.001	-	.000	5.48	22.9	.23
			constant					-218	2667	-.08
3(H)	36	5	habitat type	1	.035	-	1.000	-4.96	36.5	-.13
			constant					-6.20	36.5	-.17
3(HS)	37	5	habitat type	1	.038	-	1.000	-4.85	36.9	-.13
			constant					-6.24	36.9	-.16
4(H)	34	5	mean depth	1	.020	.544	.698	.075	.036	2.07
			constant					-4.94	1.82	-2.71
4(HS)	35	5	time	2	.039	.534	.948	-1.998	.533	-1.87
			duration	3	.100	.397	.825	12.5	8.82	1.41
			air temperature	1	.005	.773	.738	1.45	.669	2.17
			constant					-28.4	15.8	-1.80
1-4(H)	138	23	habitat type	2	.065	.251	.199	-1.03	.582	-1.76
			mean depth	1	.000	.034	.018	.110	.035	3.11
			depth range	3	.059	.280	.300	-.058	.022	-2.63
			substrate	5	.026	.294	.796	.703	.320	2.19
			stream width	4	.004	.612	.769	-.044	.015	-2.98
			constant					-2.26	1.01	-2.23
1-4(HS)	134	21	mean depth	1	.000	.295	.032	.071	.020	3.54
			substrate	2	.048	.383	.215	1.04	.337	3.10
			stream width	3	.004	.723	.671	-.034	.014	-2.41
			constant					-2.83	.969	-2.92

APPENDIX I.3.2. Results of logistic regression analysis of habitat (H) and sampling (HS) variables for *Notropis photogenis* adults in sampling periods 6 and 7

samp- ling period	total no. sub- sites	no. sub- sites with N.p.	variable	variable entered			final model		
				step no.	im- prove.: p	Hos- mer: p	Brown: p	coeff.	S.E. coeff. S.E.
6(H)	26	11	colour	1	.000	-	1.000	10.2	33.3 .308
			constant					.004	33.3 .000
6(HS)	28	10	colour	1	.000	-	1.000	76.1	.000 -
			air temperature	2	.003	.864	.352	-5.02	.052 .96.1
			constant					58.9	.000 -
7(H)	18	6	mean depth	1	.002	.457	.689	1.93	5.98 .323
			distance from shore	2	.000	-	.000	10.2	25.3 .405
			constant					-165	382 -.432
7(HS)	21	7	mean depth	1	.005	.154	.489	.117	.061 1.91
			distance from shore	2	.066	.283	.640	.296	.190 1.56
			constant					-7.46	3.06 -2.44
6-7(H)	45	18	mean temperature	2	.000	.410	.708	26.6	237 .112
			depth range	1	.000	.814	.830	1.67	21.6 .078
			mean current	6	.016	-	1.000	-159	1343 -.118
			current range	5	.014	.315	.515	148	1224 .121
			distance from shore	3	.006	.187	.299	14.0	167 .084
			stream width	4	.027	.096	.562	-1.28	20.7 -.062
			constant					-534	5163 -.103
6-7(HS)	43	17	depth range	5	.016	.329	.130	1.40	3.00 .465
			current range	6	.001	-	.000	69.9	161 .434
			distance from shore	3	.034	.362	.166	15.3	33.3 .459
			stream width	4	.013	.040	.305	-1.64	3.61 -.455
			river	1	.000	-	1.000	39.3	134 .294
			duration	2	.009	.795	.640	227	501 .454
			constant					-206	466 -.442

APPENDIX I.4
PREDICTED PROBABILITIES OF LOGISTIC REGRESSION
MODELS USING HABITAT AND SAMPLING VARIABLES
FOR NOTROPIS PHOTOGENIS ADULTS

The following abbreviations are used:

NPADPRES N. photogenis adults present

NPADABS N. photogenis adults absent

Sampling period 1: habitat variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
EACH "M" REPRESENTS 2 RESPONSES, ".5" REPRESENTS FEWER THAN
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
EACH "M" REPRESENTS 2 RESPONSES, ".5" REPRESENTS FEWER THAN
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

Sampling period 1: habitat and sampling variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
EACH "M" REPRESENTS 2 RESPONSES, ".5" REPRESENTS FEWER THAN
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
EACH "M" REPRESENTS 2 RESPONSES, ".5" REPRESENTS FEWER THAN
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

Sampling period 2: habitat variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
EACH "M" REPRESENTS 2 RESPONSES, ".5" REPRESENTS FEWER THAN
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
EACH "M" REPRESENTS 2 RESPONSES, ".5" REPRESENTS FEWER THAN
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

Sampling period 2: habitat and sampling variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
EACH "M" REPRESENTS 2 RESPONSES, ".5" REPRESENTS FEWER THAN
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
EACH "M" REPRESENTS 2 RESPONSES, ".5" REPRESENTS FEWER THAN
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

Sampling period 3: habitat variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

0 .33 .67 1.0

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

XXXXXXXXXXXXXXXXXXXX

Sampling period 3: habitat and sampling variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

0 .33 .67 1.0

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

XXXXXXXXXXXXXXXXXXXX

0 .33 .67 1.0

Sampling period 4: habitat variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

0 .33 .67 1.0

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

XXXXXXXXXXXXXXXXXXXX
XXXXX XXX XXX XXX
0 .33 .67 1.0

Sampling period 4: habitat and sampling variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

0 .33 .67 1.0

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

XXXXXXXXXXXXXXXXXXXX
XXXXX XXX XXX XXX
0 .33 .67 1.0

Sampling period 6: habitat variables	Sampling period 7: habitat variables
<p>HISTOGRAM OF PREDICTED PROBABILITIES OF NPADPRES FOR GROUP NPADPRES</p> <p>'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>	<p>HISTOGRAM OF PREDICTED PROBABILITIES OF NPADPRES FOR GROUP NPADPRES</p> <p>'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>
<p>HISTOGRAM OF PREDICTED PROBABILITIES OF NPADPRES FOR GROUP NPADABS</p> <p>'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>	<p>HISTOGRAM OF PREDICTED PROBABILITIES OF NPADPRES FOR GROUP NPADABS</p> <p>'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>
<p>HISTOGRAM OF PREDICTED PROBABILITIES OF NPADPRES FOR GROUP NPADPRES</p> <p>'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>	<p>HISTOGRAM OF PREDICTED PROBABILITIES OF NPADPRES FOR GROUP NPADPRES</p> <p>'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>
<p>HISTOGRAM OF PREDICTED PROBABILITIES OF NPADPRES FOR GROUP NPADABS</p> <p>'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>	<p>HISTOGRAM OF PREDICTED PROBABILITIES OF NPADPRES FOR GROUP NPADABS</p> <p>'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>
<p>HISTOGRAM OF PREDICTED PROBABILITIES OF NPADPRES FOR GROUP NPADPRES</p> <p>'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>	<p>HISTOGRAM OF PREDICTED PROBABILITIES OF NPADPRES FOR GROUP NPADPRES</p> <p>'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>
<p>HISTOGRAM OF PREDICTED PROBABILITIES OF NPADPRES FOR GROUP NPADABS</p> <p>'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>	<p>HISTOGRAM OF PREDICTED PROBABILITIES OF NPADPRES FOR GROUP NPADABS</p> <p>'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>

Sampling periods 1-4: habitat variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
 'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
 EACH 'X' REPRESENTS 2 RESPONSES, '.33' REPRESENTS FEWER THAN
 'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.

Sampling periods 6-7: habitat variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
 'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
 EACH 'X' REPRESENTS 2 RESPONSES, '.33' REPRESENTS FEWER THAN
 'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.

Sampling periods 1-4: habitat and sampling variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
 'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
 EACH 'X' REPRESENTS 2 RESPONSES, '.33' REPRESENTS FEWER THAN
 'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.

Sampling periods 6-7: habitat and sampling variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
 'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED PROBABILITIES OF MPADPRES FOR GROUP MPADPRES
 EACH 'X' REPRESENTS 2 RESPONSES, '.33' REPRESENTS FEWER THAN
 'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.

