# Fish life history and habitat use in the Northwest Territories: brook stickleback (*Culaea inconstans*)

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# FISH LIFE HISTORY AND HABITAT USE IN THE NORTHWEST TERRITORIES: BROOK STICKLEBACK (*Culaea inconstans*)

by

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The brook stickleback is a small, short-lived, forage fish that inhabits clear, cool, river and lake environments. Little is known of its life history in the Mackenzie Valley, where it appears to be uncommon downstream of the Liard River. Differences in habitat use by lacustrine and riverine populations and in the seasonal requirements of eggs, fry, juveniles, and adults are discussed. Shallow (<1.5 m), well-vegetated (>60% cover) shorelines with low water velocity and soft substrates provide particularly important spawning, feeding, and rearing habitats for the species. Brook stickleback populations will migrate seasonally to avoid anoxic conditions that cause winterkill. To support the assessment, avoidance and mitigation of environmental impacts in the Mackenzie Valley, the potential impacts of development activities and climate change on survival of the species are reviewed. Brook sticklebacks can tolerate low pH (5.0), low oxygen, or moderately elevated salinity. They are often early colonizers of fragmented habitats and will spawn in ephemeral habitats. As visual feeders, they are intolerant of elevated turbidity.

**Key words:** distribution; life history; habitat requirements; seasonal movements; reproduction; spawning; rearing; life cycle; Mackenzie watershed; hydrological integrity; fresh water; Gasterosteidae.

# RÉSUMÉ

Stewart, D.B., Reist, J.D., Carmichael, T.J., Sawatzky, C.D., and Mochnacz, N.J. 2007. Fish life history and habitat use in the Northwest Territories: brook stickleback (*Culaea inconstans*). Can. Manuscr. Rep. Fish. Aquat. Sci. 2799: vi + 30 p.

L'épinoche à cinq épines est un petit poisson fourrage de courte longévité qui habite les eaux froides et limpides des rivières et des lacs. On en connaît peu sur son cycle vital dans les eaux de la vallée du Mackenzie, où on ne la trouve pas souvent en aval de la rivière Liard. Nous discutons ici des différences dans l'utilisation des habitats par les populations lacustres et fluviales ainsi que des besoins saisonniers des œufs, des alevins, des juvéniles et des adultes. Les eaux littorales peu profondes (< 1.5 m), à végétation abondante (couverture > 60 %), où le courant est faible et les substrats sont mous, constituent des habitats particulièrement importants pour la fraie, l'alimentation et l'alevinage de l'espèce. L'épinoche à cinq épines migre de manière saisonnière de façon à éviter les conditions anoxiques qui peuvent entraîner une mortalité hivernale. Nous examinons les incidences éventuelles des activités humaines et du changement climatique sur la survie de l'espèce en appui de l'évaluation, de l'évitement ou de l'atténuation des incidences environnementales dans la vallée du Mackenzie. L'épinoche à cinq épines peut tolérer un faible pH (5,0), une faible concentration d'oxygène et une salinité modérée. Elle est souvent la première à coloniser un habitat fragmenté et pond dans des habitats éphémères. La capacité de voir ses proies étant essentielle à son alimentation, elle ne tolère pas une turbidité élevée.

**Mots clés :** répartition; cycle vital; exigences en matière d'habitat; déplacements saisonniers; reproduction; fraie; alevinage; bassin versant du Mackenzie; intégrité hydrologique; eau douce; Gastérostéidés.

# 1.0 INTRODUCTION

Renewed interest in natural gas pipeline development along the Mackenzie Valley has raised the prospect that fish species in this watershed may be impacted by changes to their habitat. The proposed pipeline would extend from near the Beaufort Sea coast to markets in the south (http://www.mackenziegasproject.com/). Fishes in the Mackenzie River depend upon the integrity of their aquatic habitats, so it is important to summarize knowledge that can be used to assess potential impacts of this and other developments, and to facilitate efforts to avoid and mitigate these impacts.

This report reviews knowledge of the brook stickleback, *Culaea inconstans* (Kirtland, 1840), a small forage fish (≤ 87 mm) with protective spines that typically occurs in shallow vegetated freshwater habitats. It includes information on the distribution of the brook stickleback, its habitat use during the various stages of its life history, and on threats posed to the species and its habitat by development activities. Knowledge gaps are also identified. This information was compiled to assist developers, habitat managers, and researchers. Similar reports have been prepared for other fishes that inhabit the Mackenzie River watershed.

The information that follows on brook stickleback life history and habitat use has been drawn largely from southern populations, since directed studies have not been conducted on this species in the Northwest Territories.

## 1.1 Taxonomic units

Variation in mitochondrial DNA suggests that there are two distinct lineages of brook stickleback in North America that arose when populations were isolated in geographically separate glacial refugia, one in the Mississippi and Ohio river basins and the other in the Missouri River (Gach 1996; Gach and Brown 1997). Fish in Alberta, and likely those in the Northwest Territories, belong to the former lineage.

## 1.2 Distribution

The brook stickleback is widely distributed in cool, clear waters of north-central North America; from Nova Scotia and Maine in the east to Indiana, Nebraska, Montana and eastern British Columbia in the west and north to James Bay, southern Hudson Bay and the Mackenzie River (Scott and Crossman 1973; Lee *et al.* 1980). Relict populations occur in New Mexico, and populations that may have been introduced occur in Arizona and Connecticut. The species' preference for cool water limits its southern distribution to cooler habitats. Individuals have been caught at elevations from sea level along the Hudson Bay coast to ~2,400 m above sea level (asl) in Wyoming (WY)(Quist *et al.* 2004).

