# Life History Characteristics of Freshwater Fishes Occurring in Newfoundland and Labrador, with Major Emphasis on Riverine Habitat Requirements

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# LIFE HISTORY CHARACTERISTICS OF FRESHWATER FISHES OCCURRING IN NEWFOUNDLAND AND LABRADOR, WITH MAJOR EMPHASIS ON RIVERINE HABITAT REQUIREMENTS

by

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Grant, C.G. and E.M. Lee. 2004. Life history characteristics of freshwater fishes in Newfoundland and Labrador, with major emphasis on riverine habitat requirements. Can. Manuscr. Rep. Fish. Aquat. Sci. 2672: xii + 262p.

An extensive literature review was performed to compile information on habitat use among various life stages of freshwater and anadromous/catadromous fishes occurring throughout Newfoundland and Labrador, with major emphasis on species utilizing streams or rivers for at least a portion of their life cycle. Water velocity, water depth, substrate type and cover (i.e. structural complexity) were the four main physical habitat features considered with temperature included where available. Overall, there is a general lack of information pertaining to the riverine habitat requirements for many of the fish species in Newfoundland and Labrador. Within the riverine environment, there are often seasonal and temporal shifts in habitat use by various species. Fish distributions and abundance are often related to early life history requirements, food availability, spawning requirements and the likelihood of overwintering survival which results in seasonal and/or size-related changes in habitat use. Furthermore, intra- and inter-specific competition, predation risk and various environmental variables may also cause shifts in habitat utilization.

# résumé

On a effectué une analyse documentaire exhaustive pour recueillir de l'information sur l'utilisation que font de l'habitat à divers stades biologiques les poissons d'eau douce et les poissons anadromes et catadromes présents dans les eaux de Terre-Neuve et du Labrador, en s'intéressant particulièrement aux espèces qui utilisent les rivières et autres cours d'eau pendant au moins une partie de leur cycle biologique. La vitesse du courant, la profondeur de l'eau, ainsi que le type de substrat et d'abri (c.-à-d. la complexité structurelle) étaient les quatre grandes caractéristiques physiques de l'habitat qui ont été prises en considération, avec aussi la température quand on la connaissait. De façon générale, on manque d'information sur les besoins en habitat lotique de nombreuses espèces de poisson de Terre-Neuve et du Labrador. Au sein du milieu lotique, l'utilisation de l'habitat par les diverses espèces connaît souvent des variations saisonnières et temporelles. La distribution et l'abondance du poisson sont souvent liées aux besoins de ce poisson à ses premiers stades biologiques, à la disponibilité de la nourriture, à la fraye et à la probabilité de survie à l'hiver, qui occasionnent des changements selon la saison ou selon la taille du poisson dans l'utilisation de l'habitat. De plus, la concurrence intra et interspécifique ainsi que divers facteurs environnementaux peuvent aussi occasionner des changements dans l'utilisation de l'habitat.

# 1.0 Introduction

Information on habitat use by various life stages of fish is necessary for the effective management of fish and their habitat, particularly when assessing the potential impacts of various development activities. It is believed that one of the main causes of the continuing decline of freshwater fishes in Canada is the destruction and degradation of their habitat (Beamish et al. 1986; Pearse 1988). Although physical habitat features such as water velocity, water depth, substrate type and cover are important to the growth, survival, distribution and abundance of various fish species, habitat use is not solely dependant on attributes of the physical environment. Spatial and temporal variations in prey availability (Werner and Mittlebach 1981; Werner et al. 1983a; Moyle and Baltz 1985), interspecific interactions (e.g., competition and predation) (Fausch and White 1981; Werner et al. 1983b; Schlosser 1987), and various environmental variables such as water quality may cause shifts in habitat utilization within streams and rivers. Even the location of fish within the water column can be greatly influenced by water temperature and light intensity.

Most fish species undergo ontogenetic, or size-related, shifts in habitat use as they grow, mature and reproduce. The transition to different habitat types as fish grow, particularly to areas affording more protection, has been noted in many studies of stream salmonids (Grant and Noakes 1987; Heggenes 1988) This often results in the selection of different habitats by different-sized individuals which is based on trade-offs between costs (i.e., predation risk, competition) and benefits (i.e., increased foraging, reproducing). Thus, each specific habitat which a fish needs to carry out its life processes, whether it be for spawning, nursery, rearing, feeding, over-wintering or migration must be managed appropriately to ensure a species survival. Therefore, when assessing potential impacts on fish habitat, habitat managers need to take all habitat types into consideration during decision-making in order to minimize impacts on fish populations.

This document represents a summary of physical riverine habitat requirements of various life stages of freshwater and anadromous/catadromous fishes that utilize rivers in Newfoundland and Labrador for at least a portion of their life cycle. Habitat requirements are defined as specific environmental conditions which a species needs to survive, grow and reproduce. The report is intended to be a companion document to the Bradbury et al. 1999 publication (Can. MS. Rep. Fish. Aquat. Sci. No. 2485.) which summarizes the lake habitat requirements of Newfoundland and Labrador fish species. Four habitat characteristics were summarized (water velocity, water depth, substrate and cover) for four life cycle stages of fish (spawning, young-of-the-year, juvenile and adult) in an attempt to identify habitat requirements. Temperature was included as an additional habitat characteristic when available.

Although certain conclusions regarding riverine habitat utilization can be drawn from the information compiled in this report, its limitations must be noted. First, and probably most importantly, there was a general lack of information pertaining to the riverine habitat requirements for many of the fish species in Newfoundland and Labrador. Consequently, much of the data compiled in this report was supplemented by studies from similar geographical areas in Canada, the United States and other countries in north temperate locations. On occasion, extrapolations were also made based on habitat use in lacustrine environments.

Secondly, a lot of 'grey' literature (i.e., consultant reports and unpublished records) exists which generally have a very limited distribution. These reports rarely occur in major libraries and almost never appear in standard abstracts, therefore there was no efficient way of locating this material and consequently, much of this information may have been overlooked. Thirdly, our assessment of the relative significance of particular habitats to individual species was necessarily subjective and therefore mainly qualitative in nature. Much of the information was derived from studies that sampled specific habitats, rather than a range of habitats. Undoubtedly, some habitats (e.g. predominantly boulder habitats) which are difficult to sample with traditional gear received less attention than those for which sampling equipment is better suited. Depth of occurrence also poses a problem, as water temperature often plays a critical role in depth selection which may vary depending on size of the river, season and activity levels. These limitations notwithstanding, the data summarized in this report are useful in assessing the relative significance and importance of different riverine habitats to various life stages of freshwater fishes occurring in Newfoundland and Labrador.

# 2.0 Methodology

In Newfoundland and Labrador, a total of 32 fish species are reported to utilize rivers for at least a portion of their life cycle. Many of these species exist in more than one form, such as anadromous or freshwater resident/landlocked. The family, common and scientific names of the fish species cited in this report follows Robbins et al. (1991) and are listed in Table 1.

**Table 1.** Family, common and scientific names of species included in the review.

| Family | Common Name | Scientific Name |
|---|---|---|
| Cod (Gadidae) | Atlantic tomcod | *Microgadus tomcod* |
| | burbot | *Lota lota* |
| Eel (Anguillidae) | American eel | *Anguilla rostrata* |
| Herring (Clupeidae) | alewife | *Alosa pseudoharengus* |
| | American shad | *Alosa sapidissima* |
| Killifish (Cyprinodontidae) | banded killifish | *Fundulus diaphanus* |
| | mummichog | *Fundulus heteroclitus* |
| Lamprey (Petromyzontidae) | sea lamprey | *Petromyzon marinus* |
| Minnow (Cyprinidae) | lake chub | *Couesius plumbeus* |
| | longnose dace | *Rhinichthys cataractae* |
| | pearl dace | *Semotilus margarita* |
| Perch (Percidae) | log perch | *Percina caprodes* |
| Pike (Esocidae) | northern pike | *Esox lucius* |
| Salmonid (Salmonidae) | Arctic charr | *Salvelinus alpinus* |
| | Atlantic salmon | *Salmo salar* |
| | brook trout | *Salvelinus fontinalis* |
| | brown trout | *Salmo trutta* |
| | lake trout | *Salvelinus namaycush* |
| | lake whitefish | *Coregonus clupeaformis* |
| | pink salmon | *Oncorhynchus gorbuscha* |
| | rainbow trout | *Oncorhynchus mykiss* |
| | round whitefish | *Prosopium cylindraceum* |

| Family | Common Name | Scientific Name |
|---|---|---|
| Sculpin (Cottidae) | mottled sculpin<br>slimy sculpin | *Cottus bairdi*<br>*Cottus cognatus* |
| Smelt (Osmeridae) | rainbow smelt | *Osmerus mordax* |
| Stickleback (Gasterosteidae) | blackspotted stickleback<br>fourspine stickleback<br>ninespine stickleback<br>threespine stickleback | *Gasterosteus wheatlandi*<br>*Apeltes quadracus*<br>*Pungitius pungitius*<br>*Gasterosteus aculeatus* |
| Sturgeon (Acipenseridae) | Atlantic sturgeon | *Acipenser oxyrhynchus* |
| Sucker (Catostomidae) | longnose sucker<br>white sucker | *Catostomus catostomus*<br>*Catostomus commersoni* |

The life history of each fish species reviewed was subdivided into four life stages as follows: Spawning - fish that are in spawning condition and includes egg incubation as well as emergence; Young-of-the-Year/Nursery - fish that are under one year of age (age 0+); Juvenile - fish older than one year of age, which are fundamentally like adults in appearance, but smaller and not sexually mature; and Adult - fish that have reached sexual maturity and are able to reproduce, but are not in spawning condition.

Habitat requirements were reported on the basis of four physical habitat features: i) water velocity; ii) water depth, iii) substrate type, including pelagic (i.e. open-water areas, not directly influenced by the stream margin or the bottom) and iv) cover.

Water Velocity

In the literature reviewed, sometimes the velocities occupied by fish were reported as column velocity, which is defined as the mean water velocity from surface to bottom and other times as nose velocity, defined as velocity measured at actual fish location within the water column.

Water Depth

Actual water depth was reported in cm or m. For tabular summaries, a total of five water depth categories were employed; 0-1, 1-2, 2-5, 5-10 and >10 m.

Substrate

Substrate composition was reported exactly as stated in the reference, however, if particle size was provided, substrate type was classified according to Sooley et al. (1998) as outlined in Table 2.