APPENDIX II.1
RESULTS OF UNIVARIATE ANALYSIS
OF CONTINUOUS HABITAT AND SAMPLING VARIABLES
FOR NOTROPIS PHOTOGENIS YOUNG-OF-THE-YEAR (YOY)

The following abbreviations are used:

N.p.	<u>Notropis photogenis</u>
S.D.	standard deviation
K-S 1	Kolmogorov-Smirnov one-sample test
(s)	skewed distribution
Levene	Levene's test for equality of variances
t(sep.)	t-test for separate variances
t(pool.)	t-test for pooled variances
M-W U	Mann-Whitney U-test
K-S 2	Kolmogorov-Smirnov two-sample test

APPENDIX II.1.1. Results of univariate analysis of continuous habitat and sampling variables for *Notropis photogenis* YOY in sampling period 2

variable	mean, subsites without & with N.P.	S.D., subsites without & with N.P.	K-S 1: p-value	Levene: p-value	t(sep.): p-value	t(pool.): p-value	M-W U: p-value	K-S 2: p-value
mean temperature (°C)	23.9	1.739	.628	.785		.745	.704	.751
temperature range (°C)	24.1	1.709						
	.05	.084	.001(s)	.800		.270	.142	.107
	.08	.081						
mean dissolved oxygen (mg/L)	10.3	1.827	.268	.235		.409	.466	.344
dissolved oxygen range (mg/L)	10.9	2.249						
	.15	.367	.003(s)	.517		.209	.007	.020
	.35	.536						
pH	8.2	.203	.175	.085	.454	.449	.457	.737
	8.1	.293						
conductivity (µmho/cm)	6.3x10 ²	120	.037	.456		.971	.786	.964
	6.3x10 ²	153						
turbidity (JTU)	18	5.18	.333	.042	.398		.428	.434
	20	6.96						
mean depth (cm)	30	11.2	.361(s)	.055	.003		.004	.035
	45	16.1						
depth range (cm)	30	21.5	.049(s)	.384		.047	.010	.014
	45	21.2						
mean current (m/s)	.43	.294	.444	.040	.071		.091	.190
	.28	.196						
current range (m/s)	.20	.274	.001(s)	.275		.325	.311	.693
	.30	.303						
stream width (m)	48	33.7	.465	.042	.708		.474	.163
	52	28.6						
distance from shore (m)	6.4	3.95	.520(s)	.894		.354	.411	.337
	7.8	5.43						
time	13.6	2.415	.809	.302		.803	.820	.892
	13.4	2.864						
duration (h)	.55	.236	.015	.486		.489	.059	.491
	.59	.130						
air temperature (°C)	24.1	2.410	.182	.768		.574	.338	.383
	23.7	2.324						

APPENDIX 11.1.2. Results of univariate analysis of continuous habitat and sampling variables for *Notropis photogenia* YOY in sampling period 3

variable	mean, subsites without & with N.P.	S.D., subsites without & with N.P.	K-S 1: p-value	Levene: p-value	t(sep.): p-value	t(pool.): p-value	M-W U: p-value	K-S 2: p-value
mean temperature ($^{\circ}$ C)	21.8	1.711	.739	.857		.171	.080	.065
temperature range ($^{\circ}$ C)	21.0	1.499	.000(s)	.161		.018	.009	.065
mean dissolved oxygen (mg/L)	10.7	1.522	.421	.820		.736	.519	.863
dissolved oxygen range (mg/L)	10.5	1.623	.055(s)	.335		.030	.011	.068
pH	.32	.289			.011	.016	.019	.028
	8.3	.145	.681	.056				
conductivity (μ mho/cm)	8.1	.079	.247	.454		.849	.460	.637
	6.1x10 ²	139						
turbidity (JTU)	6.2x10 ²	153	.838	.295		.832	.866	.886
mean depth (cm)	16	7.66						
	17	6.08	.378	.579		.001	.001	.005
depth range (cm)	30	13.4						
	47	14.6	.200	.067	.006	.004	.002	.007
	28	18.4						
mean current (m/s)	50	24.0	.848	.318		.000	.000	.001
	.53	.232						
current range (m/s)	.23	.176	.090(s)	.543		.553	.611	.973
	.24	.277						
stream width	.30	.323	.465	.000	.389		.878	.071
	53	39.9						
distance from shore (m)	45	11.9	.520(s)	.077	.882	.889	.382	.175
	7.0	5.55						
time	7.2	3.50	.727	.038	.021		.040	.018
	13.3	2.621						
duration (h)	11.5	1.807	.013(s)	.191		.217	.318	.996
	.50	.097	.661(s)	.597		.174	.057	.111
air temperature ($^{\circ}$ C)	.56	.193						
	21.2	3.182						
	19.8	2.593						

APPENDIX II.1.3. Results of univariate analysis of continuous habitat and sampling variables for *Notropis photogenis* YOY in sampling period 4

variable	mean, subsites without & with N.p.	S.D., subsites without & with N.p.	K-S 1: p-value	Levene: p-value	t(sep.): p-value	t(pool.): p-value	M-W U: p-value	K-S 2: p-value
mean temperature (°C)	20.8	.673	.237	.654		.645	.949	.978
temperature range (°C)	20.9	.729	.005(a)	.479		.263	.298	.973
	.05	.069						
	.09	.126						
mean dissolved oxygen	10.0	1.453	.671	.194		.437	.386	.309
(mg/L)	9.5	1.910						
dissolved oxygen range	.12	.227	.025(a)	.837		.090	.008	.012
(mg/L)	.25	.203						
pH	7.9	.365	.574	.858		.559	.532	.573
	7.9	.353						
conductivity ($\mu\text{mho/cm}$)	6.5×10^2	221	.071	.270		.588	.354	.512
	6.8×10^2	169						
turbidity (JTU)	18	4.90	.706	.115		.202	.270	.573
	20	7.12						
mean depth (cm)	28	12.6	.476	.195		.001	.001	.004
	45	14.9						
depth range (cm)	29	22.2	.311(a)	.528		.002	.000	.004
	55	22.1						
mean current (m/s)	.48	.273	.324	.014	.002		.007	.007
	.22	.173						
current range (m/s)	.23	.271	.052(a)	.704		.441	.460	.913
	.31	.316						
stream width (m)	51	39.4	.465	.001	.616		.786	.455
	46	15.9						
distance from shore (m)	7.1	5.55	.520(b)	.183		.876	.702	.512
	6.9	3.75						
time	11.3	1.936	.518	.144		.095	.147	.305
	12.6	2.518						
duration (h)	.48	.120	.021(a)	.804		.539	.514	.999
	.51	.134						
air temperature (°C)	19.9	1.574	.575	.379		.010	.016	.021
	21.5	1.850						

APPENDIX II.1.4. Results of univariate analysis of continuous habitat and sampling variables for *Notropis photogenis* YOY in sampling period 5

variable	mean, subsites without & with N.p.	S.D., subsites without & with N.p.	K-S 1: p-value	Levene: p-value	t(sep.): p-value	t(pool.): p-value	M-W U: p-value	K-S 2: p-value
mean temperature (°C)	5.8	.951	.243	.700		.403	.214	.164
temperature range (°C)	6.2	1.071						
	.15	.167	.064(s)	.050	.108		.654	.469
	.08	.045						
mean dissolved oxygen (mg/L)								
dissolved oxygen range (mg/L)								
pH	8.3	.110	.354	.346		.443	.418	.990
	8.3	.084						
conductivity (µmho/cm)	6.1x10 ²	82.1	.040	.026	.148		.504	.747
	6.5x10 ²	46.7						
turbidity (JTU)	17	7.21	.609	.040	.013		.213	.252
	12	2.17						
mean depth (cm)	40	12.7	.946	.237		.052	.112	.445
	54	17.4						
depth range (cm)	37	18.9	.167(s)	.447		.002	.006	.013
	71	23.9						
mean current (m/s)	.53	.318	.687	.382		.017	.018	.110
	.15	.215						
current range (m/s)	.33	.398	.066(s)	.781		.841	.716	.999
	.29	.429						
stream width (m)	43	26.1	.693	.606		.671	.644	.873
	48	21.0						
distance from shore (m)	6.1	3.89	.560(s)	.104		.726	.977	.469
	5.5	1.60						
time	12.6	1.804	.443	.055	.942	.919	.954	.663
	12.5	2.843						
duration (h)	.44	.088	.024	.000	.122		.055	.102
	.68	.277						
air temperature (°C)	9.3	2.12	.383	.268		.211	.250	.591
	7.9	1.66						

APPENDIX II.2. Results of χ^2 tests (p-values) of categorical habitat and sampling variables for Notropis photogenis young-of-the-year

variable	sampling period			
	2	3	4	5
habitat type	.012	.003	.002	.200
colour	.515	.792	.118	.075
clarity	.092	.214	.654	.812
secchi depth	.092	.030	.024	-
substrate	.319	.563	.223	-
encrusting vegetation	.887	.413	.299	.090
submersed vegetation	.055	.514	.067	.750
shore vegetation	.057	.142	.662	.994
river	.107	.006	.031	.152
day	.037	.022	.077	.286
distance hauled	.063	.038	.812	.504
cloud cover	.138	.098	.072	.684
wind	.913	.773	.158	.836
precipitation	.832	.718	.128	.187

APPENDIX II.3
RESULTS OF LOGISTIC REGRESSION ANALYSIS
OF HABITAT AND SAMPLING VARIABLES
FOR NOTROPIS PHOTOGENIS YOUNG-OF-THE-YEAR (YOY)

The following abbreviations are used:

N.p.	<u>Notropis photogenis</u>
p	p-value
improve.	improvement χ^2 -test
Hosmer	Hosmer-Lemeshow goodness of fit test
Brown	C.C. Brown goodness of fit test
coeff.	regression coefficient
S.E.	standard error of regression coefficient

APPENDIX II.3.1. Results of logistic regression analysis of habitat (H) and sampling (HS) variables for Notropis photogenis YOY

samp- ling period	total no. sub- sites	no. sub- sites with N.p.	variable	step no.	variable entered			final model		
					step prove.: p	im- mar: p	Brown: p	coeff.	S.E.	coeff./ S.E.
2(H)	35	17	habitat type	1	.001	-	1.000	-1.64	.639	-2.57
			clarity	2	.072	.303	1.000	-.977	.619	-1.58
			constant					-.316	.648	-.488
2(HS)	35	18	habitat type	1	.000	-	1.000	-1.61	.597	-2.70
			cloud cover	2	.099	.384	.601	-.726	.464	-1.57
			constant					-.550	.591	-.930
3(H)	36	16	habitat type	1	.000	-	1.000	-6.42	.000	-
			mean depth	4	.041	.730	.722	.115	.070	1.64
			mean current	2	.019	.351	.421	-8.78	4.22	-2.08
			shore vegetation	3	.046	.508	.150	-1.40	.779	-1.79
			constant					-7.40	2.16	-3.43
3(HS)	36	16	habitat type	1	.000	-	1.000	-6.42	.000	-
			mean depth	4	.041	.730	.722	.115	.070	1.64
			mean current	2	.019	.351	.421	-8.78	4.22	-2.08
			shore vegetation	3	.046	.508	.150	-1.40	.779	-1.79
			constant					-7.40	2.16	-3.43
4(H)	34	15	habitat type	1	.000	-	1.000	-7.80	1.87	-4.17
			colour	2	.005	.993	1.000	2.03	.847	2.39
			stream width	3	.029	.265	.399	-.059	.034	-1.74
			constant					-4.32	.000	-
4(HS)	35	15	habitat type	1	.000	-	1.000	-8.08	2.04	-3.96
			stream width	3	.002	.855	.330	-.082	.039	-2.10
			cloud cover	2	.028	.993	1.000	2.61	1.05	2.49
			constant					-3.90	.000	-
5(H)	28	5	depth range	1	.004	.339	.329	.064	.027	2.38
			constant					-4.84	1.66	-2.91
5(HS)	27	4	depth range	3	.025	-	1.000	.856	3.73	.230
			duration	1	.000	.672	.723	.278	.554	.050
			precipitation	2	.064	.965	.999	28.1	.514	.055
			constant					-230	.3277	-.070
2-4 (H)	103	48	habitat type	0	-	-	-	-1.33	.577	-2.31
			mean depth	1	.017	.567	.611	-.048	.021	2.25
			mean current	2	.041	.158	.315	-2.43	1.28	-1.91
			shore vegetation	3	.060	.637	.533	-.500	.269	-1.86
			constant					-2.03	.942	-2.16
2-4 (HS)	106	49	habitat type	0	-	-	-	-1.34	.577	-3.19
			mean depth	3	.089	.477	.339	.045	.025	1.77
			shore vegetation	1	.011	.873	1.000	-1.26	.402	-3.14
			river	2	.004	.625	.391	.898	.399	2.25
			wind	4	.089	.522	.287	-.631	.383	-1.65
			constant					-2.44	.968	-2.52

APPENDIX II.4
PREDICTED PROBABILITIES OF LOGISTIC REGRESSION
MODELS USING HABITAT AND SAMPLING VARIABLES
FOR NOTROPIS PHOTOGENIS YOUNG-OF-THE-YEAR (YOY)

The following abbreviations are used:

NPYOYPRE N. photogenis YOY present

NPYOYABS N. photogenis YOY absent

Sampling period 2: habitat variables	Sampling period 3: habitat variables
<p>HISTOGRAM OF PREDICTED PROBABILITIES OF MPTOTPRE FOR GROUP MPTOTPRE 'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>	<p>HISTOGRAM OF PREDICTED PROBABILITIES OF MPTOTPRE FOR GROUP MPTOTPRE 'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>
<p>HISTOGRAM OF PREDICTED PROBABILITIES OF MPTOTPRE FOR GROUP MPTOTPRE 'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>	<p>HISTOGRAM OF PREDICTED PROBABILITIES OF MPTOTPRE FOR GROUP MPTOTPRE 'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>
Sampling period 2: habitat and sampling variables	Sampling period 3: habitat and sampling variables
<p>HISTOGRAM OF PREDICTED PROBABILITIES OF MPTOTPRE FOR GROUP MPTOTPRE 'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>	<p>HISTOGRAM OF PREDICTED PROBABILITIES OF MPTOTPRE FOR GROUP MPTOTPRE 'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>
<p>HISTOGRAM OF PREDICTED PROBABILITIES OF MPTOTPRE FOR GROUP MPTOTPRE 'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>	<p>HISTOGRAM OF PREDICTED PROBABILITIES OF MPTOTPRE FOR GROUP MPTOTPRE 'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.</p>

Sampling period 5: habitat variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MPTOTPRE FOR GROUP MPTOTPRE

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HISTOGRAM OF PREDICTED PROBABILITIES OF EMPLOYERS FOR GROUP MPYOVABUS

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Sampling period 5: habitat and sampling variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MPOYPRE FOR GROUP MPOYPRE
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HISTOGRAM OF PREDICTED PROBABILITIES OF NPYOYPR FOR GROUP NPYOYABS

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Sampling period 4: habitat variables

HISTOGRAM OF PREDICTED PROBABILITIES OF NPYO TYPE FOR GROUP NPYOYPRE

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FOR INFORMATION OF THE GROUP MEMBERS

HISTOGRAM OF PREDICTED PROBABILITIES OF MPTOTYPE FOR GROUP 1. $\bar{m}$ MARKS THE MEDIAN, $\bar{q}$ MARKS THE QUANTILES.

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Sampling period 4: habitat and sampling variables

HISTOGRAM OF PREDICTED PROPANIL VALUES OF MPYOYPE FOR GROUP MPYOYPE

MARKS THE MEDIAN

$$0 \xrightarrow{.33} x \xrightarrow{.67} x+q \xrightarrow{.67} x+q+M \xrightarrow{.67} x+q+M+Q \xrightarrow{.67} x+q+M+Q+U$$

HISTOGRAM OF PREDICTED PROBABILITIES OF 'NPOYTPRE FOR GROUP NPYOYABG
'M' MARKS THE MEDIAN, 'U' MARKS THE QUANTILES.

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N	δ
1	0.95
2	0.85
3	0.75
4	0.65
5	0.55
6	0.45
7	0.35
8	0.25
9	0.15
10	0.05

APPENDIX III.1
RESULTS OF UNIVARIATE ANALYSIS
OF CONTINUOUS HABITAT AND SAMPLING VARIABLES
FOR NOTROPIS RUBELLUS ADULTS

The following abbreviations are used:

N.r.	<u>Notropis rubellus</u>
S.D.	standard deviation
K-S 1	Kolmogorov-Smirnov one-sample test
(s)	skewed distribution
Levene	Levene's test for equality of variances
t(sep.)	t-test for separate variances
t(pool.)	t-test for pooled variances
M-W U	Mann-Whitney U-test
K-S 2	Kolmogorov-Smirnov two-sample test

APPENDIX III.1.1. Results of univariate analysis of continuous habitat and sampling variables for *Notropis rubellus* adults in sampling period 1

variable	mean, subsites without & with N.R.	S.D., subsites without & with N.R.	K-S 1: p-value	Levene: p-value	t(sep.): p-value	t(pool.): p-value	M-W U: p-value	K-S 2: p-value
mean temperature (°C)	23.0	1.505	.742	.097	.844	.824	.464	.210
temperature range (°C)	22.9	2.236	.000(a)	.549		.708	.536	.978
	.06	.088						
	.07	.075						
mean dissolved oxygen (mg/L)	11.0	1.965	.993	.392		.992	.869	.784
dissolved oxygen range	11.0	1.666	.043(a)	.582		.895	.736	.999
	.36	.538						
	.34	.371						
pH	8.2	.166	.157	.026	.018		.021	.245
	8.0	.257						
conductivity (μmho/cm)	7.0x10 ²	280	.028(a)	.092	.599	.671	.463	.285
	6.7x10 ²	119						
turbidity (JTU)	17	8.46	.766	.058	.969	.973	.655	.775
	17	5.31						
mean depth (cm)	36	12.6	.572	.454		.279	.356	.483
	41	15.1						
depth range (cm)	34	21.2	.173(a)	.771		.638	.610	.892
	38	20.8						
mean current (m/s)	.33	.265	.429	.599		.403	.323	.415
	.41	.236						
current range (m/s)	.20	.275	.005(a)	.658		.375	.327	.683
	.28	.273						
stream width (m)	45	27.9	.465	.756		.229	.331	.714
	58	35.5						
distance from shore (m)	5.6	3.59	.520(a)	.301		.011	.007	.024
	9.7	5.53						
time	12.7	2.611	.473	.771		.374	.171	.133
	11.8	2.821						
duration (h)	.55	.172	.004	.243		.708	.733	1.000
	.53	.085						
air temperature (°C)	23.1	2.594	.684	.413		.278	.293	.737
	21.9	3.251						