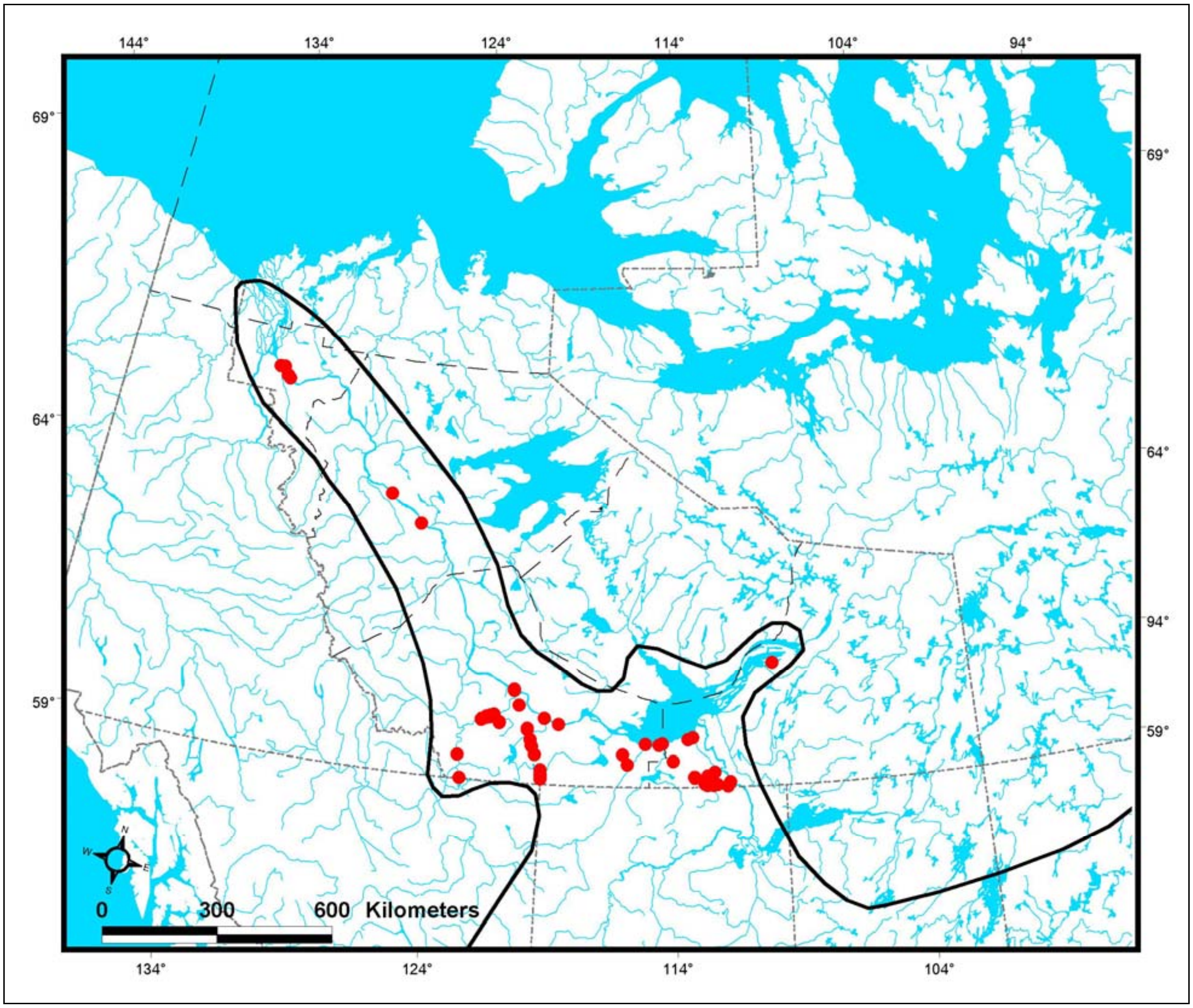


**Figure 1. Brook stickleback distribution in the Northwest Territories (from Sawatzky *et al*. 2007).**

Brook sticklebacks have been captured at scattered locations along the Mackenzie River system north to Arctic Red River (Figure 1). Most specimens north of Great Slave Lake have been taken in or near the mainstems of the Mackenzie or Liard rivers (e.g., Falk 1972; Stein *et al.* 1973a; McKinnon and Hnytka 1979; EIS Mackenzie Gas Project 2004; AMEC Americas Limited 2005; Mochnacz and Reist 2007; Sawatzky *et al*. 2007). The most northerly of these, from the mouths of Pierre (67°20'N, 133°22'W) and Tsital Trien (67°28'N, 133°35'W) creeks near Tsiigehtchic (formerly Arctic Red River), may not have been residents but strays carried downstream by spring flooding (Falk 1972). However, the species' limited distribution may be in part an artefact of sampling methods, which typically target larger species. Within the Northwest Territories, brook sticklebacks have been reported from the Fort McPherson Plain, Mackenzie River Plain, and Hay River Lowland ecoregions of the Taiga Plain ecozone (Marshall and Schut 1999).

# 2.0 LIFE HISTORY TYPES

**Riverine**[1] and **lacustrine** life histories have been observed among brook stickleback populations (McPhail and Lindsey 1970; MacLean and Gee 1971; Scott and Crossman 1973; Nelson and Paetz 1974, 1992; Wootton 1976; McKinnon and Hnytka 1979; Lee *et al.* 1980; Becker 1983; Moodie 1986). The species inhabits a wide variety of flowing water habitats, including rivers, streams, and **ephemeral** streams and ditches. It also inhabits lakes, spring fed ponds, beaver ponds, seasonal meltwater ponds, potholes, sinkholes, and hotsprings (Table 1). While primarily a freshwater species, it is occasionally found in brackish water.

**Table 1. Habitat use by brook stickleback populations with different life history types.**

| HABITAT | POPULATION | |
|---|---|---|
| | RIVERINE | LACUSTRINE |
| Seasonal streams and ditches | • Migratory corridors before and after spawning. | • Migratory corridors before and after spawning. |
| Meltwater ponds | • Spawning and rearing habitat. | • Spawning and rearing habitat. |
| Streams and rivers | • Year-round use by all life history stages for all activities. | |
| Lakes, ponds, bogs, sinkholes*, hotsprings | | • Year-round use by all life history stages for all activities. |

* Fish in the sinkhole may consist of strays from nearby rivers, and not constitute a reproducing population.

Seasonal movement patterns of brook sticklebacks with riverine or lacustrine life histories are difficult to study directly due to the fishes' small size. Consequently, they are poorly known and must be surmised based on observations of occurrence. Fish of both life history types are typically most abundant in the vegetated margins of the waterbody (Whitaker 1968; Tompkins and Gee 1983). These margins may offer more food and better cover than other stream and lake environments. Sticklebacks of both life history types use vegetated shorelines and ephemeral habitats for spawning.

Life history and habitat parameters in the discussion that follows are defined in Appendix 1. Riverine and lacustrine habitat requirements are summarized in Appendices 2 and 3, respectively.

[1] Terms in bold type are defined in the Glossary.

# 3.0 LIFE HISTORY STAGES AND HABITAT USE

Habitat used by brook sticklebacks to incubate eggs, and by young-of-the-year/juveniles and adults is discussed in the following sections. A generic life cycle for the species is provided in Figure 2. General habitat use by the life history stages is summarized in Table 2, and habitat and life history parameters related to reproduction are summarized in Table 3.