Cover

Cover is defined as features within the aquatic environment that may be used by fish for protection (or refuge) from predators, competitors and adverse environmental conditions. In addition cover may provide spawning habitat for some fish species (e.g. pike), substrate for potential prey as well as camouflage for predatory fish. The following categories outlined in Table 2 were used to define cover.

**Table 2.** Substrate and cover categories used to describe habitat use.

| | | |
|---|---|---|
| **Substrate** | bedrock | continuous solid rock exposed by the scouring forces of the river/stream. |
| | boulder | rocks ranging from 25 cm to >1 m in diameter. |
| | rubble | rocks ranging from 14 to 25 cm in diameter. |
| | cobble | rocks ranging from 3 to 13 cm in diameter. |
| | gravel | small stones ranging from 2 mm to 3 cm in diameter |
| | sand | grains ranging from 0.06 to 2 mm in diameter, frequently found along stream margins or between rocks and stones. |
| | silt | very fine sediment particles, usually < 0.06 mm in diameter. |
| | muck/detritus | organic material from dead organisms (plant and/or animal). |
| | clay/mud | fine deposits between rocks and covering other substrates. |
| **Cover** | riparian/ overhanging cover | mature trees, alders, shrubs, grasses, etc. bordering the stream edge or hanging out over the stream. |
| | overhead cover | riparian cover overhanging the stream, undercut banks and woody debris at the surface of the water. |
| | instream objects/*in situ* | cover within the streambed in the form of fallen trees, submerged logs, rocks, boulders, undercut banks, and accumulated debris. |
| | emergent vegetation | aquatic plants growing above or extending above the water surface (e.g., cattails, sedges, grasses, rushes). |
| | submergent vegetation | aquatic plants that grow entirely below the water surface (e.g., elodea, bladderwort, pipewort, potamogeton) and includes numerous mosses and macroalgae. |
| | canopy | cover provided by mature hardwood and softwood trees that have branches or foliage overhanging the stream. |

Inconsistencies with respect to habitat feature definitions, nomenclature and lack of quantification were common problems within the literature reviewed. For example, some reference sources would qualitatively describe water velocity as 'sluggish' or 'fast', while others would characterize substrate as 'rocky' or 'coarse'.

The strength of association or preference for these habitat features was reported in tabular format using a rating system as follows; high (species is nearly always associated), medium (species is frequently associated), low (species is infrequently associated), nil (species is not associated) and cases where no information was found to indicate that a species utilizes a particular habitat feature were left blank (Tables 3-35). Where there was no available information on specific riverine habitat utilization within Newfoundland and Labrador, rating were made based on riverine habitat requirements within similar geographic areas or occasionally on habitat use within lacustrine environments. These ratings appear in italics within the tables.

### 2.1.1 Data Sources and Report Format

Text (3.0 Results) and tabular summaries (Appendix 1) of habitat requirements are provided for all riverine fish species and their respective life stages occurring in Newfoundland and Labrador. Data sources included:

- Fisheries and Oceans Canada, Newfoundland and Labrador Regional Library (Northwest Atlantic Fisheries Center), St. John's, NL;
- Queen Elizabeth II Library, Memorial University of Newfoundland (MUN), Prince Phillip Drive, St. John's, NL;
- Fisheries and Marine Institute Library (MUN), Ridge Road, St. John's, NL
- Electronic searches of computer databases including Aquatic Sciences and Fisheries Abstracts (ASFA) and WAVES;
- primary literature;
- university research theses; and,
- grey literature (e.g., unpublished data, consultants' reports, etc.).

Information specific to Newfoundland and Labrador riverine fish habitat requirements was available for only 10 of the 32 species reviewed. These species included: banded killifish, sea lamprey, log perch, Arctic charr, Atlantic salmon (anadromous and freshwater resident), brook trout, rainbow trout, round whitefish and longnose sucker. The riverine habitat requirements for the remaining 22 species were drawn from publications based upon research conducted in other geographical areas. The grey literature reviewed was instrumental in providing additional information with respect to habitat requirements of Newfoundland and Labrador riverine fish species. It is important to note, however, that habitat requirements obtained from other geographic areas was interpreted and applied with caution with respect to the Newfoundland and Labrador environment.

The fish are grouped by family and within a family, species are listed in alphabetical order by common name. The summary tables for each species are subdivided by life stage (Spawning/Incubation/Emergence, Young-of-the-Year/Nursery, Juvenile, and Adult) and habitat requirements (Velocity (m/s), Water Depth (cm or m), Substrate Type, and Cover). Table headings correspond closely to those included in the text (3.0 Results) to permit easy identification of appropriate references.

# 3.0 Results

## 3.1 Cod (Gadidae)

### 3.1.1 Atlantic tomcod (*Microgadus tomcod*)

The Atlantic tomcod is a North American marine species distributed in coastal and brackish waters from the Hamilton Inlet-Lake Melville region of southern Labrador (Backus 1951) to North Carolina (Scott and Scott 1988). It is known to be seasonally abundant in specific bays and estuaries around Newfoundland and Labrador, the Gulf of St. Lawrence, and the Bay of

Fundy (Scott and Scott 1988). It is an inshore, shallow-water marine species that regularly enters brackish or fresh waters during spawning migrations in the late fall or early winter (Scott and Scott 1988). Grabe (1978) reported that spawning does not occur south of the Hudson River. Self-sustaining, landlocked populations have also been identified in Deer Lake, on the west coast of Newfoundland (Scott and Crossman 1964).

### 3.1.1.1 Spawning, Incubation, and Emergence/Young-of-the-Year

In late December or early January, adult tomcod migrate inshore and although they may spawn in salt water, they prefer to move into estuaries and up rivers to the head of the tide (Scott and Scott 1988). Spawning has been reported to occur from mid-November to early December in the Miramichi River, New Brunswick (McKenzie 1959), late December to early January in Passamaquoddy Bay, southern New Brunswick (Peterson et al. 1980), and the end of December to the end of January in Trois-Rivières, Quebec (Vladykov 1955a). In the Saint Anne River, Quebec, spawning occurred under the ice, over a substrate of sand, gravel, or boulders at a maximum velocity of 0.3 m/s (Bergeron et al. 1998).

Extruded eggs are heavy, sink to the bottom, and settle into the substrate over which they are spawned (Bigelow and Schroeder 1953a; Dew and Hecht 1976; Klauda et al. 1988) where they remain for 60-65 days until hatching (Dew and Hecht 1994). There is inconsistency in the literature with respect to egg adhesiveness; Bigelow and Schroeder (1953a), Pearcy and Richards (1962), and Scott and Crossman (1998) report that the eggs are adhesive, while Nichols and Breder (1926), Breder (1948), Watson (1978) and Klauda et al. (1988) report that they are not. Watson (1978) and Klauda et al. (1988) state that eggs are only adhesive if stripped before females are fully ripe.

Hatching required 52 days at 2 to 4°C (Scott and Scott 1988), 30 days at 6.1°C, and 24 days at 4.4°C (Bigelow and Schroeder 1953a). Kellogg et al. (1978) determined that the upper lethal temperature for tomcod eggs was 6.6°C. In the Hudson River, New York, larvae hatch in the open water during February and March (Dew and Hecht 1994; Dew 1995), when the amount and variability of freshwater flow approaches an annual maximum (Mancroni et al. 1992; Wells and Young 1992). Larvae, up to 12 mm in total length (TL) (Booth 1967), drift downstream in the spring and are generally located near the bottom in the upper reaches of estuarine areas (Pearcy and Richards 1962; Howe 1971; Dew 1995; Scott and Crossman 1998). Larval distribution within the Hudson River has been described as a well-ordered progression of mean lengths, beginning upstream with the smallest larvae and increasing in a downstream direction, with the largest larvae being near the mouth of the estuary (Dew 1995). Both the upper Miramichi and St. Lawrence estuaries provide major nursery grounds for tomcod (de Lafontaine 1990; Hanson and Courtenay 1995; Locke and Courtenay 1995).

Young-of-the-year remain in estuarine waters throughout the summer and are restricted to areas having a relatively low salinity (10 ppt) (Bigelow and Schroeder 1953a). According to Able et al. (1998), the lower Hudson River estuary serves as an important nursery area for young-of-the-year and newly settled juveniles (<100 mm TL) from May to early July. Although data is sparse, young-of-the-year are reported to attain a length of about 60 to 90 mm in their first summer (Scott and Scott 1988). The disappearance of young-of-the-year tomcod from the lower Hudson

River estuary in July probably reflects the upstream migration that occurs in the summer, possibly in response to increasing water temperatures and freshwater flow (Klauda et al. 1988; Dew and Hecht 1994).

#### 3.1.1.2 Juvenile

Klauda et al. (1988) reported that within the Hudson River, there was an annual upstream movement of Atlantic tomcod juveniles in late summer (July-August). This was felt to be in response to low freshwater flows, which permitted the further intrusion of saltwater into the estuary. Ecological Analysts Inc. (1978) reported an upper incipient lethal temperature of 26.8°C for juvenile Atlantic tomcod acclimated at 24°C.

#### 3.1.1.3 Adult

Atlantic tomcod adults are commonly found at the high tide mark of salt marshes and mudflats (Dutil et al. 1982), in eelgrass beds (Howe 1971), to a maximum depth of 6 m in bays, estuaries, and coastal waters within approximately 1.6 km of shore (Bigelow and Schroeder 1953a). Lazzari (2002) observed Atlantic tomcod within eelgrass beds in shallow subtidal (3-6 m) areas from August to November and noted that they were absent from nearby unvegetated sandy substrates. Howe (1971) reported that tomcod were not encountered at water temperatures higher than 26°C and have been found at temperatures as low as –1.2°C (Gordon et al. 1962). The ability to withstand such low temperatures is due to a glycoprotein within the blood that depresses the freezing point (Fletcher et al. 1982; Reisman et al. 1984). In the fall, tomcod return to estuaries from marine areas and remain there overwinter (LeBlanc and Chaput 1991; Hanson and Courtenay 1995). According to Chaput (1995), activity within the Miramichi estuary during winter is dominated by smelt and tomcod. Tomcod are likely one of the least migratory diadromous fish since there is minimal exchange of tomcod populations between neighbouring large embayments (Vladykov 1955a).

In the Hudson River estuary, Atlantic tomcod have been reported to mature within 11 months and usually live a maximum 4 years (McLaren et al. 1988). According to Smith (1985b) and Coad et al. (1995), they typically mature at 1 year of age.