APPENDIX III.1.2. Results of univariate analysis of continuous habitat and sampling variables for *Motropia rubellus* adults in sampling period 2

variable	mean, subsites without & with N.R.	S.D., subsites without & with N.R.	K-S 1: p-value	Levene: p-value	t(sep.): p-value	t(pool.): p-value	M-W U: p-value	K-S 2: p-value
mean temperature (°C)	23.6	1.820	.628	.275		.087	.104	.374
temperature range (°C)	24.6	1.372						
	.06	.096	.001(s)	.179		.789	.380	.374
mean dissolved oxygen	10.7	1.960	.268	.346		.712	.700	.795
dissolved oxygen range	10.4	2.178						
	.22	.505	.003(s)	.892		.700	.304	.609
pH	.28	.400						
	8.2	.261	.175	.793		.364	.508	.930
conductivity (µmho/cm)	8.1	.233						
	6.3x10 ²	167	.037	.028	.991		.231	.431*
turbidity (JTU)	18	77						
	21	5.79	.333	.583		.075	.054	.092
mean depth (cm)	32	6.05						
	45	11.3	.361(s)	.020	.021		.030	.115
depth range (cm)	32	17.8						
	45	16.9	.049(s)	.006	.112		.183	.374
mean current (m/s)	.31	27.3						
	.43	.241	.444	.489		.171	.199	.701
current range (m/s)	.26	.277						
	.24	.293	.001(s)	.701		.783	.816	.999
stream width (m)	45	.291						
	56	27.6	.465	.464		.275	.467	.746
distance from shore (m)	5.8	35.2						
	9.0	2.83	.520(s)	.016	.079		.154	.550
time	13.1	6.22						
	14.0	2.300	.809	.228		.357	.448	.790
duration (h)	.57	3.022						
	.57	.214	.015	.927		.984	.760	.991
air temperature (°C)	23.6	.149						
	24.4	2.351	.182	.772		.307	.252	.285
		2.334						

APPENDIX H1.1.3. Results of univariate analysis of continuous habitat and sampling variables for *Notropis rubellus* adults in sampling period 3

variable	mean, subsites & without & with N.R.	S.D., subsites without & with N.R.	K-S 1: p-value	Levene: p-value	t(sep.): p-value	M-W U: p-value	K-S 2: p-value
mean temperature ($^{\circ}\text{C}$)	21.8	1.354	.739	.076	.100	.054	.104
temperature range ($^{\circ}\text{C}$)	20.7	1.989	.000(s)	.100	.216	.145	.867
	.04	.077					
	.09	.116					
mean dissolved oxygen (mg/L)	10.6	1.596	.421	.447		.943	.564
dissolved oxygen range (mg/L)	10.6	1.507	.055(s)	.370		.090	.274
	.16	.243					
	.32	.302					
pH	8.3	.125	.681	.159		.003	.085
	8.1	.083					
conductivity ($\mu\text{mho/cm}$)	6.3x10 ²	149	.247	.693		.356	.813
	5.8x10 ²	131					
turbidity (JTU)	17	7.64	.838	.079	.281	.346	.377
mean depth (cm)	15	5.10	.378	.833		.112	.163
	34	16.0					
	43	15.4					
depth range (cm)	34	21.8	.200	.582		.132	.177
	46	25.2					
mean current (m/s)	.38	.285	.848	.121		.653	.699
	.42	.190					
current range (m/s)	.25	.278	.090(s)	.616		.631	1.000
	.30	.338					
stream width (m)	55	35.4	.465	.006	.066		.244
	39	14.7					
distance from shore (m)	6.5	4.88	.520(s)	.981		.266	.192
	8.3	4.29					
time	13.0	2.478	.727	.471		.087	.284
	11.6	2.122					
duration (h)	.51	.095	.013(s)	.079	.544	.425	1.000
	.55	.224					
air temperature ($^{\circ}\text{C}$)	21.2	2.241	.661(s)	.028	.176	.932	.192
	19.4	3.983					

APPENDIX III.1.4. Results of univariate analysis of continuous habitat and sampling variables for *Notropis rubellus* adults in sampling period 4

variable	mean, subsites without & with N.R.	S.D., subsites without & with N.R.	K-S 1: p-value	Levene: p-value	t(sep.): p-value	t(pool.): p-value	M-W U: p-value	K-S 2: p-value
mean temperature (°C)	20.9	.775	.237	.177		.566	.332	.340
temperature range (°C)	20.8 .06 .07	.488 .113 .063	.005(s)	.294		.845	.243	.714
mean dissolved oxygen (mg/L)	10.0 9.3	1.857 1.207	.671	.166		.242	.260	.380
dissolved oxygen range (mg/L)	.12 .25 8.0	.194 .247 .382	.025(s)	.097	.105	.080	.084	.407
pH	7.7 6.6x10 ² 6.7x10 ²	.247 .183 74	.574	.018	.004		.019	.026
conductivity (µmho/cm)	18 21	5.94 5.40	.071	.015	.939		.415	.442
turbidity (JTU)	32 43	14.9 15.7	.706	.574		.059	.071	.172
mean depth (cm)	36 46	23.4 28.7	.476	.578		.046	.042	.133
depth range (cm)			.311(s)	.220		.280	.364	.818
mean current (m/s)	.35 .40	.260 .275	.324	.816		.544	.545	.636
current range (m/s)	.27 .24	.312 .251	.052(s)	.500		.723	.921	.999
stream width (m)	49 50	28.9 35.7	.465	.908		.919	.621	.683
distance from shore (m)	6.0 9.1	3.25 6.29	.520(s)	.052	.110	.050	.118	.428
time	11.0 13.2	1.914 2.312	.518	.211		.004	.007	.047
duration (h)	.50 .50	.123 .141	.021(s)	.509		.926	.987	1.000
air temperature (°C)	20.3 20.9	1.930 1.828	.575	.941		.378	.338	.504

APPENDIX I/I.1.5. Results of univariate analysis of continuous habitat and sampling variables for *Notropis rubellus* adults in sampling period 6

variable	mean, subsites without & with N.R.	S.D., subsites without & with N.R.	K-S 1: p-value	Levene: p-value	t(sep.): p-value	M-W U: p-value	K-S 2: p-value
mean temperature (°C)	15.4	2.943	.521	.021	.089	.107	.365
temperature range (°C)	17.1	1.740	.000(a)	.675	.834	.879	1.000
mean dissolved oxygen (mg/L)	.02	.044					
dissolved oxygen range	.03	.046	.777	.042	.406	.380	.234
mean dissolved oxygen (mg/L)	12.8	2.011	.074(a)	.920	.864	.804	.988
dissolved oxygen range	11.9	3.221	.223	.111	.799	.628	.791
pH	.11	.152	.552	.986	.205	.249	.433
	.10	.130	.781	.734	.341	.335	.845
	8.3	.296	.471	.772	.301	.233	.451
	8.3	.391	.109	.067	.136	.160	.156
conductivity (µmho/cm)	52	299	.685	.818	.050	.029	.086
	29	.289	.018(a)	.232	.404	.541	.785
turbidity (JTU)	.21	.254	.716	.311	.740	.834	.828
mean depth (cm)	.30	.300	.232(a)	.386	.551	.706	.507
depth range (cm)	53	40.2	.555	.265	.801	.738	.670
mean current (m/s)	49	25.9	.069(a)	.078	.001	.001	.017
current range (m/s)	7.4	5.92	.377	.120	.688	.539	.172
stream width (m)	6.2	4.12					
distance from shore (m)	12.8	2.703					
time	12.6	2.335					
duration (h)	.46	.065					
air temperature (°C)	.62	.164					
	19.7	4.988					
	20.4	3.667					