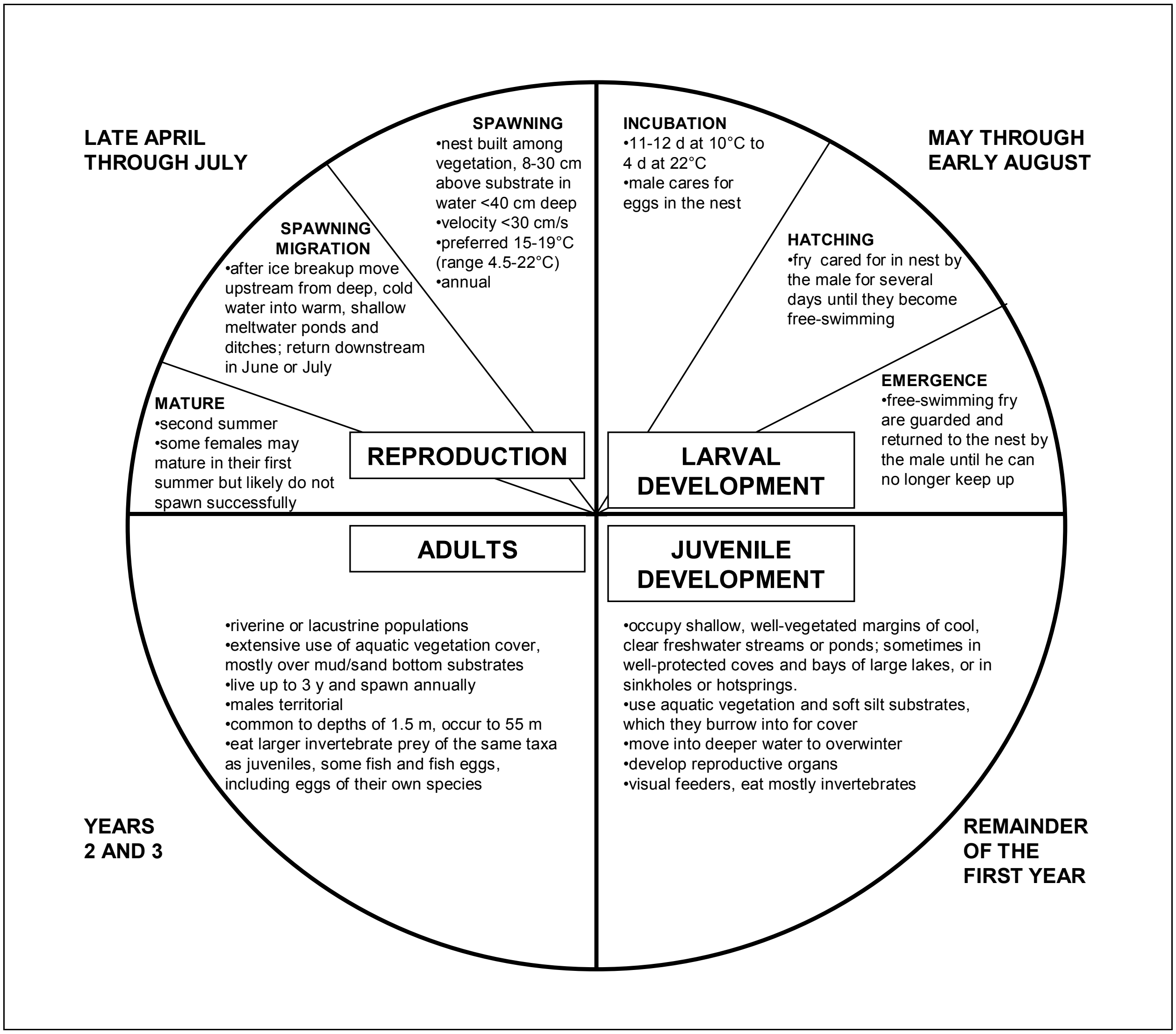


**Figure 2. Generic life cycle of the brook stickleback.**

## 3.1 Eggs (spawning and incubation habitat)

The brook stickleback spawns from late April through July, depending on water temperature (Reisman and Cade 1967; McPhail and Lindsey 1970; MacLean and Gee 1971; Scott and Crossman 1973; Wootton 1976; Becker 1983). After ice breakup, adults move upstream from deep cold water into warmer (8-19°C), shallow, meltwater ponds and ditches with low water velocity (≤ 30 cm/s) to spawn (Winn 1960; Reisman and Cade 1967; MacLean and Gee 1971; Becker 1983). In Manitoba's Roseau River, brook sticklebacks gather in large numbers where warmer meltwater runoff enters the river before moving upstream into the warmest water available below 19 to 20°C to spawn (MacLean and Gee 1971). These movements usually occur during daylight (MacLean and Gee 1971; Becker 1983). Males precede females onto the breeding grounds, where they establish a territory and build a nest (Scott and Crossman 1973; Wootton 1976).

Successful spawning typically requires water temperatures between 15 and 19°C, vegetation for nest construction, and clear water for courtship displays (Winn 1960; Reisman and Cade 1967). Outside this temperature range nest building and courtship may be seriously impaired. Prolonged exposure to temperatures above 20 to 22°C causes spawning to cease and the resorption of mature eggs (Braekevelt and McMillan 1967). In laboratory gradients, pre-spawning brook sticklebacks preferred temperatures in the range of 14.9 to 20.2°C (MacLean and Gee 1971). Post-spawning fish had a broader temperature preference of 8.9 to 25.6°C.

Brook stickleback nests are usually constructed on reeds or grass, mostly from vegetation, sticks, and debris (Scott and Crossman 1973; Wootton 1976). The male bonds these materials together using a glue protein that is produced in the kidneys and excreted as a filamentous thread. Most nests are situated among weeds, about 8 to 30 cm above the substrate, in water less than 40 cm deep (Winn 1960; McPhail and Lindsey 1970; McKenzie 1974; Wootton 1976; Goodyear *et al.* 1982; Becker 1983). They are spherical in shape with a definite entrance and no well-defined exit until the female creates one after depositing her eggs. Bottom substrate in the vicinity of the nests typically consists of organic debris and sand (Winn 1960; McPhail and Lindsey 1970; Becker 1983).

Both sexes have complex, colourful nuptial displays that change in intensity during the breeding season (McLennan 1994). Some males turn jet black, while females change from a uniform pale green to a variegated dark and light pattern (Scott and Crossman 1973). Females are courted into the nest, where they lay a clutch of eggs and then leave; the male then enters the nest and fertilizes the eggs (Reisman and Cade 1967; Winn 1960; McPhail and Lindsey 1970; Scott and Crossman 1973; McKenzie 1974; Wootton 1976; Lee *et al.* 1980). Over the spawning season, several females may be enticed to spawn in the same nest. The male chases the females away after the

**Table 2. Observed habitat use by the brook stickleback (data from Northwest Territories populations in bold type; numbers in parentheses refer to sources cited below). Habitat features are defined in Appendix 1.**

| HABITAT FEATURES | | LIFE STAGE | | |
|---|---|---|---|---|
| | | **Spawn/egg** | **Young of the year/juvenile** | **Adult** |
| **Habitat type** | | Warm, shallow meltwater ponds and ditches (4, 10) | **Cool, quiet, shallow, vegetated shoreline habitats of streams**, ponds, and lakes (6, 7, 16, **21, 22**) | **Cool, quiet, shallow, vegetated shoreline habitats of streams, ponds, and lakes** (6, 7, **21, 22**) |
| **Stream gradient** | | Low, slow flowing | **Low, slow flowing** (7, **21**); <1% (2) | **Low, slow flowing** (7, 20, **21**); <1% (2) |
| **Depth range (m)** | | <1 m (4, 8, 9, 16) | **Common to 1.5 m** (7, **21**) | **Common to 1.5 m** (**7, 21**,23, **24**), occurs to 55 m (3) |
| **Substrate** | | Organic debris and sand (4) | **Silt, mud, sand, gravel, rubble** (2, 7, **21**) | **Silt, mud, sand, gravel, rubble** (2, 7, **21,24**) |
| **Cover** | | Aquatic vegetation (4) | **Aquatic and overhanging vegetation** (7, **21, 22**) | **Aquatic and overhanging vegetation** (7, **22**), typically with >60% cover (6), **cobble** (**24**) |
| **Velocity range (cm/s)** | | <30 cm/s (10) | <90 (10); average water velocity of 60 cm/s during spring runoff declining to near 0 by late summer (7) | <90 (10,**24**); average water velocity of 60 cm/s during spring runoff declining to near 0 by late summer (7) |
| **Turbidity** | Range | | **TDS 300-350 mg/L (21)** | TDS 150-15,000 mg/L (5); **TDS 140-270 mg/L (21)** |
| | Limits | | | TDS 7 d LD50 18,900 mg/L (6) |
| **Oxygen (mg/L)** | Range | | | <1-11 mg/L (15, 20) |
| | Limits | | | <1 mg/L (20) |
| **Temperature (°C)** | Range | Spawning: 15-19°C (4, 10, 18, 19)<br>Incubation: ~10-22°C (8, 9) | | 1°C (13)-23°C (14, 15)<br>8.9-25.6°C in laboratory (7) |
| | Limits | 19-20°C (4, 10, 18, 19) | | |
| **Prey items** | Primary | | **Cladocerans, chironomid larvae** (7, 15, 17, **21**) | **Planktonic crustaceans, chironomid larvae** (3, 7, 9, 12, 15, **21**) |
| | Secondary | | **Other planktonic invertebrates** (7, 15, 17, **21**) | **Other invertebrates**, fish eggs and larvae (3, 7, 9, 12, 15, **21**) |
| **Period** | | Spawning: late April through July (3, 18)<br>Incubation: varies with water temperature from 11-12 d at 10°C to 4 d at 22°C (8,9)<br>Fry emergence: a few days after hatching (8) | Female : ~1 y; some may mature in first autumn; most before second summer (12)<br>Male : ~1 y (12) | Female: 1-3 y<br>Male: 1-3 y |
| **Size/age range** | | Egg diameter: ~1.1-1.2 mm (2) | ~30.5 mm standard length by May of the year after hatch (2) | **≤ 78 mm total length (1, 11, 21)**<br>Maximum: 87 mm (3) |

1 = Stein *et al.* 1973a - Mackenzie R., Northwest Territories
2 = Weselowski 1974 - Mink and Drifting rivers, Manitoba
3 = Scott and Crossman 1973 - review
4 = Winn 1960 - Michigan.
5 = Rawson and Moore (1944) - see Whitaker 1968
6 = Whitaker 1968 - 26 lakes and 14 streams in northern Saskatchewan
7 = Thompkins and Gee 1983 - Bog, Rennie, and Brokenhead rivers, Manitoba
8 = McKenzie 1974 - ponds in Thames R. drainage, Ontario
9 = Wootton 1976 - review
10 = MacLean and Gee 1971 - Roseau River, Manitoba
11 = Falk 1972 - Mackenzie R., Northwest Territories
12 = Moodie 1986 - “Lake 200” (50°30’N, 100°10’W), Manitoba
13 = Kaminski 1977 - Astotin Lake, Alberta
14 = Nelson 1983 - Cave and Basin Hotsprings, Alberta
15 = Robinson 1972 - Astotin Lake, Alberta
16 = Goodyear *et al.* 1982 - Great Lakes
17 = Abrahams 1996 - Delta Marsh, Lake Manitoba, Manitoba
18 = Reisman and Cade 1967 - artificial pond, Thornden Park, Onondaga, New York
19 = Braekevelt and McMillan 1967 - laboratory
20 = Klinger *et al.* 1982 - Mystery Lake, Wisconsin and laboratory
21 = McKinnon and Hnytka 1979 - tributary streams of the Liard River, Northwest Territories
22 = EIS Mackenzie Gas Project 2004 - streams and lakes along the pipeline route, Northwest Territories
23 = Becker 1983 - Review, Wisconsin
24 = Mochnacz and Reist 2007 - Helava Creek, Northwest Territories