### 3.1.2 Burbot (*Lota lota*)

Burbot are unique in that they are the only freshwater cod species (Scott and Crossman 1998). They occur in continental Eurasia and North America, southward to about 40° N (Scott and Crossman 1998), where they frequent cool waters of large rivers, lower reaches of tributaries, and large lakes (Becker 1983). Burbot have been reported within the Churchill River (Beak Consultants Ltd. 1979; Ryan 1980; Black et al. 1986) and the Atikonak Lake watersheds (LGL Limited 1999) of southern Labrador. There have been no reports of burbot within insular Newfoundland (Scott and Crossman 1998).

### 3.1.2.1 Spawning, Incubation, and Emergence

Burbot either spawn in lakes (Mansfield et al. 1983; Boag 1989; Ghan and Sprules 1991; Scott and Crossman 1998; Bradbury et al. 1999) or rivers (Cahn 1936; Robins and Deubler 1955; Chen 1969; McPhail and Lindsey 1970; Sorokin 1971; Johnson 1981; Breeser et al. 1988; Evenson 1993; Scott and Crossman 1998; Arndt and Hutchinson 2000). For a complete description of lacustrine habitat preferences, refer to Bradbury et al. (1999).

Many burbot populations reside in lakes, but migrate into rivers to spawn (McPhail 1997). Riverine populations have been observed migrating to spawning sites within their respective watersheds (Tripp et al. 1981) and some have been reported to migrate up to 125 km (Breeser et al. 1988). Upstream migration occurs in October within tributaries of Lake Baikal, Russia (Sorokin 1971) and as late as February in tributaries of Columbia Lake, British Columbia (McPhail 1997).

Burbot are one of the few freshwater species to spawn in the winter or early spring (December to early March), often under ice or in areas where the river remains open (Bjorn 1940; Clemens 1951; McCrimmon and Devitt 1954; Lawlor 1963; Meshkov 1967; Chen 1969; Johnson 1981; Kouril et al. 1985; Sandlund et al. 1985; Breeser et al. 1988; Boag 1989). In the Kootenay River, British Columbia, spawning occurred in late January or February (McPhail 1997). Most of the literature indicates that burbot spawn at night (Carl et al. 1959; Scott and Crossman 1998; Simpson and Wallace 1978; Morrow 1980), however, Fabricius (1954) reported daytime spawning in a stream tank and Boag (1989) observed mid-morning spawning under the ice of an Albertan Lake. According to Pulliainen and Korhonen (1993), some portions of burbot populations may not spawn every year.

Burbot spawn at water temperatures ranging from 0 to 4°C (Fabricius 1954; McCrimmon and Devitt 1954; Hewson 1955; Lawler 1963; Meshkov 1967; Sorokin 1971). Field observations suggest that the eggs are adapted for maximum survival at temperatures between 0 and 2°C (McPhail 1997), however, Jager et al. (1981) reported an optimum development temperature between 4 and 7 °C with increasing mortality below 4°C.

In rivers, burbot spawn in low velocity areas of the main channel (Breeser et al. 1988), in side channels behind deposition bars (Sorokin 1971; McPhail and Lindsey 1997) or in areas having good aeration such as mouths of small streams, which are either open in the winter or have an air space between the ice and water (Sorokin 1971). Sorokin (1971) described preferred spawning habitat in tributaries of Lake Baikal, Russia, as large cobble/small boulder substrate with small to moderate amounts of silt, sand, and detritus, clear water, depths less than 1 m, and weak currents of approximately 0.03 m/s. A number of other authors report a preferred substrate of sand or fine gravel (Becker 1983; Breeser et al. 1988; Ford et al. 1995; McPhail 1997) at depths ranging from 0.3-3.0 m (McPhail and Lindsey 1970; Ford et al. 1995).

Spawning has been described as involving: a single male and female (Fabricius 1954); more than a single pair (McCrimmon 1959; Boag 1989); or one or two females surrounded by a 'writhing ball' of intertwined males (Cahn 1936; McPhail 1997). There is no site preparation or care of the young and the non-adhesive eggs are broadcast into the water column well above the substrate

(Fabricius 1954). Depending upon the current, the semi-buoyant eggs may drift, but eventually settle into substrate interstices (Sorokin 1971).

Jager et al. (1981) estimated the optimal incubation temperature as being between 1 and 7°C, with mortality increasing above or below 4°C, however, the majority of the literature indicates that most incubation occurs below 4°C. Incubation requires 71 days at temperatures <2°C (McCrimmon 1959, Ontario), 30 days at 6.1°C (Bjorn 1940, Wyoming), 28 to 35 days at 4°C (Breder and Rosen 1966), 41 days at 2°C (Andersson 1942, Sweden), and 98 to 128 days at 0°C (Meshkov 1967, Russia).

In eastern North America, since egg incubation takes approximately 3-4 months, pelagic larvae are usually present by mid-April (McCrimmon 1959; Ghan and Sprules 1993). Little is known about the riverine habitat requirements of larvae. Jager et al. (1981) reported that larvae require a temperature of at least 8°C to initiate feeding and survived in water temperatures up to 20°C.

#### 3.1.2.2 Young-of-the-Year/Nursery/Juvenile

McPhail (1997) reported that areas of quiet water downstream of spawning sites may provide nursery areas for developing larvae. Young-of-the-year and juveniles occupy essentially the same habitat (McPhail 1997). Young burbot are usually found in shallow regions of streams having a rocky or gravel bottom (Robins and Deubler 1955; Lawler 1963; Hartmann 1977; Becker 1983; Ford et al. 1995), although Hanson and Quadri (1980) reported that young-of-the-year utilized sandy substrate in the Ottawa River (probably due to a lack of preferred habitat). Young burbot require cover during the day, such as, weed beds, rocks, debris, and undercut banks (Robins and Deubler 1955; Hanson and Quadri 1980; Scott and Crossman 1998; Ford et al. 1995). They typically move from shallow to deeper water during the summer if water temperatures exceed their upper tolerance limit of 13.3 °C (Hartmann 1977; Thornburgh 1986).

#### 3.1.2.3 Adult

There is limited information available on the riverine habitat requirements of adult burbot. They are common in northern rivers where summer water temperatures rarely exceed 18°C (Chen 1969; Hatfield et al. 1972; Bishop 1975; Breeser et al. 1988; Kirillov 1988; Hvengaard and Boag 1993), but are relatively uncommon in southern rivers where summer temperatures exceed 20°C (McPhail 1997).

Adults tend to congregate over gravel, rock, or cobble substrates (Ford et al. 1995) and often utilize undercut banks, roots of trees and dense vegetation as cover (Becker 1983). They have been observed inhabiting deep sections of rivers (Rawson 1951; McPhail and Lindsey 1970) and deep eddies in large northern rivers (Thornburgh 1986), mostly at depths >1.5 m (Becker 1983). Preferred holding and feeding areas have been described as deep, fast riffles and back eddies or backwater areas with velocities <0.3 m/s (Ford et al. 1995). In northern rivers, adults are usually associated with main stream channels and appear to prefer turbid water (Chen 1969; Hatfield et al. 1972; Breeser et al. 1988). Their optimum temperature ranges between 15.6 and 18.6°C, with an upper lethal limit of 23.3°C (Scott and Crossman 1998). A preferred temperature of 21.1°C was reported for burbot in Ontario (Spotila et al. 1979).

Age at sexual maturity ranges from 2 to 4 years in the south up to 6 to 8 years in the north (Clemens 1951; Hewson 1955; Thornburgh 1986; Kirillov 1988). In Labrador, burbot have been reported to mature at 5 years of age (Ryan 1980). Other than spawning migrations, adults appear to be relatively sedentary (McPhail 1997).

# 3.2 Eels (Anguillidae)

## 3.2.1 American eel (*Anguilla rostrata*)

The American eel is distributed from the southern tip of Greenland, southward along the Atlantic coast and the Gulf of Mexico to the northern portion of the east coast of South America (Tesch 1977; Facey and Van Den Avyle 1987). In Newfoundland, American eels occur in most streams which have an uninterrupted flow to the sea and have also been reported along the south eastern coast of Labrador as far north as the Churchill River (Backus 1951; Black et al. 1986; Scott and Scott 1988; Scott and Crossman 1998). According to Eales (1968), they are abundant on the Avalon Peninsula, Trinity Bay, Bonavista Bay, Hamilton Sound, Notre Dame Bay, White Bay, and the Lake Melville area of Labrador.

American eels occur in warm brackish and freshwater streams, estuaries and coastal rivers, and in cold freshwater trout streams (Facey and Van Den Avyle 1987; Scott and Crossman 1998). American eels are catadromous; spawning occurs in the ocean, young migrate into estuarine and inland waters where they grow and begin to mature, and then they return to the sea to spawn once maturation is complete (Tesch 1977; Scott and Crossman 1998).

### 3.2.1.1 Spawning, Incubation, and Emergence

Castonguay et al. (1994) found that migrating silver eels in the St. Lawrence River ranged in age from 15 to 16 years, while in Newfoundland, they ranged from 9 to 18 years of age with a mean of 12 years (Gray and Andrews 1971). Eels begin their spawning migration in late summer and fall throughout much of New England and eastern Canada, although migration from distant inland lakes may begin earlier (Facey and Van Den Avyle 1987). Scruton et al. (1997) reported that downstream migration of silver eels generally occurs between mid-August to mid-October in Newfoundland. Peak migration typically occurs during the last quarter of the moon and is further enhanced by dark, stormy nights and rising water levels (Communications Directorate 2000).

Although American eels have never been observed spawning, spawning locations have been inferred based upon larval collections at sea (Schmidt 1923). Spawning is thought to occur in the Sargasso Sea in an area south of Bermuda and north of the Bahamas centered at about 25 °N and 69 °W (Vladykov 1964; Smith 1968; Vladykov and March 1975). Spawning begins as early as February and continues until April (Kleckner et al. 1983; McCleave et al. 1986). Although, the depth at which spawning occurs is unknown, some authors suggest it occurs in the upper few hundred meters of the water column (Kleckner et al. 1983; McCleave and Kleckner 1985). Because no spent adult eels have been captured, it is presumed that they die after spawning (Facey and Van Den Avyle 1987).

Hatching of American eels in North American waters is thought to begin and peak in February, continuing through April (Kleckner et al. 1983; Kleckner and McCleave 1985; McCleave et al. 1986).

### 3.2.1.2 Young-of-the-Year/Nursery

Eggs develop and hatch in 1-2 days and the resultant larvae (Leptocephali) drift with the ocean currents for a period of 8 to 12 months after which time they metamorphose into glass eels (Tesch 1977; Kleckner and McCleave 1985). Glass eels are 'eel'-shaped, but lack pigmentation. As they migrate into estuaries and streams, they undergo internal changes that will allow them to live in low salinity and fresh water. At this time, they become pigmented and are referred to as elvers (Scott and Crossman 1998).