APPENDIX III.1.6. Results of univariate analysis of continuous habitat and sampling variables for *Notropis rubellus* adults in sampling period 7

variable	mean, subsites without & with N.r.	S.D., subsites without & with N.r.	K-S 1: p-value	Levene: p-value	t(aep.): p-value	t(pool.): p-value	H-M U: p-value	K-S 2: p-value
mean temperature (°C)	16.0	1.677	.405	.034	.639		.622	.372
temperature range (°C)	16.4	2.327						
	.01	.030	.000(a)	.017	.258		.199	.976
mean dissolved oxygen (mg/L)	12.3	1.707	.578	.627		.004	.022	.026
dissolved oxygen range (mg/L)	9.9	1.463	.007(a)	.128		.512	.712	.991
pH	.71	.285						
	.04	.073						
conductivity (μmho/cm)	6.2x10 ²							
	6.0x10 ²	259	.447(a)	.024	.830		.322	.250
turbidity (JTU)	14	128						
	16	3.93	.780	.300		.436	.522	.937
mean depth (cm)	31	5.89	.663(a)	.188		.016	.018	.032
depth range (cm)	45	8.4						
	23	15.4	.744(a)	.023	.019		.035	.037
	43	7.1						
mean current (m/s)	.49	21.1	.615	.126		.115	.101	.230
	.26	.332						
current range (m/s)	.34	.309	.243	.684		.932	.933	.999
	.36	.334						
stream width (m)	35	24.2	.990	.469		.454	.549	.493
	42	19.7						
distance from shore (m)	4.7	2.67	.519(a)	.151		.061	.062	.250
	7.9	4.44						
time	12.6	1.760	.778	.491		.178	.159	.294
	11.5	1.992						
duration (h)	.50	.148	.195	.807		.419	.308	.886
	.55	.127						
air temperature (°C)	17.2	3.263	.681(a)	.200		.788	.972	.932
	17.6	4.073						

APPENDIX III.2. Results of X^2 tests (p-values) of categorical habitat and sampling variables for Notropis rubellus adults

variable	sampling period					
	1	2	3	4	6	7
habitat type	.156	.433	.155	.423	.288	.141
colour	.022	.251	.435	.015	.146	.674
clarity	.498	.068	.730	.130	.088	.216
secchi depth	.184	.025	.959	.395	-	-
substrate	.099	.703	.538	.508	.683	.004
encrusting vegetation	.158	.254	.334	.574	.113	.280
submersed vegetation	.186	.281	.120	.023	-	.110
shore vegetation	.790	.205	.296	.096	.586	.439
river	.134	.046	.060	.026	.392	.174
day	.316	.019	.291	.078	.386	.256
distance hauled	.651	.029	.186	.510	.959	.119
cloud cover	.535	.778	.482	.087	.109	.587
wind	.966	.556	.995	.093	.086	.537
precipitation	.947	.137	.211	.156	.638	.476

APPENDIX III.3
RESULTS OF LOGISTIC REGRESSION ANALYSIS
OF HABITAT AND SAMPLING VARIABLES
FOR NOTROPIS RUBELLUS ADULTS

The following abbreviations are used:

N.r.	<u>Notropis rubellus</u>
p	p-value
improve.	improvement χ^2 -test
Hosmer	Hosmer-Lemeshow goodness of fit test
Brown	C.C. Brown goodness of fit test
coeff.	regression coefficient
S.E.	standard error of regression coefficient

APPENDIX III.3.1. Results of logistic regression analysis of habitat (H) and sampling (HS) variables for Notropis rubellus adults in sampling periods 1 to 3

sampling period	total no. sub-sites	no. sub-sites with N.r.	variable	step no.	variable entered			final model		
					im- step prove.: no. p	Hos- mar: p	Brown: p	coeff.	S.E.	coeff./ S.E.
1(H)	34	13	colour	5	.066	.873	.733	2.08	1.38	1.50
			current range	2	.029	.253	.200	8.75	4.05	2.16
			encrusting vegetation	4	.014	.988	.677	2.89	1.86	1.55
			submersed vegetation	3	.010	.581	.000	-1.83	1.39	-1.14
			distance from shore	1	.010	.274	.397	.367	.156	2.36
			constant					-6.18	2.47	-2.50
1(HS)	35	13	colour	3	.008	.007	.106	2.96	1.33	2.22
			current range	2	.020	.180	.250	9.51	4.58	2.08
			encrusting vegetation	4	.006	.265	.655	2.03	.985	2.07
			distance from shore	1	.013	.804	.503	.383	.169	2.27
			constant					-6.71	2.86	-2.35
2(H)	35	15	depth range	4	.034	.505	.980	.221	.101	2.19
			mean current	2	.007	.616	.510	17.0	7.98	2.13
			distance from shore	3	.000	.733	.837	.978	.479	2.04
			constant					-22.5	10.3	-2.17
2(HS)	35	14	depth range	1	.018	.699	.453	.221	.096	2.29
			mean current	3	.000	.192	.685	16.1	7.88	2.04
			distance from shore	2	.003	.420	.144	.957	.456	2.10
			constant					-21.9	9.88	-2.22
3(H)	36	12	mean temperature	1	.064	.160	.389	-1.13	.494	-2.28
			turbidity	3	.042	.777	.566	-.209	.099	-2.11
			mean depth	2	.068	.680	.306	.103	.042	2.43
			mean current	4	.045	.664	.668	4.68	2.64	1.78
			constant					20.4	10.0	2.04
3(HS)	36	12	mean temperature	1	.064	.160	.389	-1.06	.455	-2.32
			turbidity	3	.042	.777	.566	-.254	.115	-2.21
			mean depth	2	.068	.680	.306	.080	.038	2.13
			precipitation	4	.019	.967	.908	-6.19	10.1	-.614
			constant					16.4	0.00	-

APPENDIX III.3.2. Results of logistic regression analysis of habitat (H) and sampling (HS) variables for *Notropis rubellus* adults in sampling periods 4, 6, and 7

samp- ling period	total no. sub- sites	no. sub- sites with N.r.	variable	variable entered			final model			
				step no.	im- prove. p	Hos- mer: p	Brown: p	coeff.	S.E.	coeff./ S.E.
4(H)	35	13	colour	1	.004	-	1.000	100	1710	.059
			dissolved oxygen	3	.016	.436	.847	427	6170	.069
			range							
			turbidity	7	.023	-	1.000	2.72	27.0	.101
			mean depth	5	.008	.902	.762	3.22	45.4	.071
			mean current	4	.009	.539	.549	458	6630	.069
			distance from	2	.088	.466	.650	20.9	328	.064
			shore							
4(HS)	34	12	stream width	6	.001	.258	.000	-1.97	30.8	-.064
			constant					-528	6820	-.077
4(HS)	34	12	day	2	.064	.440	.388	.953	.585	1.63
			time	1	.004	.909	.720	.432	.217	1.99
			constant					-6.14	2.56	-2.40
6(H)	26	14	clarity	3	.002	.834	.841	101	12.6	7.98
			temperature range	7	.003	.872	.000	-342	173	-1.98
			conductivity	2	.011	.254	.017	.554	.057	9.69
			turbidity	6	.093	.962	.812	3.38	.000	-
			constant					-404	36.7	-11.0
6(HS)	26	14	clarity	3	.007	.134	.351	2.86	1.65	1.74
			conductivity	2	.020	.309	.013	.019	.0088	2.16
			duration	1	.000	.948	.954	28.2	13.4	2.11
			constant					-26.4	10.6	-2.48
7(H)	18	9	mean dissolved	1	.004	.224	.988	-18.0	105	-.171
			oxygen							
			depth range	2	.036	.255	.681	6.81	33.9	.201
			current range	4	.012	-	1.000	74.3	417	.178
			shore vegeta-	3	.014	.386	.487	84.3	800	.105
			tion							
7(HS)	18	9	constant					14.5	979	.015
			mean dissolved	1	.004	.224	.988	-18.0	105	-.171
			oxygen							
			depth range	2	.036	.255	.681	6.81	33.9	.201
			current range	4	.012	-	1.000	74.3	417	.178
			shore vegeta-	3	.014	.386	.487	84.3	800	.105
			tion							
			constant					14.5	979	.015

APPENDIX III.3.3. Results of logistic regression analysis of habitat (H) and sampling (HS) variables for Notropis rubellus adults in sampling periods 1-4 and 6-7

samping period	total no. sub- sites	no. sub- sites with N.R.	variable	step no.	variable entered			final model		
					im- prove.: p	Hos- mer: p	Brown: p	coeff.	S.E.	coeff. S.E.
1-4(H)	139	51	colour	3	.000	.842	.342	2.06	.585	3.52
			clarity	5	.004	.893	.143	-1.63	.620	-2.63
			mean depth	1	.000	.145	.632	.054	.026	2.08
			depth range	6	.033	.636	.574	.046	.022	2.12
			mean current	2	.000	.765	.624	7.27	1.39	4.57
			distance from shore	4	.000	.001	.028	.308	.072	4.26
			constant					-9.21	1.67	-5.52
1-4(HS)	133	49	colour	1	.000	-	1.000	2.12	.602	3.53
			clarity	5	.010	.248	.295	-1.43	.634	-2.25
			mean depth	6	.050	.206	.287	.048	.025	1.93
			depth range	4	.000	.476	.237	.052	.021	2.49
			mean current	3	.001	.400	.609	7.84	1.79	4.38
			distance from shore	2	.000	.604	.795	.327	.075	4.36
			constant					-9.86	1.88	-5.25
6-7(H)	45	24	clarity	3	.012	.358	.823	1.24	.584	2.12
			conductivity	2	.072	.177	.154	.0071	.0029	2.45
			depth range	1	.003	.060	.031	.041	.022	1.84
			constant					-5.91	2.04	-2.90
6-7(HS)	49	26	depth range	2	.008	.548	.688	.041	.017	2.40
			duration	1	.003	.342	.272	8.12	3.28	2.47
			constant					-5.54	1.87	-2.97

APPENDIX III.4
PREDICTED PROBABILITIES OF LOGISTIC REGRESSION
MODELS USING HABITAT AND SAMPLING VARIABLES
FOR NOTROPIS RUBELLUS ADULTS

The following abbreviations are used:

NRADPRES N. rubellus adults present

NRADABS N. rubellus adults absent

Sampling period 2: habitat variables

HISTOGRAM OF PREDICTED PROBABILITIES OF WRAPPERS FOR GROUP WRAPPRES
 IF MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED PROBABILITIES OF READERES FOR GROUP READERS
 101 MARKS THE MEDIAN, 100 MARKS THE QUANTILES.