**Table 3. Habitat and life history parameters related to brook stickleback reproduction, with data from the Northwest Territories in bold type. Numbers in parentheses refer to data sources listed below. Parameters are defined in Appendix 1.**

| PARAMETER | STREAM (data source) |
|---|---|
| **Reproductive strategy:** | **Iteroparous, polygynous** |
| **Age at maturity:** | Female: second summer (7). Some may mature in their first summer but they are unlikely to reproduce successfully.<br>Male: second summer (7) |
| **Fecundity (eggs/female):** | Mean fecundity: ranges from 104 at high population density to 451 at low population density, with typical values near the middle of this range (214 to 261) and large fish being more fecund than small fish (4, 7). Females may spawn every 3 d over a 28 d spawning period, so the total annual egg production per female may be much higher (7)<br>Egg size: ~1.1 to 1.2 mm (1) |
| **Spawning:** | Annually, in the spring, following maturity (7, 9) |
| Habitat type | Warm margins of streams, ponds or ditches with a dense growth of aquatic vegetation; sometimes in well-protected coves and bays of large lakes, springs, or sluggish stagnant water (6) |
| Builds nest | Yes. Most constructed on reeds or grass using vegetation, sticks, and debris (2, 8) |
| Temperature (°C) | 15-19°C preferred (2, 3, 6), range 4.5°C (5) to about 22°C (9) |
| Depth | Nest is located among weeds, 8-30 cm above the substrate in water <40 cm deep (3, 8-13) |
| Substrate | Organic debris and sand (3, 9, 10,12) |
| Current velocity (cm/s) | <30 (3, 6, 9) |
| **Maximum age:** (Note: fish are considered to be age 0 until December 31 of the year they are hatched) | Female: age 3 (1, 3, 7)<br>Male: age 3 (1, 3, 7) |
| **Age at senescence:** | No evidence of **reproductive senescence**. |

1 = Weselowski 1974 - Mink and Drifting rivers, Manitoba
2 = Scott and Crossman 1973 - review
3 = Winn 1960 – Sylvan Ponds, Michigan
4 = Hechter *et al.* 2000 - “Lake 200”, Manitoba
5 = Carlander 1969 cited in Newbrey and Ashworth 2004 - review
6 = Reisman and Cade 1967 - artificial pond, Thornden Park, Onondaga, New York
7 = Moodie 1986 - “Lake 200”, Manitoba
8 = Wootton 1976 - review
9 = MacLean and Gee 1971 - Roseau River, Manitoba
10 = Becker 1983 – review, Wisconsin
11 = McKenzie 1974 – Thames River system, Ontario
12 = McPhail and Lindsey 1970 – review, northwestern Canada and Alaska
13 = Goodyear *et al*. 1982 – Great Lakes

eggs are laid and he remains to guard the nest and care for the eggs, which he fans to provide aeration (McKenzie 1974). Average fecundity ranges from 104 eggs per female at high population density to 451 eggs per female at low population density, with typical values near the middle of this range (Moodie 1986; Hechter *et al.* 2000). Higher fecundity has been observed among females with symmetrical rather than asymmetrical pectoral fins (Hechter *et al.* 2000), and fecundity is positively correlated with body size

(Moodie 1986). When food is abundant females may spawn every 3 days over a 28 day spawning period, so the total annual egg production per female may be much higher (Moodie 1986).

Eggs are **demersal** and adhesive (Winn 1960). The time to hatching varies with water temperature, from 11 or 12 days at 10°C, to 9 or 10 days at 16°C, 5 to 7 days at 18 or 19°C, and only 4 days at 22°C (McKenzie 1974; Wootton 1976). During the incubation period males may dismantle the nest and move it and the eggs to a new site (McKenzie 1974). They may also steal eggs from other nests. After spawning the adults return downstream into deeper, cooler waters for the rest of the summer (Winn 1960; Lamsa 1963). In southern Ontario streams these runs occur in mid-June to early July at an average water temperature of 19°C (Lamsa 1963).

## 3.2 Fry and juveniles (rearing habitat)

When the **fry** emerge, the male brook stickleback pulls apart the top of the nest into a loose network of material that entangles the young until they become free swimming a few days later (Reisman and Cade 1967; Scott and Crossman 1973; Wootton 1976). The male guards the young and returns them to the nest when they stray until he can no longer keep up and discontinues parental behaviour. In Astotin Lake, Alberta, schools of fry, herded by males, were often observed near the surface feeding on plankton (Robinson 1972).

Habitat use by young-of-the-year brook sticklebacks is similar to that of the adults. In both riverine and lacustrine habitats, young-of-the-year are found associated with vegetation in shallow, quiet water, often over soft silt bottom substrates (Goodyear *et al.* 1982; McKinnon and Hnytka 1979; Tompkins and Gee 1983; EIS Mackenzie Valley Gas Project 2004). They select smaller prey than the adult sticklebacks, mostly insects and planktonic crustaceans (Robinson 1972; McKinnon and Hnytka 1979; Tomkins and Gee 1983; Abrahams 1996).

## 3.3 Adults

Adult brook sticklebacks are often found in association with vegetation (Winn 1960; Reisman and Cade 1967; McPhail and Lindsey 1970; Wootton 1976; Nelson and Paetz 1992; EIS Mackenzie Valley Gas Project 2004), sometimes in large aggregations either swimming or still (McPhail and Lindsey 1970). During the open water period, brook sticklebacks are most common over sand, gravel, silt or mud substrates; less so over rubble, boulders, clay, detritus or bedrock (Table 2). They are typically considered a shallow-water species and are common in water depths up to 1.5 m (Becker 1983; Tompkins and Gee 1983), but have been found at depths of up to 55 m (30 fathoms) in Lake Huron (Scott and Crossman 1973). Upward shifts in the species' vertical distribution in the water column have been observed as winter progresses (Kaminski 1977; Klinger *et al.* 1982; Magnuson *et al.* 1985). These shifts often occur in response to decreasing oxygen levels in the deeper waters. The fish may also be attracted to the upper water column by zooplankton that feed on algal blooms as light levels under-ice increase in February and March (Kaminski 1977).

Few data are available on habitat use by brook sticklebacks in the Northwest Territories. McKinnon and Hnytka (1979) found brook sticklebacks in a number of small, low-gradient tributary streams of the Liard River. The bottom substrates of these streams typically consisted of silt and degraded organic material overlain with debris, sometimes interspersed with gravel and boulders. The water was relatively clear, with total dissolved solid concentrations of 140 to 350 mg/L. Mochnacz and Reist (2007) caught a stickleback in Helava Creek, near Norman Wells. The mean depth and water velocity in the reach they were taken were 7.1 cm and 14 cm/s, respectively, with predominately gravel substrate and cobble cover. In September 1971, two brook sticklebacks were caught further north in the Mackenzie River near the Arctic Red River in turbid backwater areas of creek mouths (Falk 1972). They occurred in water temperatures of 5°C, over a sand-silt bottom that lacked aquatic vegetation. These fish may have been swept downstream into this area (Falk 1972).

Brook sticklebacks inhabit sinkholes (59°09'N, 112°29'W) in the vicinity of the Klewi River, Northwest Territories (Nelson and Paetz 1974). They likely access these habitats via underground channels that connect to the river. They will also inhabit cool (≤ 21°C), quiet waters with aquatic vegetation along the margins of hotsprings (Nelson 1983).