In Newfoundland, elvers migrate into freshwater at night from mid-June to mid-August (Scruton et al. 1997). During these upstream migrations, they typically move up in the water column on flood tides and return to the bottom on ebb tides, thereby utilizing tidal stream transport (Hudson 1974; McCleave and Kleckner 1982; McCleave and Wippelhauser 1987). Although some elvers may penetrate rivers for many kilometers, a proportion remains in estuarine and coastal areas where they feed and grow into yellow eels. Upstream movements of young eels may occur over many years as they seek less crowded or better quality habitat and replace eels that have matured and left the river (Communications Directorate 2000). The broad geographic range of this eel suggests they have flexible temperature requirements (Facey and Van Den Avyle 1987), and in fact, elvers have been found at temperatures as low as –0.8°C (Jeffries 1960).

Upstream migrating elvers tend to be bottom dwellers, hiding in burrows, snags, plant masses, under rocks or any other type of shelter, including burrowing directly into the substrate (Fahay 1978; Facey and Van Den Avyle 1987). Soft undisturbed bottom sediments are critical shelter for migrating elvers (Fahay 1978; Facey and Van Den Avyle 1987). Sorensen (1986) reported that elvers are strongly attracted to the odour of brook water and decaying leaf detritus. Tesch (1977) observed elvers orienting towards river currents, and if currents were too strong they would move into backwater areas, thereby delaying migration. Dintaman (1975) reported that elvers in the state of Maine, migrated upstream at night in shallow water close to the shoreline, and would leave the water to cling to wet rocks or wet grass to facilitate passage in areas of high flow. They have also been observed moving upstream by climbing, clinging, and crawling up the sides of rocks, fishways, and dams (Becker 1983).

### 3.2.1.3 Juvenile/Adult

Juvenile or yellow eels may remain in coastal waters or continue their migration upstream into rivers, streams, and muddy or silt bottomed lakes (Scott and Crossman 1998). Their snakelike movements permit them to enter extremely shallow water, and their ability to remain out of water for up to 24 hours enables them to travel overland for short distances over marshy or damp areas to another lake or stream (Becker 1983; Scott and Scott 1988).

Yellow eels are primarily nocturnal and usually spend the day under cover or buried in soft substrates with only their snouts protruding (Becker 1983). The presence of a soft substrate is particularly crucial during winter months (water temperature <4°C) when the eels hibernate in the bottoms of lakes and rivers (Vladykov 1955b; Tesch 1977; Scott and Scott 1988; Scott and Crossman 1998; Communications Directorate 2000). Trautman (1981) also reported that eels partially or completely bury themselves in mud, sand and gravel during the day, emerging at dusk to begin feeding. The following preferred water temperatures have been reported for yellow eels: 16.7°C (Barila and Stauffer 1980); 17.4°C (Karlsson et al. 1984); and 19°C (Minns et al. 1993).

Over a period of several years as juvenile or yellow eels, they reach the appropriate size for the adult stage to begin. Duration of the yellow eel life stage varies depending upon temperature, food availability, and length of the growing season. Prior to downstream migration, which typically occurs in the fall, yellow eels undergo sexual maturation and transform into silver eels, which prepares them for life in the ocean (Tesch 1977; Communications Directorate 2000). Fahay (1978) reported that in U.S. populations, eel maturation occurred after age 3 for males and at 4 to 6 years of age for females, while ages up to 18 years have been reported in Newfoundland (Gray and Andrews 1971).

## 3.3 Herring (Clupeidae)

### 3.3.1 Alewife (*Alosa pseudoharengus*)

Alewives occur from southern Labrador and northeastern Newfoundland (Scott and Scott 1988) southward to northern South Carolina (Berry 1964) possibly as far south as Florida (Williams and Grey 1975; Rulifson and Huish 1982). In Newfoundland and Labrador, alewives have been reported from: Paquet on the northeast coast (Winters et al. 1973); the southeast coast (Anon. 1952); Humber and Little Codroy rivers on the west coast (Scott and Crossman 1964); North Harbour River (Winters et al. 1973); Holyrood Pond in St. Mary's Bay (Anon. 1952; O'Connell et al. 1984); and coastal waters of the southern Labrador coast (Hare and Murphy 1974; Anderson 1985).

Alewives occur in anadromous (Winters et al. 1973; Hare and Murphy 1974; Anderson 1985) and landlocked forms, with the greatest numbers of landlocked populations occurring in the Great Lakes (Scott and Crossman 1998). Anadromous alewives spend most of their adult life at sea, entering freshwater only to spawn in lakes and quiet stretches of rivers above tidal influence (Scott and Crossman 1998; Scott and Scott 1988).

#### 3.3.1.1 Spawning, Incubation, and Emergence

During spawning, it is believed that most alewives home to their natal streams (Communications Directorate 1990a), where they spawn above tidal influence (Pardue 1983; Scott and Scott 1988; Scott and Crossman 1998). Upstream spawning migration occurs from January to June in a south-north progression, which is related to water temperature (Pardue 1983). Spawning runs of a 1-2 month duration (Scott and Crossman 1998) have been reported to begin during April in St. Mary's Bay, Newfoundland (Winters et al. 1973), the Bay of Fundy (Leim and Scott 1966), and the Chesapeake Bay region (Hildebrand and Schroeder 1928); May in the Margaree River, Nova Scotia (Scott and Crossman 1998); June in North Carolina rivers (Street 1970; Sholar 1977;

Fisher 1980); and, January in Florida Rivers (Williams et al. 1975). Richkus (1974) also found that fish movement was positively correlated with volume outflow. Water temperatures during upstream spawning migrations typically range from 12 to 16°C (Bigelow and Schroeder 1953a; Havey 1961; Thunberg 1971; Jones et al. 1978; Pardue 1983).

Spawning typically commences in mid-May or June, once water temperatures reach 9-12°C (Lackey 1970; Scott and Scott 1988; Jessop 1990). Optimal spawning temperatures are reported to range from 15 to 20°C (Marshall 1977; Sholar 1977; Bulak and Curtis 1978; Pardue 1983) with spawning activity ceasing when temperatures exceed 27°C (Hawkins 1979). Spawning generally occurs in areas of sluggish flow, water depths of 15 cm to 3 m, over substrates of gravel, sand, detritus, and submerged vegetation (Edsall 1964; Mansuetti and Hardy 1967; Pardue 1983; Loesch 1987; Bozeman and Van Den Avyle 1989). In contrast to this, McKenzie (1959) reported large numbers of alewife spawning in rapids within the Miramichi River, New Brunswick. Eggs are initially demersal and adhesive (for 24 hours until they are water-hardened) in still water and pelagic in running water (Loesch and Lund 1977; Jones et al. 1978; Communications Directorate 1990a).

Hatching of alewife eggs have been reported to require: 2 days at 29°C (Edsall 1970); 4 days at 21°C (Edsall 1970); 3 to 5 days at 20°C (Jones et al. 1978); 6 days at 15.6°C (Jones et al. 1978); 3 to 5 days at 10 to 12°C (Cianci 1969); and, 15 days at 7.2°C (Rulifson and Huish 1982). Kellogg (1982) reported maximum hatching success at 20.8°C, decreasing significantly at 27°C and ceasing at 29.7°C.

#### 3.3.1.2 Larvae/Nursery

Newly hatched larvae measure 2.5 to 5.0 mm in length and absorb their yolk sac within 2-5 days (Mullen et al. 1986). Kellogg (1982) reported that daily larval growth increments were greatest at 26.3 °C. Larval alewives were reported to remain near or slightly downstream of spawning sites in Chesapeake Bay rivers (Dovel 1971). In Nova Scotia rivers, larvae were associated with warm, shallow (<2 m), sandy areas in the vicinity of spawning sites (O'Neill 1980). Transformation from larvae to juvenile (20 mm TL) generally takes 2 to 3 weeks (Bozeman and Van Den Avyle 1989).

#### 3.3.1.3 Juvenile

Juvenile alewives are commonly referred to as young-of-the-year (Loesch 1987). Juveniles typically spend 3-9 months in their natal rivers before migrating to sea (Kosa and Mather 2001; Yako et al. 2002). Although late fall and early winter are the most common times for downstream emigration, it can occur anytime from June to November during the first year of life (Tyus 1972; Burbidge 1974; Kissil 1974; Richkus 1975a; O'Neill 1980). Downstream migration has been linked with rainfall, declines in water temperature, and increases in discharge (Cooper 1961; Kissel 1974; Burbidge 1974; Richkus 1975a; O'Neill 1980).

In the Santuit River, Massachusetts, seaward migration occurred over a four-month period from July through early November, with peaks of migration in early July and early September (Yako et al. 2002). The peaks of migration occurred during a new moon when density of *Bosmina* spp., a preferred prey, was low (Yako et al. 2002). Stokesbury and Dadswell (1989) also reported increases in seaward migration at the new moon in the Annapolis River, Nova Scotia. All periods of migration in the Santuit River occurred when water visibility was low and during decreased levels of rainfall (Yako et al. 2002). Others have noted that abundance and movement is reduced at low discharge and peaks occur during periods of elevated discharge and rainfall (Cooper 1961; Kissil 1974; Richkus 1975a; Jessop 1994). In the Santuit River, most migration events also occurred during the mid to late afternoon, which is consistent with the findings in other systems (Kissil 1974; Richkus 1975a; Richkus and Winn 1979; Kosa and Mather 2001). In a number of small, coastal Massachusetts systems, little or no emigration occurred in late summer when stream channels were often dewatered (Kosa and Mather 2001) and others have reported decreased emigration during extremely high discharge (Richkus 1975b; Jessop 1994). In laboratory experiments, juveniles avoided water velocities >0.1 m/s, especially in narrow stream channels (Gordon et al. 1992).

In spring and early summer, alewives are widely distributed in tidal freshwater nurseries within tributaries of Chesapeake Bay, but with the encroachment of salt water they tend to move upstream (Warinner et al. 1969). Juveniles have been shown to utilize high salinity estuaries as secondary nurseries before migrating to the sea (Holland and Yelverton 1973; Hanson and Courtenay 1995).

According to Loesch (1987), juveniles are often concentrated near the bottom during the day and move up into the water column at night. In the Potomac River, Warinner et al. (1969) reported that juveniles were most abundant in surface waters prior to September, at water depths of 4.6 m during late September, and on the bottom prior to emigration in late September-October. When water temperatures decrease in early winter, young move downstream and may remain in deep estuarine waters throughout the winter (Hildebrand and Schroeder 1928). Once at sea, young typically remain there for 4-5 years before returning to freshwater to spawn (Communications Directorate 1990a).