Sampling period 2: habitat and sampling variables

HISTOGRAM OF PREDICTED PROBABILITIES OF READPRES FOR GROUP READPRES
IN MARKS THE MEDIAN, Q MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED LIABILITIES OF READPERS FOR GROUP READABS IN: MARKS THE MEDIAN TO MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED PROBABILITIES OF READINGS FOR GROUP READINGS
'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED PROBABILITIES OF READPSES FOR GROUP READABS
 100 MARKS THE MEDIAN, 50 MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED PROBABILITIES OF MARRIAGES FOR GROUP MRAADPES
'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED PROBABILITIES OF TRAUMAS FOR GROUP HEADS
 'M' MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.

Sampling period 3: habitat variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MRADPRES FOR GROUP MRADPRES
 "M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

XX XX XX XX XX
 .33 .67 1.0

HISTOGRAM OF PREDICTED PROBABILITIES OF MRADPRES FOR GROUP MRADABS
 "M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

XX XX XX XX XX
 .33 .67 1.0

Sampling period 3: habitat and sampling variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MRADPRES FOR GROUP MRADPRES
 "M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

XX XX XX XX XX
 .33 .67 1.0

HISTOGRAM OF PREDICTED PROBABILITIES OF MRADPRES FOR GROUP MRADABS
 "M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

XX XX XX XX XX
 .33 .67 1.0

Sampling period 4: habitat variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MRADPRES FOR GROUP MRADPRES
 "M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

XX XX XX XX XX
 .33 .67 1.0

HISTOGRAM OF PREDICTED PROBABILITIES OF MRADPRES FOR GROUP MRADABS
 "M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

XXXXXXXXXXXXXXXXXXXX
 .33 .67 1.0

Sampling period 4: habitat and sampling variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MRADPRES FOR GROUP MRADPRES
 "M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

XX XX XX XX XX
 .33 .67 1.0

HISTOGRAM OF PREDICTED PROBABILITIES OF MRADPRES FOR GROUP MRADABS
 "M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

XXXXXXXXXX
 .33 .67 1.0

Sampling period 6: habitat variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MRADPRES FOR GROUP MRADPRES
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED PROBABILITIES OF MRADPRES FOR GROUP MRADABS
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

Sampling period 6: habitat and sampling variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MRADPRES FOR GROUP MRADPRES
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED PROBABILITIES OF MRADPRES FOR GROUP MRADABS
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

Sampling period 7: habitat variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MRADPRES FOR GROUP MRADPRES
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED PROBABILITIES OF MRADPRES FOR GROUP MRADABS
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

Sampling period 7: habitat and sampling variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MRADPRES FOR GROUP MRADPRES
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED PROBABILITIES OF MRADPRES FOR GROUP MRADABS
"M" MARKS THE MEDIAN, "Q" MARKS THE QUANTILES.

APPENDIX IV.1
RESULTS OF UNIVARIATE ANALYSIS
OF CONTINUOUS HABITAT AND SAMPLING VARIABLES
FOR NOTROPIS RUBELLUS YOUNG-OF-THE-YEAR (YOY)

The following abbreviations are used:

N.r.	<u>Notropis rubellus</u>
S.D.	standard deviation
K-S 1	Kolmogorov-Smirnov one-sample test
(s)	skewed distribution
Levene	Levene's test for equality of variances
t(sep.)	t-test for separate variances
t(pool.)	t-test for pooled variances
M-W U	Mann-Whitney U-test
K-S 2	Kolmogorov-Smirnov two-sample test

APPENDIX IV.1.1. Results of univariate analysis of continuous habitat and sampling variables for *Notropis rubellus* YOY in sampling period 2

variable	mean, subsites without & with N.R.	S.D., subsites without & with N.R.	K-S 1: p-value	Levene: p-value	t(sep.): p-value	t(pool.): p-value	M-W U: p-value	K-S 2: p-value
mean temperature (°C)	23.7	1.736	.628	.714		.176	.141	.193
temperature range (°C)	24.5	1.586	.001(a)	.820		.354	.250	.940
mean dissolved oxygen (mg/L)	.08	.089						
dissolved oxygen range	11.1	2.038	.268	.284		.048	.044	.211
pH	9.7	1.747	.003(a)	.552		.895	.592	.640
	.25	.499						
	.23	.397	.175	.885		.088	.121	.371
	8.2	.251						
conductivity (µmho/cm)	8.0	.228	.037	.116		.768	.394	.579
	6.3x10 ²	162						
turbidity (JTU)	6.2x10 ²	82	.333	.438		.011	.016	.004
mean depth (cm)	17	5.11						
depth range (cm)	22	6.40	.361(a)	.415		.036	.045	.056
	33	13.4						
	44	16.7	.049(a)	.017	.002		.002	.005
	28	24.0						
mean current (m/s)	54	.291	.444	.108		.352	.424	.594
current range (m/s)	.39	.195	.001(a)	.740		.188	.147	.435
	.31	.279						
stream width (m)	.20	.295	.465	.916		.685	.627	.702
	.33	33.1						
distance from shore (m)	48	28.1	.520(a)	.778		.870	.672	.435
	52	4.80						
time	7.2	4.76	.809	.700		.462	.501	.579
	6.9	2.600						
duration (h)	13.2	2.666	.015	.858		.490	.196	.579
	13.9	.211						
air temperature (°C)	.56	.152	.182	.159		.261	.074	.021
	.60	2.049						
	23.6	2.755						
	24.5							

APPENDIX IV.1.2. Results of univariate analysis of continuous habitat and sampling variables for *Notropis rubellus* YOY in sampling period 3

variable	mean, subsites without & with N.R.	S.D., subsites without & with N.R.	K-S 1: p-value	Levene: p-value	t(aep.): p-value	t(pool.): p-value	M-W U: p-value	K-S 2: p-value
mean temperature (°C)	21.9	1.218	.739	.023	.070		.085	.129
temperature range (°C)	20.7 .03	1.871 .045	.000(a)	.000	.012		.004	.129
mean dissolved oxygen (mg/L)	11.1 9.7	1.704 .695	.421	.044	.002		.007	.046
dissolved oxygen range (mg/L)	.16 .35	.219 .332	.055(a)	.168		.056	.074	.242
pH	8.3 8.1	.151 .093	.681	.056	.056	.048	.066	.132
conductivity (μmho/cm)	5.8x10 ² 6.6x10 ²	157 111	.247	.062	.116	.155	.070	.149
turbidity (JTU)	14 20	7.06 5.66	.838	.260		.031	.026	.051
mean depth (cm)	33 49	14.7 13.8	.378	.851		.004	.003	.011
depth range (cm)	26 63	12.4 21.4	.200	.034	.000		.000	.000
mean current (m/s)	.44 .28	.280 .172	.848	.042	.039		.083	.018
current range (m/s)	.21 .40	.303 .261	.090(a)	.867		.087	.029	.042
stream width (m)	50 46	34.8 21.9	.465	.303		.748	.835	.850
distance from shore (m)	6.9 6.5	4.79 4.48	.520(a)	.862		.801	.626	.588
time	12.9 11.7	2.252 2.571	.727	.987		.161	.130	.428
duration (h)	.48 .62	.078 .208	.013(a)	.073	.051	.009	.010	.021
air temperature (°C)	21.7 18.8	1.675 3.710	.661(a)	.004	.024		.020	.129