In the Rennie River, Manitoba from April through to October, brook sticklebacks were significantly more abundant in the vegetated margins of the stream than in the stream centre (Tompkins and Gee 1983). Stream sampling in Wyoming captured brook sticklebacks over a broad range of elevations (~1,200-2,400 m asl), but mostly in streams less than 12 m wide and above 2,200 m (Quist *et al.* 2004). In Paint Creek, Michigan, the species occurs in clear water 10 to 50 cm deep with flow velocity of 2.54 cm/s and temperatures of 3.3 to 8.9°C (Degraeve 1970). In another Michigan stream it occurs in areas with leaves, sticks, algae, and vascular aquatic plants over a silt bottom (Winn 1960).

In Hemming Lake, Manitoba, sticklebacks were most abundant in shoreline habitats with 100% vegetation cover, while catch per unit effort was very low where cover was less than 60% (Whitaker 1968). The heavily vegetated habitats had muck (mud) or muck-sand bottom substrates, and the less vegetated sites had mud-gravel, sand-gravel, or gravel-rubble substrates. However, vegetation was a more important determinant of habitat use than substrate, since fish were not caught over muck substrates that lacked vegetation.

Brook sticklebacks will undertake extensive migrations into ephemeral habitats, possibly as a strategy to reduce competition (Abrahams 1996). They will burrow into soft silt to escape predators and forage for food, but are unable to do so in sand (Degraeve 1970). Individuals also hide amongst rocks, dead leaves and vegetative detritus (Reisman and Cade 1967).

Brook sticklebacks grow rapidly, attain sexual maturity in one year, and live about 3 years (Winn 1960; Scott and Crossman 1973; Becker 1983; Moodie 1986). In prairie potholes, where all of the adult fish were reproductively active each summer, the species has a generation time of 1 year (Moodie 1986). The presence of very small **gravid** females in August suggests that some females mature in their first summer (i.e., as young-of-the-year). However, they are unlikely to reproduce successfully due to the absence of reproductively active males in late summer. Adults make seasonal migrations from shallow-water in the spring to deep water in which they overwinter (Wootton 1976).

Adult and juvenile brook sticklebacks eat a wide variety of seasonally available invertebrate taxa of various life stages (eggs, larvae, pupae, nauplii, adults) that originate mostly from aquatic habitats (Robinson 1972; Scott and Crossman 1973; Wootton 1976; Tompkins and Gee 1983; Moodie 1986; Stewart *et al*. 2007). In summer, the intensity of feeding in Manitoba streams was greatest between 1200 and 2000 h (Tompkins and Gee 1983); in winter, few of the fish taken from Astotin Lake, Alberta, had food in their stomachs (Kaminski 1977). Fish in their first year select smaller items than older fish, and both age groups eat smaller prey than they are morphologically capable of handling. Their hover-aim-dart feeding behaviour implies that they rely on vision when feeding (Tompkins and Gee 1983). Consequently, turbidity may limit the species distribution within the Mackenzie River.

Brook sticklebacks are eaten by a variety of large invertebrates, fishes, mammals and birds, and brook stickleback will eat their own eggs (Moodie 1986; Beaudoin *et al.* 2001; Zimmerman 2006). However, because of their small size, protective spines and armour plates, and predator avoidance behaviour they are usually only a minor prey item for other species (Winn 1960). Ponds and lakes of the Athabasca watershed in Alberta that support brook stickleback and fathead minnow (*Pimephales promelas*) species assemblages are significantly shallower and smaller than those supporting northern pike and yellow perch (*Perca flavescens*) assemblages (Robinson and Tonn 1989). These waterbodies typically lack brook sticklebacks if northern pike (*Esox lucius*) are present, probably due to predation by pike.

Growth of brook sticklebacks may be sensitive to both intra- and interspecific competition (Abrahams 1996; Gray and Robinson 2002). For example, their diet is more diverse in the presence of fathead minnows (Abrahams 1996). The growth and female reproductive effort of brook sticklebacks in prairie potholes was inversely related to population density (Moodie 1986).

When brook stickleback and ninespine stickleback (*Pungitius pungitius*) are **sympatric** in fresh water the former species occupies the **littoral** and the latter the **pelagic** zone (Moodie 1977). In Hemming Lake, Manitoba, the ninespine stickleback was less closely associated with vegetation than the brook stickleback, and was caught mostly over sand substrates. Ninespine sticklebacks are found in schools with other fish species more often than are brook sticklebacks. These differences effectively isolate the two species and reduce the potential for interspecific competition. The zone of interspecific competition is likely greatest during breeding season, when both species nest in vegetation.

The brook stickleback is tolerant of low oxygen conditions (Klinger *et al.* 1982; Magnuson *et al.* 1985). The species' pointed snout enables it to use microlayers of water with higher oxygen content, and its small size and relatively low metabolic rate keep oxygen demand low (Klinger *et al.* 1982). As dissolved oxygen concentrations under the ice decline these fish will emigrate to more favourable habitats or move to the ice-water interface and toward inflows where oxygen levels are highest (Magnuson *et al.* 1985). In Kempville Creek, Ontario, large schools move upstream in spring to populate areas abandoned in winter due to low oxygen levels (Coad 2005). These adaptations enable them to inhabit prairie pothole lakes, where most other species winterkill (Moodie 1986).

The brook stickleback is also tolerant of a wide range of alkaline and acid conditions. It occurs in water with a pH from 4.6 (Wiener and Eilers 1987; Cusimano *et al.* 1990) to at least 9.5 (Robinson 1972; Weselowski 1974).

This species has a lower salinity tolerance than other members of the stickleback family (F. Gasterosteidae) (Nelson 1968). It is stressed by seawater concentrations of over 20% (i.e., salinity ~7 g/L) (Armitage and Olund 1962), but can tolerate salinities of about 15 g/L (Hankinson 1929; Rawson and Moore 1944; Nelson 1968). Its salinity tolerance decreases as temperature increases from 4°C to 30°C (Kochsiek and Tubb 1967; Nelson 1968), although it can adjust buoyancy to compensate for changes in water density and maintain its swimming efficiency (Gee and Holst 1992). Significant mortality is observed among fish acclimated to 20 g/L (Nelson 1968; Whitaker 1968; Gee and Holst 1992).

# 4.0 HABITAT IMPACTS ON FISH BIOLOGY

Activities with the potential to affect key aspects of brook stickleback habitat and thereby the species' biology are discussed below and summarized in Table 4. Habitat degradation, habitat fragmentation, species introductions, and improved access related to development could affect the species, and these effects might also be modified by climate change. Based on the small numbers of brook sticklebacks caught during surveys conducted for the Mackenzie pipeline, Stein *et al.* (1973b) suggested that the local environment may not be suitable to support larger numbers and that, in the event of development, they would be adequately protected by measures taken to protect abundant species. Nevertheless, it is important that potential impacts to the species be considered, since it has not been studied in detail in the Northwest Territories.

## 4.1 Habitat degradation

Development activities that alter the physical and biological characteristics of fish habitats, especially the **hydrological regime**, bottom substrate, littoral vegetation, or water quality can damage brook stickleback populations. Spawning success could be reduced by water removal or drainage alterations that eliminate ephemeral ponds or streams that provide spring spawning habitat. It could also be reduced by the elimination of aquatic vegetation along quiet, shallow shorelines. The species' tolerance for low oxygen conditions (Klinger *et al*. 1982; Magnuson *et al*. 1985) makes it resilient to the impacts of flow alterations or other habitat degradation that reduces oxygen availability.

Brook sticklebacks are intolerant of elevated turbidity (Reisman and Cade 1967) because they locate their prey by sight (Tompkins and Gee 1983), and engage in colourful displays during breeding (Winn 1960; Reisman and Cade 1967). The thresholds for effects of turbidity on feeding and reproductive success by the brook stickleback are not known. However, activities such as forest clearing or channel dredging that alter flow and mobilize sediment may reduce or eliminate local populations. These effects will likely last as long as the turbidity remains high.

The brook stickleback is sometimes found in marginally suitable habitats, such as brackish water (Woolman 1895; Cox 1922), or in water that is fairly alkaline or acidic (Hankinson 1929; Trautman 1957). It tolerates a wide range of pH, from 4.6 to 9.5 (Robinson 1972; Weselowski 1974; Wiener and Eilers 1987, Cusimano *et al.* 1990; Mills *et al*. 2000), and is quick to recolonize lakes that are recovering from acidification to pH 5.0 (Mills *et al.* 2000). These fish may detect and avoid waters with low pH and high heavy metal concentrations, such as abandoned mining and refining sites (Rutherford and Mellow 1994).