The temperature range for juveniles is from 3°C to 24.5-34°C, depending upon acclimation temperature (Otto et al. 1976; Becker 1983) and is consistently 3-6°C higher than the temperature range of adults (Otto et al. 1976). McCauley and Binkowski (1982) reported an upper lethal temperature for juveniles of 30°C. Juveniles have been collected in the lower portion of estuaries to a distance of 8 km offshore, at temperatures between 4.5 and 6.5°C (Milstein 1981). Dorfman and Westman (1970) reported survival and feeding temperatures up to 35°C.

### 3.3.1.4 Adult

Adults only enter freshwater to spawn, and then return to sea where they inhabit a narrow band of coastal water within the vicinity of natal nurseries (Jones et al. 1978; Scott and Crossman 1998). Downstream migration usually occurs in late August (Loesch 1987; Jessop 1990; Scott and Crossman 1998). At sea, adults are largely confined to depths less than 100 m and water temperatures between 2 and 17°C (Neves 1981). McCauley and Binkowski (1982) reported an upper lethal temperature limit of 31-34°C for adults, while Coutant (1977) reported a preferred temperature of 18.8°C. For information on the habitat requirements of lacustrine and landlocked alewives, refer to Bradbury et al. (1999).

Age at first spawning, percentage of repeat spawners, and longevity in alewife populations can fluctuate annually, but appears to increase slightly in more northerly populations (Pardue 1983). Spawning ages have been reported as 3-4 years in the Gulf of St. Lawrence (LeBlanc and Chaput 1991), 4 to 5 years in North Carolina (Sholar 1977; Street et al. 1975; Rulifson and Huish 1982), 3 to 8 years in the Connecticut River (Joseph and Davis 1965; Marcy 1969; Loesch and Lund 1977), and 4 to 10 years in Nova Scotia (O'Neill 1980). The percentage of repeat spawners has been reported as 10 to 45% in North Carolina (Tyus 1974; Street et al. 1975; Sholar 1977), 61% in Virginia (Joseph and Davis 1965), and 60% in Nova Scotia (O'Neill 1980). The maximum reported age attained by alewife was 9 years in North Carolina (Street et al. 1975; Johnson et al. 1977) and 10 years in Nova Scotia (O'Neill 1980).

### 3.3.2 American shad (*Alosa sapidissima*)

The American shad, largest member of the family Clupeidae (Heidinger 2000), is an anadromous species, inhabiting Atlantic coastal waters off Newfoundland and Labrador (Dempson et al. 1983) to Florida (Scott and Crossman 1998). In Newfoundland, shad have been sporadically reported in Bay Bulls, Bay of Islands, St. Phillips, and Western Arm Brook (Scott and Crossman 1964; Hodder 1966; Chadwick et al. 1978; Chadwick 1981), while in Labrador, they have been reported from the Sand Hill River, Voisey's Bay, Nain, and Black Island (Hare and Murphy 1974; Dempson et al. 1983; Anderson 1985). Given the small numbers and infrequent incidence of occurrence in Newfoundland and Labrador waters, it is doubtful that these individuals represent self-sustaining populations and more likely represent strays (Dempson et al. 1983).

#### 3.3.2.1 Spawning, Incubation, and Emergence

Spawning has been reported in rivers and brackish water (Leim and Scott 1966; Scott and Scott 1988; Scott and Crossman 1998), rarely, if ever, in lakes (Scott and Crossman 1998). No spawning populations have been reported north of the Gulf of St. Lawrence and St. Lawrence River (Leggett 1976). According to Chaput and Bradford (2003), there are no spawning runs of shad in Newfoundland and Labrador. The majority of American shad return to their natal rivers to spawn (Dodson and Leggett 1973; 1974; Carscadden and Leggett 1975; Melvin et al. 1986). Its entry into rivers is highly dependent upon water temperature, with peak migrations occurring earlier in the south than in the north (Weiss-Glanz et al. 1986). As a result, peak spawning migrations may occur as early as January in Florida and as late as June or July in New Brunswick and Quebec (Walburg and Nichols 1967; Leggett and Whitney 1972; Scott and Crossman 1998). Leggett (1976) found that upstream spawning migrations usually begin when water temperatures reach at least $4^0$C. In the northern part of their range and especially in Canadian waters, shad are repeat spawners and may return to the same river, even the same tributary, as many as five times (Carscadden and Leggett 1975). The percentage of repeat spawners increases from south to north (Weiss-Glanz et al. 1986), ranging from 0% in the St. John's River, Florida to 73% in the St. John River, New Brunswick (Leggett and Carscadden 1978).

Estuarine water temperatures during the arrival of shad in rivers along the Atlantic coast ranges from 3 to 15°C, with the lower values for northern populations and the higher values for those in the south (Talbot 1954; Massman and Pacheco 1957; Walburg and Nichols 1967; Leggett 1972; Leggett and Whitney 1972; Chittenden 1976). The peak in juvenile downstream migration usually occurs simultaneously with upstream spawning migrations (Leggett and Whitney 1972; Williams and Bruger 1972). Spawning has been reported at water temperatures ranging from 8 to 26°C, with peak spawning usually occurring between 13 to 21°C (Walburg and Nichols 1967; Scott and Scott 1988; Ross et al. 1993a). Marcy (1972) reported that upstream spawning migrations cease in the Connecticut River when water temperatures rise above 20°C, yet Beasley and Hightower (2000) reported spawning in North Carolina at temperatures up to 26°C.

In the Maritimes, shad have been reported to spawn in the spring from May to July (Weiss-Glanz et al. 1986; Scott and Scott 1988; Scott and Crossman 1998). Shad may spawn practically anywhere in rivers, but prefer broad flats or shallow water (Smith 1907; Bigelow and Welsh 1925; Hildebrand and Schroeder 1928; Massman 1952; Marcy 1972). As a result, spawning occurs over a wide range of water velocities from 0.09 to 1.32 m/s (Kuzmeskus 1977), but usually occurs at velocities ranging from 0.31 to 0.91 m/s (Walburg 1960; Walburg and Nichols 1967; Ross et al. 1993b). Spawning has been reported at various depths in rivers ranging from 0.45 to 12.2 m (Mansueti and Kolb 1953; Walburg 1960; Walburg and Nichols 1967; Kuzmeskus 1977).

Spawning either occurs in clear water at night (Leim 1924; Whitney 1961) or in turbid water during the day (Chittenden 1975). During spawning, females extrude non-adhesive eggs into the open water, where they are fertilized by males (Scott and Crossman 1998). Due to the pelagic nature of spawning, shad do not exhibit strong substrate preferences and have been observed spawning over sand, silt, muck, gravel, and boulder substrates providing there is sufficient flow to remain silt-free (Mansueti and Kolb 1953; Walburg 1960; Leggett 1976). Jones et al. (1978) reported that after hardening, eggs settle singly and may lodge in rubble.

Shad spawn far enough upstream to allow the eggs sufficient time to drift and hatch before reaching saltwater (Weiss-Glanz et al. 1986). Depending upon water currents, eggs may drift several meters to 6 km downstream before settling (Marcy 1972). Temperatures for optimum hatching and survival of eggs range from 13.0 to 26.0°C (Leim 1924; Massman 1952; Walburg 1960; Bradford et al. 1966; Marcy 1972; Klauda et al. 1991). Leach (1925) reported a minimum temperature of 11°C and Marcy (1976a) reported a maximum temperature of 26.7°C for hatching success. Shad eggs have been reported to hatch in about 8 to 12 days at 11 to 15°C (Scott and Crossman 1998) and in 3 days at temperatures from 14 to 23°C (Marcy 1976a).

#### 3.3.2.2 Larvae/Nursery

The optimum temperature range for American shad larvae is 15.5-26.5°C (Klauda et al. 1991). Newly hatched larvae are approximately 7 mm in length, and since they are initially planktonic, are carried passively downstream from spawning grounds (Marcy 1976a). Ross et al. (1993b) reported that larval shad in the Delaware River demonstrated an affinity for riffle pools characterized by moderate depth and currents of varying velocity and direction.

Larvae absorb their yolk sacs in 4 to 7 days (Walburg and Nichols 1967) and transform into juveniles within 4 to 5 weeks after hatching (Leim 1924; Walburg and Nichols 1967; Jones et al. 1978). Young form large schools and gradually migrate downstream in the fall when water temperatures drop below 15.5°C (Leggett and Whitney 1972; Scott and Crossman 1998) or 19.9°C (O'Leary and Kynard 1986). Although some may remain within estuaries for their first year (Hildebrand 1963), others move directly to the open ocean where they spend the majority of their life (Chittenden 1969; Jones et al. 1978; O'Leary and Kynard 1986; Stevens et al. 1987). According to Talbot and Sykes (1958), shad from all Atlantic Coast rivers spend the summer and fall in the Gulf of Maine.

### 3.3.2.3 Juvenile

Juvenile American shad measure approximately 25 to 28 mm in TL (Walburg and Nichols 1967). Juveniles have been captured in offshore Atlantic waters (Neves and Depres 1979) where they may remain until mature (Weiss-Glanz et al. 1986), which may take 4-5 years (Communications Directorate 1990b).

Although the lower thermal tolerance limit for juvenile shad is about 2.2°C, they tend to avoid temperatures below 8°C (Chittenden 1972) and prolonged exposure to temperatures of 4 to 6°C cannot be tolerated. Juveniles have been reported in water temperatures ranging from 10 to 31°C (Marcy et al. 1972). Juvenile shad in the Connecticut River have been found at depths ranging from 0.9 to 4.9 m, switching from the bottom during the day to surface waters at night (Marcy 1976a). Ross et al. (1997) reported that juveniles within the Delaware River exhibited no strict habitat or substrate preferences.

### 3.3.2.4 Adult

American shad remain at sea for 2-6 years (Talbot and Sykes 1958; Walburg and Nichols 1967; Leggett 1976; Leggett and Carscadden 1978; Morrow 1980; Melvin et al. 1986) before returning in the spring to spawn in rivers and streams (Weiss-Glanz et al. 1986; Scott and Crossman 1998). Adults are generally found at ocean depths between 50 and 100 m, and bottom temperatures of 3 to 15°C (Talbot and Sykes 1958; Neves and Depres 1979). Migration ranges at sea extend from Labrador to Florida (Dadswell et al. 1987). Prespawning adults select ocean isotherms of 13 to 18°C and migrate nearshore (presumably to facilitate homing) (Leggett and Whitney 1972; Dadswell et al. 1987), while nonspawning adults migrate further offshore in isotherms of 3 to 15°C (Neves and Depres 1979; Dadswell et al. 1987). Adults that survive river spawning enter coastal waters in a broad front towards the middle Atlantic coast (Stier and Crance 1985).