APPENDIX IV.1.3. Results of univariate analysis of continuous habitat and sampling variables for *Notropis rubellus* YOY in sampling period 4

variable	mean, subsites without & with N.R.	S.D., subsites without & with N.R.	K-S 1: p-value	Levene: p-value	t(sep.): p-value	t(pool.): p-value	M-W U: p-value	K-S 2: p-value
mean temperature (°C)	20.7	.819	.237	.001	.123		.458	.375
temperature range (°C)	21.1	.387	.005(a)	.425		.628	.985	1.000
	.05	.115						
mean dissolved oxygen (mg/L)	10.0	.065	.671	.526		.240	.299	.774
dissolved oxygen range	9.3	1.819	.025(a)	.313		.465	.454	.596
	.14	1.506						
pH	.19	.223	.574	.788		.006	.006	.020
	8.0	.330						
conductivity (μmho/cm)	7.7	.314	.071	.026	.427		.478	.499
	6.8x10 ²	246						
turbidity (JTU)	18	100	.706	.871		.147	.128	.308
	5.93							
mean depth (cm)	21	6.20	.476	.047	.197		.298	.234
	32	13.9						
depth range (cm)	39	17.9	.311(a)	.010	.047		.057	.044
	32	19.4						
mean current (m/s)	52	30.6	.324	.180		.328	.428	.612
	.39	.287						
current range (m/s)	30	.232	.052(a)	.968		.829	.689	.921
	.25	.298						
stream width (m)	.28	.290	.465	.276		.327	.479	.499
	44	24.3						
distance from shore (m)	53	28.7	.520(a)	.570		.489	.448	.397
	6.3	3.68						
time	7.3	3.89	.518	.865		.501	.448	.921
	11.5	2.245						
duration (h)	12.1	2.509	.021(a)	.366		.816	.533	1.000
	.49	.130						
air temperature (°C)	.50	.096	.575	.996		.774	.790	.875
	20.5	1.989						
	20.7	1.855						

APPENDIX IV.1.6. Results of univariate analysis of continuous habitat and sampling variables for *Notropis rubellus* YOY in sampling period 5

variable	mean, subsites without & with M.R.	S.D., subsites without & with M.R.	K-S 1: p-value	Levene: p-value	t(sep.): p-value	t(pool.): p-value	M-W U: p-value	K-S 2: p-value
mean temperature (°C)	5.8	.870	.243	.256		.099	.855	.129
temperature range (°C)	6.6	1.338						
	.14	.166	.064(a)	.020	.240		.567	.517
	.10	.000						
mean dissolved oxygen								
dissolved oxygen range								
(mg/L)								
pH	8.3	.108	.354	.682		.440	.631	.996
	8.3	.096						
conductivity (µmho/cm)	6.1x10 ²	78	.040	.263		.146	.926	.459
	6.7x10 ²	62						
turbidity (JTU)	17	7.13	.609	.086	.033	.227	.097	.405
	12	2.50						
mean depth (cm)	41	13.9	.946	.982		.158	.169	.464
	54	15.1						
depth range (cm)	39	20.4	.167(a)	.624		.006	.028	.065
	76	25.1						
mean current (m/s)	.49	.344	.687	.389		.334	.234	.763
	.31	.235						
current range (m/s)	.32	.395	.066(a)	.695		.833	.161	1.000
	.36	.458						
stream width (m)	44	25.7	.693	.716		.931	.926	.950
	45	23.8						
distance from shore (m)	6.3	3.75	.560(a)	.106		.242	.714	.167
	4.0	1.18						
time	12.6	1.804	.443	.015	.998		.068	.577
	12.6	3.114						
duration (h)	.46	.141	.024	.020	.465		.019	.459
	.58	.263						
air temperature (°C)	9.2	2.218	.383	.811		.631	.710	.927
	8.6	2.157						

APPENDIX IV.2. Results of χ^2 tests (p-values) of categorical habitat and sampling variables for Notropis rubellus young-of-the-year

variable	sampling period			
	2	3	4	5
habitat type	.106	.159	.578	.118
colour	.002	.018	.008	.118
clarity	.013	.020	.009	.224
secchi depth	.014	.005	.545	-
substrate	.006	.055	.167	-
encrusting vegetation	.496	.114	.383	.562
submersed vegetation	.126	.037	.033	.562
shore vegetation	.711	.825	.487	.592
river	.036	.021	.025	.100
day	.041	.053	.019	.041
distance hauled	.283	.217	.805	.558
cloud cover	.344	.058	.132	.941
wind	.165	.646	.062	.013
precipitation	.482	.191	.311	.667

APPENDIX IV.3
RESULTS OF LOGISTIC REGRESSION ANALYSIS
OF HABITAT AND SAMPLING VARIABLES
FOR NOTROPIS RUBELLUS YOUNG-OF-THE-YEAR (YOY)

The following abbreviations are used:

N.r.	<u>Notropis rubellus</u>
p	p-value
improve.	improvement χ^2 -test
Hosmer	Hosmer-Lemeshow goodness of fit test
Brown	C.C. Brown goodness of fit test
coeff.	regression coefficient.
S.E.	standard error of regression coefficient

APPENDIX IV.3.1. Results of logistic regression analysis of habitat (H) and sampling (HS) variables for *Metropis rubellus* YOY in sampling periods 2 to 5

samp- ling period	total no. sub- sites	no. sub- sites with N.r.	variable	step no.	variable entered			final model		
					prove.: p	Hos- mer: p	Brown: p	coeff.	S.E.	coeff./ S.E.
2(H)	35	13	colour	1	.000	-	1.000	5.90	.991	5.95
			depth range	2	.034	.826	1.000	.042	.022	1.90
			constant					-7.40	0.00	-
2(HS)	34	13	colour	1	.000	-	1.000	5.97	1.04	3.76
			depth range	2	.076	.979	.999	.037	.023	1.62
			constant					-7.20	0.00	-
3(H)	34	11	habitat type	4	.004	-	.000	28.0	54.2	.516
			mean temperature	2	.004	.922	.607	-25.2	37.9	-.664
			depth range	1	.000	.770	.868	3.44	5.38	.639
			stream width	3	.022	.841	.656	1.01	1.61	.626
			constant					353	525	.673
3(HS)	35	12	depth range	1	.000	.758	.870	1.63	12.8	.128
			duration	3	.041	.769	.897	223	1640	.136
			air temperature	2	.001	.971	.352	-14.4	118	-.123
			wind	4	.007	-	.000	15.2	126	.120
			constant					131	1410	.093
4(H)	33	14	colour	1	.001	-	1.000	1.49	.548	2.71
			mean temperature	2	.067	.804	.858	1.44	.888	1.62
			constant					-30.8	18.8	-1.64
4(HS)	34	13	colour	1	.001	-	1.000	16.2	0.00	-
			mean temperature	2	.061	.567	.858	7.87	3.31	2.38
			air temperature	3	.002	.950	.620	-3.41	1.43	-2.38
			cloud cover	3	.042	.485	.623	-13.8	0.00	-
			wind	4	.029	.991	.683	-5.48	2.13	-2.58
			constant					-92.7	42.7	-2.17
5(H)	29	4	habitat type	1	.054	-	1.000	-347	727	-.478
			temperature range	3	.022	.565	.880	-646	1330	-.484
			turbidity	4	.005	-	1.000	-14.0	28.9	-.482
			distance from shore	2	.011	.236	.644	-25.2	51.7	-.488
			constant					7.95	0.00	-
5(HS)	29	4	distance from shore	4	.001	-	.000	-40.4	56.8	-.712
			river	1	.049	-	1.000	91.3	456	.200
			duration	3	.016	.426	.586	423	588	.718
			cloud cover	2	.067	1.000	1.000	-63.7	448	-.142
			constant					-94.4	136	-.692

APPENDIX IV.3.2. Results of logistic regression analysis of habitat (H) and sampling (HS) variables for *Notropis rubellus* YOY in sampling periods 2-4

samping period	total no. sub- sites	no. sub- sites with N.R.	variable	variable entered			final model			
				step no.	in- prev.: p	Hos- mer: p	Brown: p	coeff.	S.E.	coeff./ S.E.
2-4(H)	100	36	colour	2	.000	.129	.783	1.63	.513	3.18
			sacchi depth	3	.032	.626	.475	-1.17	.554	-2.12
			depth range	1	.000	.508	.958	.090	.023	3.86
			shore vegetation	4	.047	.002	.003	.673	.361	1.87
			constant					-5.72	1.37	-4.17
2-4(HS)	101	36	colour	2	.000	.839	.811	1.76	.513	3.45
			sacchi depth	4	.027	.001	.002	-1.08	.546	-1.98
			depth range	1	.000	.427	.959	.089	.023	3.82
			shore vegetation	3	.050	.108	.020	.854	.367	2.33
			time	5	.097	.013	.018	.191	.118	-1.62
			constant					-3.23	1.94	-1.66

APPENDIX IV.4

PREDICTED PROBABILITIES OF LOGISTIC REGRESSION
MODELS USING HABITAT AND SAMPLING VARIABLES
FOR NOTROPIS RUBELLUS YOUNG-OF-THE-YEAR (YOY)

The following abbreviations are used:

NRYOYPRE : N. rubellus YOY present

NRYOYABS : N. rubellus YOY absent

Sampling period 2: habitat and sampling variables

HISTOGRAM OF PREDICTED PROBABILITIES OF NRYOYPRE FOR GROUP NRYOYPRE
 1.0 MARKS THE MEDIAN, .50 MARKS THE QUANTILES.