**Table 4. Some activities with the potential to affect key aspects of brook stickleback habitat and their potential effects on the species.**

| Activity | Potential impact | | |
|---|---|---|---|
| | Habitat | Species | Directly affected life stage(s) |
| • drainage alterations<br>• water removal<br>• seismic testing | • drying of ponds and wetlands<br>• reduced littoral areas, increased turbidity, reduced oxygen levels<br>• ditch creation and streamflow alterations<br>• reduced groundwater flow<br>• altered baseflow and ice and temperature regimes | • degradation, reduction or loss of spawning or overwintering habitat, possibly with direct mortality<br>• ditching may increase suitable spawning habitat | • all |
| • construction of roadways, pads, and structures<br>• stream crossings | • sediment mobilization<br>• streambed destabilization<br>• streambed alteration by removal or disturbance of substrates | • degradation, reduction or loss of habitat for all purposes<br>• mortality from physical damage, exposure, loss of cover, sediment mobilization | • all |
| • logging<br>• clearing for right-of-ways, camps, etc.<br>• stream crossings | • inland clearing<br>• loss of riparian and instream cover (i.e., shoreline, large woody debris)<br>• altered hydrological regime with more abrupt runoff<br>• warming, increased sediment inputs<br>• flow blockage (ice bridges) | • degradation of habitat for most uses<br>• higher mortality rates for all life stages | • all |
| • culvert installation for stream crossings<br>• dam construction<br>• in-stream construction | • flow impoundment<br>• changes in seasonal flow regimes, water depth, water velocity<br>• habitat fragmentation | • interruption of spawning migrations<br>• inundation or dewatering of spawning areas and other habitat<br>• population extirpation<br>• creation of new habitat suitable for colonization | • all, but particularly spawners |
| • road and right-of way construction<br>• population growth | • improved human access to brook stickleback habitat | • visual and physical disturbance<br>• increased potential for species introductions<br>• population reduction or extirpation | • all |
| • contaminants releases | • chemical pollution | • decline in fish health<br>• increased mortality | • all |
| • climate change | • changes in the temperature and precipitation regimes, and hydrological cycles<br>• warming<br>• UV light exposure | • increase in suitable habitat at higher elevations and latitudes<br>• increasing competition and predation by warmer water species<br>• possible adverse health effects on fish from increased exposure to UV light | • all |

Nitrite is toxic to the brook stickleback, which is more sensitive to this chemical than many other species (Lewis and Morris 1986). Nitrite can be released to the aquatic environment in sewage and industrial effluent, by explosives used for mining and construction, and by fertilizer and livestock manure (CCME 1987). At a water chloride concentration of 10 mg/L the 24 h LC50 for Nitrite-N is < 5 mg/L (McCoy 1972 cited in Lewis and Morris 1986). The 96 h LC50 is < 3 mg/L, which increases to < 9 mg/L if the chloride concentration is raised to 20 mg/L.

Brook sticklebacks can accumulate organic contaminants derived from pesticides (e.g., dieldrin, DDT, pentachlorobenzene) (Scrimgeour *et al.* 1998), and from mercury mobilized by dredging operations (Munro and Gummer 1980). Experimental applications of farm herbicides (bromoxynil octanoate and bromoxunil butyrate) at concentrations ≥ 100 µg/L caused complete mortality of brook stickleback fry held in cages in subsurface waters within 24 h (Muir *et al.* 1991). At lower concentrations (2.1-5.8 µg/L) about 40% of the fry were alive after 50 h.

Water intakes for hydroelectric or nuclear power generation facilities can entrain and damage fish. However, seasonally abundant brook stickleback **larvae** were not very susceptible to entrainment by cooling water intakes at the Douglas Point Nuclear Power Generating Station (Kelso and Leslie 1979).

## 4.2 Habitat fragmentation

Habitat fragmentation is a common problem associated with development. It can result from improperly constructed roadways, typically improper culvert installations that constrict flow and raise flow velocities beyond the swimming capability of the fish, or by installations that are perched above the water and prevent fish entry. Dams can also fragment habitats if they are not designed to permit fish passage. Because of their small size and limited range, brook sticklebacks may not be particularly susceptible to the impacts of habitat fragmentation. However, fragmentation that prevents or delays movement between tributary streams and warm ephemeral spawning habitats should be avoided.

Brook stickleback populations may be capable of rebounding quickly from habitat fragmentation. They are among the earliest and most successful colonizers of habitats fragmented by beaver dams, due in part to their tolerance for low oxygen conditions (Schlosser and Kallemeyn 2000).

## 4.3 Species introductions

The introduction of larger predatory fishes, such as northern pike and smallmouth bass (*Micropterus dolomieu*), can reduce the abundance, alter habitat use, and extirpate brook stickleback and other small-bodied species from small lakes (Robinson and Tonn 1989; MacRae and Jackson 2001). The susceptibility of brook stickleback populations in the Northwest Territories to damage from species introductions is unknown. However, the stickleback's protective spines and armour plates make it difficult prey for many species. Within populations, individuals with defensive pelvic spines may be more likely to escape from predators once they are captured, while those that lack these spines have better startle responses and may be more likely to avoid capture (Andraso and Barron 1995; Andraso 1997). Brook sticklebacks also learn to recognize unfamiliar predators quickly by observing the fright responses of members of their own or other species (Mathis *et al.* 1996), and when predation risk is high tend to associate with unarmoured species such as the fathead minnow (*Pimephales promelas*) (Mathis and Chivers 2003). These adaptations may allow them to efficiently exploit habitats that contain predators (Abrahams 1995), and confer some protection against introduced predators.

The introduction of invertebrate species could also have a negative impact on stickleback populations by altering survival and population dynamics. Fish infected with the trematode parasite *Schistocephalus solidus*, for example, are found closer to the surface, making them more vulnerable to predation (Robinson 1972). The ability of female brook sticklebacks to compete for a mate has been negatively correlated with their intensity of infection by two intestinal parasites, *Bunodera insonstans* and *Neoechinorhynchus rutili* (McLennan and Shires 1995). Where stickleback populations are free of them, the introduction of these parasites would have a negative effect. The potential for damage to brook stickleback populations by competition from introduced invertebrate or fish species is unknown.

## 4.4 Improved access

Increased harvesting pressure is often an important impact of improving human access to aquatic habitats, particularly for game fishes. However, harvesting pressure is unlikely to pose a significant threat to the brook stickleback, which is seldom harvested for bait. Greater impacts are likely from the disturbance of shallow, vegetated shorelines and introduction of new species that are being used as live bait.

## 4.5 Climate change

Climatic warming may enable the brook stickleback to expand its distribution northward in response to warmer water temperatures and greater growth of aquatic plants. At the same time the more southerly brook stickleback populations in the Northwest Territories might be exposed to greater predation pressure from warm water fish species that expand their distributions northward. Studies of the fossil record suggest that the dispersal of species such as the brook stickleback, which prefer slow-moving, warmer water, is slower in response to climatic warming (deglaciation) than species that tolerate moderate water velocities and cooler temperatures (e.g., yellow perch and brassy minnow *Hybognathus hankinsoni*) (Newbrey and Ashworth 2004).

The effects of hydrological and temperature changes related to climate change are complex and unpredictable. However, because brook sticklebacks often spawn in shallow, ephemeral habitats (Tompkins and Gee 1983), a reduction in spring runoff or an increase in the rate at which these habitats dry out might adversely affect populations by causing spawning failures.

Climate change may also increase the exposure of aquatic biota to ultraviolet light (Wrona *et al*. 2005). Increasing exposure to ultraviolet light (UV-B) in the laboratory decreased the survival, altered the integument, and affected the horizontal position of brook sticklebacks (Young *et al.* 2003).