Males generally mature at 3 to 4 years of age, while females mature at 4 to 6 years of age (Leim 1924). Maki et al. (2001) reported that shad matured between 3-7 years of age, while Leggett and Carscadden (1978) found they matured at age 4-6. In the Connecticut River, Weiss-Glanz et al. (1986) reported that shad make their first spawning run when they were 4-5 years old and by age 6 all had spawned at least once.

## 3.4 Killifishes (Cyprinodontidae)

### 3.4.1 Banded killifish (*Fundulus diaphanous*)

Banded killifish occur along the eastern seaboard from South Carolina to the Maritimes and west through southern Canada to the Red River, Manitoba and the Yellowstone River in Montana (Scott and Crossman 1998; Scott and Scott 1988). Although widely distributed in the Atlantic provinces, banded killifish have only been reported from a few localities in Newfoundland; in the vicinity of Stephenville Crossing, Freshwater Pond on the Burin Peninsula (Scott and Crossman 1964; Gibson et al. 1984; Scott and Scott 1988; Scott and Crossman 1998), and Indian Bay Brook (van Zyll de Jong et al. 1999) and there are no reports of the species occurring in Labrador. Although thought to be abundant at these locations, suitable habitat along the coast is limited, and the steep gradient of the rivers may constitute barriers to immigration to inland sites (Gibson et al. 1984). Houston (1990) also suggested that the cooler waters of Newfoundland may limit their distribution and further immigration to the island is unlikely either due to a lack of suitable habitat or thermal barriers to dispersion.

The banded killifish, although euryhaline and salinity tolerant, is considered a fresh water resident (Houston 1990; Scott and Scott 1998). They are most abundant in shallow waters of clear glacial lakes with sluggish currents, sand, gravel, or detritus covered bottoms, and abundant vegetation (Smith 1979; Trautman 1981; Cooper 1983; Scott and Crossman 1998).

#### 3.4.1.1 Spawning, Incubation, and Emergence/Young-of-the-Year/Nursery/Juvenile

Spawning takes place from April to May depending upon water temperature, with a preferred temperature of approximately 21°C (Richardson 1939; Carlander 1969; Scott and Crossman 1998). In a tributary of the Richelieu River, Quebec, Richardson (1939) reported prespawning activity at temperatures of 21°C and spawning in May when temperatures reached 23°C. In the Ottawa River Watershed, McAllister and Coad (1974) reported females in spawning condition in June at 23°C. Banded killifish collected by Gibson et al. (1984) from Freshwater Pond, Newfoundland, indicated that spawning may be delayed (occurring in mid- to late summer) with respect to other localities in Newfoundland.

The preferred spawning areas, selected by the males, are quiet shallows of weedy pools (Scott and Crossman 1998). Males spawn individually with females and there is no nest building or care of the young (Cooper 1983). The eggs are attached to the female by an adhesive thread, which becomes detached after fertilization and sticks to vegetation (Scott and Crossman 1998). Eggs hatch in 11 to 12 days at water temperatures of 22 to 27°C (Cooper 1936). Larvae/fry are 6 to 12 mm in length (Auer 1982) and undergo growth during their first year of life to a length of 20 to 64 mm (Smith 1952; Trautman 1981).

#### 3.4.1.2 Adult

Adults are usually found in schools where they tend to prefer shallow water with sand, gravel or detritus covered bottoms near patches of submerged aquatic plants (Keast et al. 1978; Rozas and Odum 1987; Killgore et al. 1989; 1991; Houston 1990; Page and Burr 1991; Scott and Crossman

1998). Their preferred position is near the surface of the water (Becker 1983). In south eastern Newfoundland, Gibson et al. (1984) captured killifish over a sand/cobble substrate. Although there is no information with respect to seasonal movements, its distribution is thought to be related to salinity and temperature preferences as well as prey availability (Fritz and Garside 1974a; Griffith 1974; Garside and Morrison 1977; Weisberg 1986; Houston 1990).

Banded killifish have a wide range of temperature tolerances and have been reported at 38.3°C (Carlander 1969, Iowa), although Rombough and Garside (1977) report an upper limit of 34.5°C. Melisky et al. (1980) reported that banded killifish in Pennsylvania preferred water temperatures of 28.6°C, while those in Nova Scotia exhibited a preference of 21°C. Garside and Morrison (1977) also reported that banded killifish prefer water temperatures around 21°C.

Banded killifish generally reach sexual maturity by the end of their first year (Carlander 1969) or by age 2 (Keast and Eadie 1984; Portt et al. 1988). Adult lengths usually range from 64 to 76 mm, but larger sizes are common in the Maritime provinces (Scott and Crossman 1998). The largest individual on record was 11.4 cm TL, which was captured in Lake O' Law, Nova Scotia (Scott and Crossman 1998).

### 3.4.2 Mummichog (*Fundulus heteroclitus*)

Mummichogs are a small, relatively sedentary fundulid fish (Parenti 1981). It occurs in Atlantic coastal and brackish waters from south western Newfoundland (Leim and Scott 1966) to north eastern Florida (Scott and Crossman 1998), including the shore waters of the Maritime provinces to Port au Port Bay (Scott and Crossman 1998) and the Bay of Islands in south western Newfoundland (Dickinson 1974). Mummichogs are most commonly found in salt marsh flats, estuaries, brackish-water ponds, and tidal areas, particularly where there is submergent or emergent vegetation (Abraham 1985; Scott and Scott 1988; Scott and Crossman 1998). They are considered to be eurythermal and euryhaline (de Silva 1969; Fritz and Garside 1974b; Abraham 1985) and especially tolerant of abrupt salinity changes (Garside and Chin-Yuen-Kee 1972). Although they can tolerate short exposures to fresh water, prolonged exposures can cause death (Nead and Buttner 1987). Due to its high tolerance of low oxygen conditions, it may also be found in marginal habitats trapped by tidal movements or in small drying up ponds (Scott and Scott 1988).

The only evidence of a landlocked population was reported by Klawe (1957) in Digby Neck, Nova Scotia. In addition, Chidester (1920) reported a single spring migration of mummichog through a New Jersey salt marsh, which continued upstream to fresh water. This migration was thought to be attributable to a unique combination of temperature, food availability, current velocity, and dissolved oxygen levels (Chidester 1920). There has been no evidence since to indicate that mummichog engage in regular or predictable migrations (Scott and Scott 1988).

#### 3.4.2.1 Spawning, Incubation, and Emergence

Spawning typically begins in spring (March-May) and ends in late summer/early autumn (July-September) (Hardy 1978; Scott and Crossman 1998). In New England, spawning has been reported to occur from June to early August (Scott and Crossman 1998); June and the first two weeks of July in Woods Hole, Massachusetts (Newman 1907); and February to September in a Georgian salt marsh (Kneib 1984). In the Miramichi estuary, the spawning period lasted nine weeks from the end of May to the end of July and was discontinuous, with four spawning peaks (LeBlanc and Couillard 1995). According to Taylor and DiMichele (1980), mummichog may spawn eight or more times in a single season, with each peak lasting five or more days. Maximal spawning typically occurs during high spring tides at night (Taylor et al. 1979; Taylor 1986). Mummichog spawning may be timed by a combination of different environmental stimuli (Wallace and Selman 1981) such as temperature (Brummett 1966), tides, moonlight, photoperiod, and salinity (Taylor et al. 1979; Day and Taylor 1983).

Although spawning areas are selected by the female, there are no nests prepared (Scott and Scott 1988). A number of authors have reported that mummichog commonly deposit eggs in empty mussel shells within the intertidal zone (Able and Castagna 1975 – Virginia; Taylor et al. 1977; 1979; Kneib and Stiven 1978 – North Carolina; Taylor and DiMichele 1983 - Delaware; and, Yozzo et al. 1994 - Virginia), while others have found that they deposit eggs in sand and mud substrates (Taylor 1986 – New England), algal mats (Pearcy and Richards 1962 – New England; Taylor 1986 – Delaware Bay), or aquatic plants, such as tidal grasses (Able and Castagna 1975 – Virginia; Taylor et al. 1979 - Delaware Bay; Day and Taylor 1981 – Delaware River; Taylor 1986 – New England, Georgia and Florida). Northern populations appear to spawn preferentially in sand, while more southern populations utilize plants or mussel shells (Taylor 1986).

Mummichogs spawn in shallow fresh, salt, or brackish water at temperatures ranging from 13 to 29°C (Hardy 1978); usually near the high water mark (Taylor 1986). Eggs occur in clutches of 10-100 which are buried several centimetres below the surface (Taylor 1986). The reproductive strategy of mummichog is based on aerial incubation of eggs in the high intertidal zone (Taylor 1986). Eggs are resistant to desiccation and hatch when they are inundated, usually on spring tides (Taylor 1986; 1999). Bigelow and Schroeder (1953b) reported that incubation usually takes 9 to 18 days depending upon water temperature. Incubation in the wild was reported to take 7 to 8 days at 22 to 34°C (Taylor et al. 1977), and 10.5 days in the laboratory at 20°C (Armstrong and Child 1965). The stranding of mummichog eggs has been documented upon shelves of shores and tall aquatic plants in Delaware Bay (Taylor et al. 1977) and is considered to be a fairly common occurrence (Scott and Scott 1988). Under such circumstances, hatching may be delayed for several days or even weeks, but hatching normally occurs within seconds of eggs being re-immersed (DiMichele and Taylor 1980).

### 3.4.2.2 Young-of-the-Year/Nursery

Newly hatched larvae range from 4.0 to 7.7 mm in TL (mean 5.0 mm) (Hardy 1978) and in the laboratory, they have been shown to require 5.5 days at 5°C to absorb the yolk sac (Armstrong and Child 1965). Taylor et al. (1979) reported that young remain in the intertidal zone for 6-8 weeks after hatching, inhabiting shallow puddles and pools on the vegetated marsh surface during low tide. Kneib (1984) reported that larvae were present from late May to December in shallow puddles of tidal water in a Georgian salt marsh. Kneib (1984) also found that smaller larvae inhabited aquatic microhabitats near the upland edge of the tidal marsh, but moved to lower elevations near a tidal creek as they increased in size. At 15-20 mm SL young begin to move, like the adults, on and off the marsh surface with the tidal flow (Kneib 1986).