0
+

X X X X X
7
+

X X X X X

0
+

X X X X X
3
+

X X X X X

HISTOGRAM OF PREDICTED PROBABILITIES OF MRYOYPRE FOR GROUP MRYOYABS-
 'M'. MARKS THE MEDIAN, 'Q' MARKS THE QUANTILES.

Sampling period 3: habitat and sampling variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MAYOPIRE FOR GROUP MAYOPIRE
IN MARKS THE MEDIAN, '0' MARKS THE QUANTILES.

	+-----+	1.0
	+-----+	.67
	+-----+	.33
	+-----+	0

HISTOGRAM OF PREDICTED PROBABILITIES OF MOVEMENT FOR GROUP MAYAGVAD-
IN MARKS THE MEDIAN, IN MARKS THE QUANTILES.

Time	Temperature	Pressure	Humidity	Wind Speed	Wind Direction	Cloud Cover	Visibility	Remarks
0000	10.0	1010	65	10	090	04	10	Clear
0100	10.0	1010	65	10	090	04	10	Clear
0200	10.0	1010	65	10	090	04	10	Clear
0300	10.0	1010	65	10	090	04	10	Clear
0400	10.0	1010	65	10	090	04	10	Clear
0500	10.0	1010	65	10	090	04	10	Clear
0600	10.0	1010	65	10	090	04	10	Clear
0700	10.0	1010	65	10	090	04	10	Clear
0800	10.0	1010	65	10	090	04	10	Clear
0900	10.0	1010	65	10	090	04	10	Clear
1000	10.0	1010	65	10	090	04	10	Clear
1100	10.0	1010	65	10	090	04	10	Clear
1200	10.0	1010	65	10	090	04	10	Clear
1300	10.0	1010	65	10	090	04	10	Clear
1400	10.0	1010	65	10	090	04	10	Clear
1500	10.0	1010	65	10	090	04	10	Clear
1600	10.0	1010	65	10	090	04	10	Clear
1700	10.0	1010	65	10	090	04	10	Clear
1800	10.0	1010	65	10	090	04	10	Clear
1900	10.0	1010	65	10	090	04	10	Clear
2000	10.0	1010	65	10	090	04	10	Clear
2100	10.0	1010	65	10	090	04	10	Clear
2200	10.0	1010	65	10	090	04	10	Clear
2300	10.0	1010	65	10	090	04	10	Clear

3 3

OF / DE

Sampling periods 2-4: habitat variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MRYOTPRE FOR GROUP MRYOTPRE
M MARKS THE MEDIAN, Q MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED PROBABILITIES OF MRYOTPRE FOR GROUP MRYOTPRE
M MARKS THE MEDIAN, Q MARKS THE QUANTILES.

Sampling periods 2-4: habitat and sampling variables

HISTOGRAM OF PREDICTED PROBABILITIES OF MRYOTPRE FOR GROUP MRYOTPRE
M MARKS THE MEDIAN, Q MARKS THE QUANTILES.

HISTOGRAM OF PREDICTED PROBABILITIES OF MRYOTPRE FOR GROUP MRYOTPRE
M MARKS THE MEDIAN, Q MARKS THE QUANTILES.

APPENDIX V.1.1. Results of analysis of interspecific associations for *Notropis photogenis* adults in sampling periods 1 to 4

species	watershed analysed	1		2		3		4	
		no. subites analysed	χ^2 -test: p-value	no. subites analysed	χ^2 -test: p-value	no. subites analysed	χ^2 -test: p-value	no. subites analysed	χ^2 -test: p-value
<i>Dorosoma cepedianum</i>	Thames			14	.469				
<i>Nocomis</i> sp.	both	37	.095	36	.110	37	.118	36	.088
<i>Notropis cornutus</i> group	both	37	.620	37	.614	37	.121	36	.829
<i>N. photogenis</i> YOY	both	37	.960	37	.063	37	.416	36	.451
<i>N. rubellus</i> adults	both	37	.067	37	.001	37	.015	36	.231
<i>N. rubellus</i> YOY	both	37	.601	37	.112	35	.771	34	.056
<i>N. spilopterus</i>	Thames	14	.308	14	.134			14	.733
<i>N. volucellus</i>	Thames			14	.262				
<i>Pimephales notatus</i>	both	37	.070	36	.230	37	.342	36	.898
<i>Rhinichthys catarractae</i>	Grand	23	.246			23	.313		
<i>Semotilus atromaculatus</i>	Grand	23	.183			23	.394		
<i>Catostomus commersoni</i>	Grand	23	.133			23	.313		
<i>Hypentelium nigricans</i>	Grand								
<i>Ambloplites rupestris</i>	Thames	14	.216	14	.852				
<i>Micropterus dolomieu</i>	both	37	.228	37	.129	37	.246	36	.404
<i>Etheostoma blennioides</i>	Thames			14	.040			14	.597
<i>E. caeruleum</i>	Grand	23	.328			23	.313		
<i>E. nigrum</i>	Grand					23	.394		

APPENDIX V.1.2. Results of analysis of interspecific associations for *Notropis* photogenis adults in sampling periods 6 and 7

species	6 sampling period				7 sampling period			
	watershed analysed	no. subsites analysed	χ^2 -test: p-value	no. subsites analysed	χ^2 -test: p-value	watershed analysed	no. subsites analysed	χ^2 -test: p-value
<i>Dorosoma cepedianum</i>	Thames							
<i>Nocomis</i> sp.	both	30	.804	21	.306			
<i>Notropis cornutus</i> group	both	30	.098	21	.116			
<i>N. photogenis</i> YOY	both							
<i>N. rubellus</i> adults	both	30	.034	21	.001			
<i>N. rubellus</i> YOY	both							
<i>N. spilopterus</i>	Thames							
<i>N. volucellus</i>	Thames	11	.886					
<i>Pimephales notatus</i>	both	30	.002	21	1.000			
<i>Rhinichthys catarractae</i>	Grand							
<i>Semotilus atromaculatus</i>	Grand							
<i>Catostomus commersoni</i>	Grand							
<i>Hypentelium nigricans</i>	Grand							
<i>Ambloplites rupestris</i>	Thames							
<i>Micropterus dolomieu</i>	both							
<i>Etheostoma blennioides</i>	Thames							
<i>E. caeruleum</i>	Grand	19	.372	18	.160			
<i>E. nigrum</i>	Grand							

APPENDIX V.2. Results of analysis of interspecific associations for *Notropis photogenis* young-of-the-year

species	watershed analysed	sampling period				χ^2 -test: p-value	no. subites analysed	χ^2 -test: p-value	no. subites analysed	χ^2 -test: p-value
		2	3	4	5					
<i>Dorosoma cepedianum</i>	Thames	14	14	.826	.001					
<i>Nocomis</i> sp.	both	36	37	.888	.202		36	.018	29	.209
<i>Notropis cornutus</i> group	both	37	37	.030	.151		36	.548	29	.002
<i>N. photogenis</i> adults	both	37	37	.063	.416		36	.451		
<i>N. rubellus</i> adults	both	37	37	.638	.199		36	.393		
<i>N. rubellus</i> YOY	both	37	35	.898	.072		34	.201	29	.001
<i>N. spilopterus</i>	Thames	14	14	.124	.733		14	.036		
<i>N. volucellus</i>	Thames	14		.393						
<i>Pisephaeus notatus</i>	both	36	37	.881	.036		36	.210	29	.001
<i>Whitichthys cataractae</i>	Grand	23	23	.231	.108		22	.203		
<i>Semotilus atromaculatus</i>	Grand	23	23	.103	.175		22	.746		
<i>Catostomus commersoni</i>	Grand	23	23	.054	.108		22	.131		
<i>Hypentelium nigricans</i>	Grand	23	23	.103	.280		22	.926		
<i>Ambloplites rupestris</i>	Thames	14	14	.733	.826		36	.121		
<i>Micropterus dolomieu</i>	both	37	37	.291	.982		36		9	.257
<i>Etheostoma blennioides</i>	Thames	14	14	.119	.006		14	.010	20	.389
<i>E. caeruleum</i>	Grand	23	23	.704	.108		22	.952		
<i>E. nigrum</i>	Grand	23	23	.412	.175		22	.203		

END

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