# 5.0 SUMMARY

The brook stickleback is a small forage fish with protective spines. Within the Northwest Territories it has only been reported from the Mackenzie River watershed, where it is uncommon downstream of the Liard River. The species may be more common in tributaries south of Great Slave Lake, from the Liard River east to the Slave River. Little is known of its life history in the Northwest Territories. Elsewhere, brook sticklebacks live in clear, cool, river and lake environments where they can tolerate low pH (5.0), low oxygen, and moderately elevated salinity. The brook stickleback feeds by sight and uses colourful mating displays, so it is intolerant of elevated turbidity. Both sexes spawn in the spring or early summer of the year after they hatch, and annually thereafter. Few fish live longer than 3 years. Shallow (<1.5 m), well-vegetated (>60% cover) shorelines with low water velocity and soft substrates are important spawning, feeding, and rearing habitats for the species. Brook sticklebacks will migrate seasonally to avoid anoxic conditions that cause winterkill, and into warmer ephemeral habitats that are favourable for spawning. These fish are often early colonizers of fragmented habitats.

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# 8.0 GLOSSARY

**Demersal** eggs are heavier than water and sink to the bottom.

**Ephemeral** stream or pond habitats only contain water for a short period each year, typically during the spring when they receive meltwater runoff, or later after heavy rains.

**Fry** are young fish, newly hatched, after yolk has been used up and active feeding has commenced.

**Gravid** female brook stickleback are full of eggs and ready to spawn.

The **hydrological regime** is the pattern and volume of river or stream flow over time.

**Iteroparous** fish spawn more than once in their lives.

**Lacustrine** populations live and grow in lakes or ponds.

Fish **larvae** are newly hatched fish that have not yet used up all the yolk from their egg.

**Littoral** habitats in waterbodies are near the shore.

**Pelagic** habitats in waterbodies are not near the bottom or shore.

**Polygynous** males mate with more than one female in a single breeding season.

**Reproductive senescence** refers to the loss of fertility that sometimes occurs with aging, such that there is a post-reproductive period to the species lifespan.

**Riverine** populations live and grow in streams or rivers.

**Sympatric** fish species inhabit the same waterbody.

# Appendix 1. Life history and habitat parameters

The emphasis of this work is on observations from within the Mackenzie Valley region. Terms such as "dominant", "preferred" and "optimum", which have been used in other summaries (e.g., Ford *et al*. 1995; Roberge *et al*. 2002), are avoided unless they are supported by directed research studies. This is because sampling observations may not accurately reflect a species' preferences unless the spatial and temporal biases related to sampling design and gear are carefully controlled. The following sections define what is meant by the various life history and habitat use parameters used in the text and tables and in the appendices that follow. Some parameters described here may not be used in this report because this description applies to all of the habitat use reports in the series.

## PARAMETERS USED IN TABLES 2 AND 3

### *Habitat use and requirements*

These tables summarize habitat associations during the life history stages of the species. Separate tables may be included for stream, river, and lake environments. Observations from areas within the Mackenzie River watershed are in bold type. The following parameters are included, with the units of measurement typically used:

- **Habitat type** – habitat type most commonly associated with observations of the life history stage (e.g., streams–pools, runs, riffles; lakes–littoral, pelagic, benthic);
- **Stream gradient** – percent (%) slope;
- **Depth range (m)** – range of depths from which the species has been reported;
- **Substrate** – substrate type(s) most commonly associated with observations of the species;
- **Cover** – cover type(s) most commonly associated with observations of the species:
- **Habit** – typical distribution within the habitat type (e.g., surface, midwater, benthic, above or below thermocline, inshore or offshore);
- **Velocity range** – water velocities (cm/s) wherein the species is most commonly observed;
- **Turbidity:**
    - **range** – turbidity range wherein the species has been reported;
    - **limits** – upper and lower lethal limits as tested experimentally;
- **Oxygen (mg/L):**
    - **range** – dissolved oxygen levels wherein the species has been reported;
    - **limits** – upper and lower lethal limits as tested experimentally;
- **Temperature (°C):**
    - **range** – water temperatures wherein the species has been reported;
    - **limits** – upper and lower lethal limits as tested experimentally;
- **Prey:**
    - **Primary** – taxa or taxon typically comprising the majority (by weight/volume/food value) of the food found in the stomachs of fishes sampled, or that were seen to be eaten during *in situ* behavioural studies;
    - **Secondary** – taxa or taxon comprising the minority (by weight/volume/food value) of food found in the stomach of fish sampled, or that were seen to be eaten during *in situ* behavioural studies. [Note: Differences in prey selection (i.e., primary/secondary) may reflect changes in the seasonal availability rather than the relative importance of food items.];
- **Duration** – number of seasons, months, or years in which each specific life stage exists or occurs;
- **Size/Age range** – average and/or maximum size range (mm) of the life history stage; or maximum size range (mm); FL = fork length, SL = standard length, TL = total length. A fish is age 0 until December 31 of the year it was hatched unless otherwise indicated.

### *Reproduction*

This table summarizes habitat and life history parameters related to the species' reproduction. Observations from areas outside the Mackenzie River watershed are italicized. The following parameters are included:

- **Reproductive Strategy** – *oviparous* species produce eggs that hatch outside the body of the mother; *iteroparous* species produce their young in annual or seasonal batches (most fishes); *semeloparous* species (e.g., salmon) produce all of their offspring at one time and then usually die; *annual* spawners reproduce each year following maturity until they die or reach reproductive senescence; under marginal conditions a portion of the reproductive population may rest for a year or more between spawning events (*% resting*);
- **Age at maturity** – range of ages at which males (M) and females (F) become sexually mature, with any estimate of the most common age at maturity provided in brackets;
- **Fecundity** – range in the number of eggs produced by females;
- **Spawning habitat** – habitat types wherein spawning has been observed, ripe and running fish have been caught, ripe and spent fish have been caught together, or eggs or sac larvae have been found. The presence of mobile young-of-the-year was used to identify nursery areas, and sometimes "suspected" spawning areas;
- **Spawning habit** – some species *build a nest* by altering the bottom substrates to meet their requirements before spawning; others *use existing nests* constructed by other species; *broadcast spawners* spread their eggs over suitable areas of unaltered bottom substrates; some species *care for the eggs* or *care for the young*;
- **Spawning temperature** – temperature range at which spawning has been observed;
- **Spawning depth** – depth range at which spawning has been observed;
- **Spawning substrate** – substrate type(s) observed at spawning locations;
- **Spawning current velocity** – current velocity observed at spawning locations;
- **Maximum age** – life expectancy of the species;
- **Reproductive senescence** – age at which the species stops reproducing.

## PARAMETERS USED IN APPENDICES 2 AND 3

The seasonal habitat requirements for each life history stage are presented below in separate appendices for stream (Appendix 2) and lake (Appendix 3) environments.

### *Life history stage*

Observations on habitat use are summarized by life history stage. Four stages are recognized:

- **Spawning/eggs** – includes habitats on the spawning grounds where adults spawn and eggs mature and hatch;
- **Young of the year (YOY)** – larvae and fry less than age 1 (age 0 until December 31 of the year they are hatched);
- **Juveniles** – sexually immature fish older than age 1;
- **Adults** – include fish that have attained sexual maturity.

### *Seasons*

Habitat use was divided into four seasons, which correspond to the environmental conditions rather than to the calendar seasons. Calendar months are also provided if possible, but the correspondence between environmental variables and calendar months varies from south to north and from year to year. In the north of the Mackenzie River watershed (Inuvik; S. Stephenson, DFO, pers. comm. 2006), the seasons used are:

- **Spring (Sp)** – the period of ice breakup and spring runoff, typically late April to mid June;
- **Summer (Su)** – the period of open water, typically mid-June to late September;
- **Fall (Fa)** – the period of ice formation, typically late September to late November;

- **Winter (Wi)** – the period of ice cover, typically late November to late April.

In the south (Hay River; G. Low, DFO, pers. comm. 2006) they are:

- **Spring (Sp)** – the period of ice breakup and spring runoff, mid-April to early June;
- **Summer (Su)** – the period of open water, typically early June to late-September;
- **Fall (Fa)** – the period of ice formation, typically late-September to mid-November;
- **Winter (Wi)** –- the period of ice cover, typically mid-November to mid-April.

These date ranges are averages, since the timing of breakup varies from river to river and lake to lake depending upon factors such as stream gradient, exposure to sunlight, and lake size.