### 3.4.2.3 Juvenile/Adult

There is a paucity of information within the literature with respect to the habitat requirements of juvenile mummichog. In Chesapeake Bay, adults were found to prefer mud substrates (Hildebrand and Schroeder 1928; Abraham 1985). They follow rising tides onto salt marsh surfaces during the day to feed (Butner and Brattstrom 1960; Weisberg et al. 1981; Halpin 1997) and spawn (Taylor et al. 1977), returning to tidal creeks, ditches, and shallow embayments as tides recede (Kneib 1984). Abraham (1985) concluded that they prefer areas with submerged grass (which aided in predator avoidance) and mud substrate. In Newfoundland, they were found in a stagnant backwater area of an estuary at a depth of 1 m over a mud substrate devoid of vegetation, and a small lagoon with a dense growth of eelgrass (*Zostera* sp.) and soft mud substrate (Dickinson 1974). Other investigators have also reported the use of eelgrass beds by mummichog (Penzak 1985 – Nova Scotia; Graham et al. 1998 - Massachusetts). The maximum depths at which mummichog are found is seldom greater than 4 m (Bigelow and Schroeder 1953a).

In Delaware salt marshes, mummichogs can be exposed to temperature fluctuations of 6 to 35°C (Schmelz 1964), while in Maine, summer tidal cycles can result in rapid temperature changes from 15 to 30°C (Abraham 1985). Garside and Morrison (1977) reported that mummichogs prefer water temperatures around 22°C. They have been reported to survive salinities of 0.0-120.3 ppt (Griffith 1974) and temperatures from -1.5°C (Umminger 1972) to 36.3°C (Garside and Chin-Yuen-Kee 1972). In laboratory experiments, mummichog have died of heat shock in 63 minutes at 34°C, 28 minutes at 36°C, 9 minutes at 37°C, and 2 minutes at 42°C (Orr 1955). Maximum growth efficiency has been reported in the range of 13 to 29°C (Targett 1979) and feeding rates have been observed to increase rapidly at temperatures above 24°C.

In southern New England, mummichogs have been found residing within salt marshes throughout the year (Halpin 1997). In New Jersey, Chidester (1920) reported that mummichogs appeared to remain within tidal creeks throughout the summer, while other species moved in and out of the creeks with the tides. During winter, mummichogs residing in pools have been observed burrowing 1.5 to 2.5 cm into the mud (Chidester 1920; Hardy 1978), while others have migrated to the mouths of their respective tidal channels (Butner and Brattstrom 1960). Lotrich (1975) and Fritz et al. (1975), on the otherhand, found that most mummichogs migrated upstream into shallow, less saline waters of tidal creeks to overwinter.

Lotrich (1975) reported that although most mummichogs within a Delaware tidal creek had a summer home range of approximately 36 m, which persisted from July through September, three individuals were recaptured 3.75 km away from their initial point of capture. Sweeney et al. (1998) found that mummichogs within a macrotidal (>3 m) estuary occupied home ranges of approximately 650 m.

Mummichogs typically reach sexual maturity at 2 years of age (Coad et al. 1995) and a minimum length of 25 mm (Hardy 1978). Adult mummichogs have been reported to reach a maximum size of 130 mm in Prince Edward Island (Needler 1940), the Magdalen Islands, and the Gulf of St. Lawrence (Scott and Crossman 1998). Armstrong and Child (1965) reported adult mummichog of Wood's Hole, Massachusetts ranged from 51 to 102 mm in length. Bigelow and Schroeder (1953a) reported lengths of 89 to 102 mm in the Gulf of Maine.

# 3.5 Lampreys (Petromyzontidae)

## 3.5.1 Sea lamprey (*Petromyzon marinus*)

The sea lamprey is an anadromous, parasitic and predatory species, ascending streams in spring to spawn, but otherwise spending their adult life at sea or in lakes (Downs 1982; Scott and Scott 1988). However, landlocked populations do exist and in fact, most available information on sea lampreys is for freshwater (landlocked) populations in the Great Lakes. Although valued as a food delicacy throughout much of Europe, it is viewed primarily as a nuisance species in North America. This is primarily because it attacks species of economic and aesthetic importance including; Atlantic salmon, lake trout, lake whitefish, and lake herring in freshwater, and cod, mackerel, haddock, and hake in the marine environment (Becker 1983; Scott and Crossman 1998).

The sea lamprey occurs off the Atlantic coast of North America from southwest Greenland to northern Florida (Scott and Scott 1988). In Canada, spawning runs have been reported in New Brunswick and Quebec rivers flowing into the Gulf of St. Lawrence and Nova Scotia rivers flowing south westerly into the Atlantic (Beamish 1980; Scott and Scott 1988; Scott and Crossman 1998). Smaller, landlocked populations are present within the watersheds of all the Great Lakes (Scott and Crossman 1998). In Newfoundland, prior to 1993, reports of spawning populations of sea lamprey occurrences had been primarily anecdotal, including: a report from the Bersimis River, Labrador (Low 1895); various unconfirmed reports of sea lamprey in the Terra Nova River (Dempson and Porter 1993); a confirmed sighting of a lamprey attached to an Atlantic salmon in the Humber River in the mid 1970's (Crane, Fisheries and Oceans Canada, Corner Brook, NL, Pers. Comm., in Dempson and Porter 1993); an adult captured in the Sand Hill River, Labrador in 1971 (Murphy 1972; Anderson 1985); a single individual from Cat Arm Brook, Northern Peninsula (O'Connell, Fisheries and Oceans Canada, St. John's, NL, Pers. Comm., in Dempson and Porter 1993); and a mature female captured in an Atlantic salmon smolt trap on the Gander River in 1999 (O'Connell, Fisheries and Oceans Canada, St. John's, NL, Pers. Comm.). Dempson and Porter (1993) documented the first occurrence of a Newfoundland spawning population of sea lamprey in the Terra Nova River.

### 3.5.1.1 Spawning, Incubation, and Emergence

Lampreys enter rivers to spawn in the spring after spending approximately two years at sea or in a lake (Manion and Hanson 1980; Noltie and Robilliard 1987; Scott and Scott 1988). Manion and McLain (1971) observed lamprey entering a Michigan stream 6 to 8 weeks before spawning. At the onset of migration, they cease feeding and begin to mature sexually; this is the only true adult phase (Scott and Crossman 1998). Although spawning usually occurs in the spring, the timing can vary significantly based upon latitude, ranging from early March in Virginia to late September in New Brunswick (Scott and Scott 1988). In three Lake Superior tributaries (Kelso and Gardner 2000) and the River Mondego, Portugal (Almeida et al. 2002), sea lamprey were shown to move more frequently at dusk or night during the spawning migration. Although sea lampreys were observed in a variety of habitats, they were almost always in areas with reduced light, seeking cover in refugia, such as brush or log piles, overhanging or undercut banks and boulders (Kelso and Gardner 2000).

The distances which lampreys migrate upstream to spawn may extend to several hundred kilometers and include up to 50,000 individuals (Beamish 1980, Connecticut River). Fast water is of little hindrance to migrating lampreys as they can alternate between swimming and attaching to stones. They can ascend nearly vertical barriers up to 2 m high by creeping up the face using their suctorial disc (Scott and Crossman 1998). Bigelow and Schroeder (1948) collected spawning lamprey in the Delaware River approximately 350 km from the sea. Spawning lampreys collected in July in the Terra Nova River, Newfoundland, were located approximately 9 km from the sea (Dempson and Porter 1993). Dempson and Porter (1993) caution that due to the relatively low numbers encountered, it is possible that these individuals represented the end of the spawning component for that year and spawning onset was actually in late June.

Upstream migration of landlocked sea lamprey peaks at temperatures between 10 and 18.5°C and seldom occurs at temperatures less than 4.5°C (Beamish and Potter 1975). Anadromous lamprey in a tributary of the St. John River, New Brunswick, reached peak spawning in late June and early July at temperatures between 17 and 19°C (Beamish 1980; Johns 2002). Spawning activity typically begins when water temperatures are approximately 11.0°C and peaks at temperatures of 14.4 to 15.6°C, although successful spawning has been documented at temperatures as high as 26.1 °C (Manion and Hansen 1980; Scott and Crossman 1998).

Sea lamprey prefer spawning substrates comprised of a mixture of sand, gravel and cobble, at water depths ranging from 13 cm to 1.7 m, and water velocities between 0.5 and 1.5 m/s (Beamish 1980; Manion and Hanson 1980; Mormon et al. 1980; Scott and Scott 1988; Scott and Crossman 1998; Johns 2002). Morman et al. (1980) reported that in tributaries of the Great Lakes, lamprey utilized other materials such as clam shells and lumps of clay for nest construction when gravel of a certain quality was not present. In the Carp River, Lake Superior, lampreys were observed spawning in riffle areas containing mixed gravel, pebbles and small boulders (Kelso et al. 2001). Dempson and Porter (1993) found lamprey nests within the Terra Nova River, Newfoundland, at water depths ranging from 25 cm to 1 m over a gravel/cobble substrate ranging from 2 to 8 cm in diameter. According to Johns (2002), gravels deposited below an obstruction are often preferred (e.g., downstream of a weir), as well as deposits found at the upstream margins of riffles and rapids or where water is spilling out from a pool.

Lampreys may spawn communally (Huggins and Thompson 1970), be monogamous (Manion and Hanson 1980), or exhibit little fidelity to a mate (Noltie and Robilliard 1987; Kelso et al. 2001). Males initiate nest building (Manion and Hanson 1980), with the females joining in after 48 to 72 hours. Up to 13 kg of sand, gravel, and cobble is cleared using a thrashing body motion and/or by dragging material with the suctorial mouth (Scott and Crossman 1998; Johns 2002), thereby creating shallow depressions (Kelso et al. 2001). The dimensions of a typical nest are about 45 cm wide, 40 cm long, with a downstream crest (of moved material) 8 cm high (Manion and McLain 1971). Dempson and Porter (1993) reported that nests in Terra Nova River, Newfoundland, ranged from 30 cm in diameter to 2.5 m long by 1 m wide. Spawning occurs in the nest, with each female depositing up to 300,000 adhesive, non-buoyant eggs (Scott and Scott 1988). Kelso et al. (2001) found that once nest construction began, sea lampreys rarely traveled distances of more than 100 m and spent most of their time in refugia. Approximately one month after spawning, all lamprey die (Beamish 1980; Dees 1980; Manion and Hanson 1980; Scott and Scott 1988; Scott and Crossman 1998).