## *Water depth*

Five water depth categories are used for stream environments: 0–0.2, >0.2–0.6, >0.6–1, >1–2, and >2 m. Depth represents the distance from the surface of the water downwards. The depth association of a fish found in the upper meter of the water column, for example, would be reported as 0–0.2, >0.2–0.6 and >0.6–1.0. Depth is reported as stated in the reference, but if "shallow" water was the only descriptor, a depth of 0–20 cm was used to represent "shallow" water. A broader range of depths is used to describe lake environments: 0-1, >1–2, >2–5, >5–10, and >10 m.

## *Substrate type*

Substrate type was reported as stated in the reference. However, if particle size was not provided, substrate type was classified as follows:

- **bedrock** = uniform continuous substrate;
- **boulder** = >25 cm;
- **cobble** = 17–<25 cm;
- **rubble** = 6.4–<17 cm;
- **gravel** = 0.2–<6.4 cm;
- **sand** = <0.2 cm;
- **silt/clay** = finer than sand with fine organic content;
- **muck (detritus)** = mud with coarse organic content;
- **hard-pan clay** = clay; and
- **pelagic** = open water.

## *Cover type*

Cover features that may provide protection, or a refuge, from predators, competitors, and adverse environmental conditions include:

- **None** – no cover;
- **Submergent vegetation** – aquatic plants that grow entirely below the surface and are attached to the bottom by roots or rhizomes;
- **Emergent vegetation** – aquatic plants with foliage that is partly or entirely borne above the water surface (e.g., cattail *Typha* spp.) or float on the surface of the water (e.g., milfoil);
- **Algae** – aquatic algae present on the bottom or within the water column;
- **Wood** – large (LWD) or smaller woody debris (SWD) on the bottom or within the water;
- ***In situ*** – submerged cavities and/or crevices, undercut banks;
- **Substrate** – interstitial spaces between any size of substrate (boulder-sand);
- **Overhead** – cover originating outside the riparian zone that overhangs the stream and/or banks, which includes overhanging banks or riparian vegetation, woody debris outside the channel, or anything above the surface that provides shade.

## *Habitat*

In flowing water, habitat refers to the type of channel unit, and typical water velocity within the unit that the species inhabits, including:

- **Pool** – velocity range <0.25 $m \cdot s^{-1}$;
- **Run** – velocity range 0.25 – 0.50 $m \cdot s^{-1}$;
- **Riffle** – velocity range 0.50 – 1.00 $m \cdot s^{-1}$;
- **Rapid** – velocity range >1.00 $m \cdot s^{-1}$;
- **River margin** – habitat along the banks of the mainstem channel, often low velocity;
- **Off-channel** – any habitat that is outside the mainstem flow including side channels, backwaters, and off channel habitats, often low or no velocity.

Water velocity differences are not used to differentiate lake habitats; rather they are differentiated on the basis of their proximity to flowing water or shorelines, as follows:

- **Lake inlet** – near or within stream or river plumes entering the lake;
- **Lake outlet** – near or within the channel that drains the lake;
- **Inshore** – typically associated with littoral habitat along the edges, rather than the middle of the lake;
- **Offshore** – typically associated with the middle, rather than the edges of the lake. Where possible their typical position in the water column is described (e.g., surface, midwater, benthic, above or below thermocline).

**Appendix 2. Stream habitat requirements for the brook stickleback. Data from the Northwest Territories are in bold type.**

| **Stream habitat features:** | **LIFE STAGES** [Season of use (reference)] | | | **LEGEND/COMMENTS/REFERENCES** |
|---|---|---|---|---|
| | **Spawn/egg** | **YOY** | **Adult** | **Season of use:** |
| **Depth (m)** | | | | Sp = spring |
| 0-0.2 | | **Su (4)**; All (2, 3) | **Su (4,6);** All (2, 3, 5) | Su = summer |
| >0.2-0.6 | | **Su (4)**; All (2, 3) | **Su (4);** All (2, 3, 5) | Fa = fall |
| >0.6-1 | | **Su (4)**; All (2, 3) | **Su (4);** All (2, 3, 5) | Wi = winter |
| >1-2 | | All (2, 3) | All (2, 3) | All = year-round |
| >2 | | | | |
| **Substrate** | | | | |
| Bedrock | | | | |
| Boulder | | | | |
| Cobble | | | | |
| Rubble | | | | |
| Gravel | | **Su (4)**; All (2) | **Su (4,6),** All (2) | |
| Sand | | All (2) | **Su (1)**; All (2) | |
| Silt/Clay | | **Su (4)**; All (2) | **Su (1,4)**; All (2, 5) | |
| Muck (Detritus) | | **Su (4)** | **Su (4)** | |
| Hard-pan clay | | | | |
| Pelagic | | | | |
| **Cover** | | | | |
| None | | | | |
| Submergents | | **Su (4)**; All (2, 3) | **Su (4)**; All (2, 3) | |
| Emergents | | | | |
| Algae | | | | |
| Wood | | | | |
| In situ | | | | |
| Substrate | | | **Su (6)** | |
| Undercut bank/overhang | | | | |
| Overhead | | **Su (4)**; All (2) | **Su (4)**; All (2) | |
| Other | | | | |
| **Velocity/Habitat** | | | | |
| Pool | | | **Su (1)** | |
| Run | | | | |
| Riffle | | | | |
| Rapid | | | | |
| River Margin | | **Su (4)**; All (2) | **Su (4)**, All (2, 5) | |
| Off-channel | | | | |

1 = Falk 1972 – Mackenzie R., Northwest Territories
2 = Tompkins and Gee 1983 – Bog, Rennie, and Brokenhead rivers, Manitoba
3 = Whitaker 1968 – 26 lakes and 14 streams in northern Saskatchewan
4 = McKinnon and Hnytka 1979 –- Liard River drainage, Northwest Territories
5 = Degraeve 1970 – Paint Creek, Michigan
6 = Mochnacz and Reist 2007 – Helava Creek, Northwest Territories

**Appendix 3. Lake habitat requirements for the brook stickleback.**

| Lake habitat features: | LIFE STAGE [Season of use (reference number)] | | | LEGEND/COMMENTS/REFERENCES |
|---|---|---|---|---|
| | **Spawn/egg** | **YOY** | **Adult** | **Season of use:** |
| **Depth (m)** | | Wi (3, 4)* | Wi (3, 4)* | Sp = spring |
| 0-1 | | Sp-Fa (1) | Sp-Fa (1,2) | Su = summer |
| >1-2 | | Sp-Fa (1) | Sp-Fa (1) | Fa = fall |
| >2-5 | | | | Wi = winter |
| >5-10 | | | | All = year-round |
| >10 | | | | |
| **Substrate** | | | | |
| Bedrock | | | | |
| Boulder | | | | |
| Cobble | | | | |
| Rubble | | | | |
| Gravel | | | Sp-Fa (2) | |
| Sand | | | Sp-Fa (1, 2) | |
| Silt/Clay | | | Sp-Fa (1, 2) | |
| Muck (Detritus) | | | Sp-Fa (1, 2) | Most common substrate. |
| Hard-pan clay | | | | |
| Pelagic | | | | |
| **Cover** | | | | |
| None | | | | |
| Submergents | | | Sp-Fa (1, 2) | |
| Emergents | | | Sp-Fa (1, 5) | |
| Algae | | | | |
| Wood | | | | |
| In situ | | | | |
| Substrate | | | | |
| Undercut bank/overhang | | | | |
| Overhead | | | | |
| Other | | | | |
| **Habitat** | | | | |
| Lake inlet | | | | |
| Lake outlet | | | | |
| Inshore (littoral) | | | Sp-Fa (1) | |
| Offshore-surface | | | | |
| Offshore-midwater | | | | |
| Offshore-benthic | | | | |

1 = Whitaker 1968 ─ 26 lakes and 14 streams in northern Saskatchewan

2 = Winn 1960 ─ Sylvan Ponds, Michigan

3 = Kaminski 1977 ─ Astotin Lake, Alberta

4 = Magnuson *et al*. 1985 ─ Mystery Lake, Wisconsin

5 = Moodie 1986 ─ "Lake 200", Manitoba

* Under low oxygen conditions in winter and early spring fish move toward the surface at or near the ice-water interface (Kaminski 1977; Magnuson *et al*. 1985).