Hatchery reared eggs hatched in 13 to 14 days at temperatures ranging from 13.9 to 18.3°C (Wigley 1959) and 18.3°C was considered optimal for artificial hatching (Piavis 1961). Although McCauley (1963) suggested a temperature range of 15 to 25°C for successful stream hatching in U.S. streams, Manion and McLain (1971) noted successful hatches in a temperature range of 10 to 18.3°C in the Big Garlic River, Michigan.

#### 3.5.1.2 Young-of-the-year

Within 18 to 21 days after spawning, eggs hatch into a larval form (ammocoetes) that is blind and toothless (Scott and Scott 1988). The ammocoetes remain buried in the substrate, burrowing their way out of the nest within 4 to 8 days after hatching (Becker 1983; Scott and Scott 1988; Scott and Crossman 1998). After emergence, they drift downstream into eddies and pools containing sand, silt, and mud bottoms (Beamish 1980; Trautman 1981; Scott and Crossman 1998). Ammocoetes possess photo-sensitive cells, which stimulate an impulse to move away from light and it is this urge that encourages them to burrow (Johns 2002). Thus, ammocoetes burrow, tail first, approximately 13 mm deep into the soft substrate where they remain as filter feeders for 3-17 years until they undergo metamorphosis (Wigley 1959; Wadden 1968; Beamish 1980; Dees 1980; Downs 1982; Scott and Scott 1988). Suitable nursery habitats are typically characterized by marginal deposits of fine sediments, a degree of shading, and the presence of aquatic plants and organic detritus (Johns 2002). However, nursery habitats have also been found in other locations, including silted cobble deposits and among submerged block stones which were used to reinforce stream banks (Johns 2002).

#### 3.5.1.3 Juvenile

Manion and McLain (1971) found that larval sea lampreys live in the bottom substrate of the Great Lakes' tributaries and begin metamorphosis after reaching a minimum length of 100 mm. According to Scott and Crossman (1998), transformation usually begins in mid-July to September at lengths of 112 to 167 mm and is completed externally in 1 to 2 weeks. In Big Garlic River, New York, Manion and McLain (1971) observed larvae that were 17 years old, while MacDonald (1959) and Hardistry (1969) reported larval transformation occurring at 5 years in Scottish and English rivers, respectively. Evidence has been presented that at least some ammocoetes larvae exhibit little or no growth during the final year of larval life (O'Boyle and Beamish 1977; Beamish 1980).

Following metamorphosis, sea lampreys can remain in streams, enter lakes and immediately start feeding on fish (Swink 1995) or begin moving downstream to estuaries (Beamish 1980). This occurs during late fall/winter (October-February) (Potter and Beamish 1977) or spring (May-

June) (Davis 1967; Potter and Beamish 1977; Montgomery et al. 1983), usually during periods of fluctuating stream flow (Beamish 1980; Scott and Scott 1988). If prey are available, the juveniles will attach and begin feeding during the downstream migration (Scott and Scott 1988), however, there is also evidence that some juveniles may not feed for an extended period of time after transformation (Potter and Beamish 1977). Subsequent to downstream migration, juveniles remain largely within the confines of estuarine water or at least close to shore (Bigelow and Schroeder 1948; 1953a). Reports on host species indicates that feeding on anadromous and small marine fish is likely restricted to the first juvenile year and that large pelagic fish and marine mammals are hosts at later stages (Halliday 1991).

The marine distribution of juvenile sea lamprey is poorly understood. Beamish (1980) stated that sea lamprey occur mainly within shallow coastal waters and are predominantly small (<40 cm in length). However, small individuals (20 to 40 cm) have been collected in offshore bottom trawl catches at depths up to 200 m (Halliday 1991) and larger specimens (58-65 cm) have been collected at depths ranging from 247-645 m (Halliday 1991) to 4,099 m (Haedrich 1977).

The juvenile feeding period is completed during the third winter (between 23 and 28 months) when individuals increase in weight to approximately 900 g (Beamish 1980). However, Halliday (1991) has stated that a 1.5 year period cannot be ruled out until intermediate-sized (39-55 cm in length) individuals are captured at sea.

#### 3.5.1.4 Adults

According to Wismer and Christie (1987), sea lampreys prefer water temperatures ranging from 6-15°C. Beginning January, prespawning juveniles cease feeding or feed at a reduced rate (Anderson and Manion 1977). They gather at the mouths of estuaries between fall and early spring where they begin to mature sexually (Becker 1983). Lampreys do not feed once they have returned to fresh water, being totally dependent on stored energy (Johns 2002).

Adults typically range in size from 15-63.5 cm TL and sexual maturity is usually attained at lengths >30.5 cm TL (Trautman 1981).

## 3.6 Minnows (Cyprinidae)

### 3.6.1 Lake chub (*Couesius plumbeus*)

The lake chub occurs widely throughout Canada and in scattered localities throughout the northern United States (Scott and Crossman 1998). In eastern Canada, the species is found in streams, rivers, and lakes of Nova Scotia, New Brunswick, Quebec, and Labrador (Scott and Crossman 1998). It has been reported in Labrador streams and lake-like expansions of the Churchill River system, Hamilton Inlet basin, and the Grand Lake system (Backus 1951; Ryan 1980; Black et al. 1986), but is not present on the island of Newfoundland (Black et al. 1986). The lake chub is known to tolerate a wide variety of conditions, ranging from clear to turbid waters and cool northern waters to the outlets of hot springs (McPhail and Lindsey 1970; Becker 1983; Scott and Crossman 1998).

#### 3.6.1.1 Spawning, Incubation, and Emergence

Shortly after ice-out in the spring, lake chub undertake spawning migrations from lakes to tributary streams, or within streams to desired spawning locations (Becker 1983; Scott and Crossman 1998). Lake chub emigration occurred from late May to early June in Rivière a la Truite, a tributary of the Moisie River, Quebec, which coincided with declining water levels and discharge (Montgomery et al. 1983). In Catamaran Brook, a sub-tributary of the Miramichi River, upstream migration occurred mostly in June (Cunjak et al. 1993). Spawning has been reported to occur in April in the Great Lakes region (Scott 1954), June and July in Lake Ontario (Dymond et al. 1929), late June to early August in British Columbia (Geen 1955), May in the Montreal River, Saskatchewan (Brown et al. 1970), and as late as August in southern Yukon Territory (McPhail and Lindsey 1970). Mature females from the Lower Churchill River, Labrador, were collected in June and July (Ryan 1980).

Spawning at 14°C has been reported in a tributary stream of Lac Saugay, Quebec (Richardson 1935). Brown et al. (1970) reported that in the Montreal River, Saskatchewan, lake chub entered the river in May at 4°C, remained hidden among rocks until the temperature reached 8°C, and spawned at temperatures $\geq$10°C. They also reported that when water temperatures reached 16°C at the end of May, most of the spent fish had made their way back to the lake.

Spawning occurs along stream margins at depths of 5 cm, over gravel or beneath and between large rocks with slow flow (Brown et al. 1970; McPhail and Lindsey 1970; Morrow 1980; Becker 1983). In lakes, spawning usually takes place along shallow shores over rocky substrates, but has been observed over silt and leaves (Brown et al. 1970). There have been reports of spawning chub occupying water depths of <1 m in Mile 66 Brook, western Labrador (Bruce and Parsons 1976). Males have not been observed building nests or protecting eggs (Brown et al. 1970; Scott and Crossman 1998). Richardson (1935) found that the majority of spent lake chub in a south western Quebec stream died, indicating postspawning mortality.

Brown et al. (1970) reported that eggs hatched in 10 days at temperatures between 8-19°C and in the Montreal River, Saskatchewan the first fry were captured during the first week of June.

#### 3.6.1.2 Young-of-the-Year/Nursery

According to Brown et al. (1970), fry were captured at depths <5 cm amongst submerged vegetation away from the main current and were also reported at depths of approximately 0.5 m near river mouths. In the Tanana River, Alaska, Mecum (1984) reported that although young-of-the-year were captured in shallow (<0.9 m) backwaters over sand and silt, where velocities were <0.5 m/s, they were captured mainly at depths <0.1 m and velocities <0.3 m/s. Becker (1983) reported that lake chub growth is rapid, and by mid-September, young-of-the-year in Lake Michigan were 44 to 100 mm in length.

#### 3.6.1.3 Juvenile

In the Tanana River, Alaska, although juvenile lake chub were captured over a variety of substrates, including silt, sand, gravel, cobble and rubble, at depths <0.6 m and velocities ranging from 0-0.9 m/s, they tended to prefer depths between 0.2-0.5 m and velocities <0.3 m/s (Mecum 1984).

#### 3.6.1.4 Adult

Adult lake chub are more common in lakes in the southern part of its range, while northward it is more common in streams and lake-like expansions of large rivers (Becker 1983; Scott and Crossman 1998). According to Brown et al. (1970), adults prefer areas in creeks with rocky bottoms. Lake chub are also commonly found near the mouths of streams at depths <1 m over a sand bottom interspersed with large-sized boulders (Becker 1983) and have been reported to remain hidden among rocks (assumed to be cobble, rubble and boulders) until water temperatures reached $8^{0}$C (Brown et al. 1970). Adults are also commonly observed in gravel-bottomed pools and runs of streams (Page and Burr 1991). In the Tanana River, Alaska, adults preferred shallow (<0.6 m) riffle areas over gravel, cobble and rubble substrates and although they were observed at velocities ranging from 0-0.9 m/s, they were most commonly captured at velocities >0.4 m/s (Mecum 1984). Mecum (1984) suggested that their preference for swift, shallow gravel riffle areas, particularly at the head of side channels, might be related to the presence of an abundant food supply. According to Scott and Crossman (1998), aquatic insect larvae are the primary prey organism of these species, which tend to be more abundant in riffle areas of streams (Surber 1946).

Based on field studies conducted in Catamaran Brook, New Brunswick, Reebs et al. (1995) found that lake chub were most active at dawn or dusk, except when strong food cues were present, in which case their activity might extend into the day, and during spawning migration, when they moved mostly at night. In Labrador, lake chub generally mature at 2-3 years of age (Bruce and Parsons 1976) or as old as 5 years of age (Ryan 1980).

### 3.6.2 Longnose dace (*Rhinichthys cataractae*)

The longnose dace is widely distributed from coast to coast in north and central North America (Scott and Crossman 1998). In the Atlantic provinces, it has only been found in Labrador within the Churchill, Naskaupi, Atikonak, Minipi, Dominion, and Elizabeth river systems and within tributaries of Atikonak Lake (Beak Consultants Ltd. 1979; Black et al. 1986; LGL Limited 1999). It typically occurs in swift flowing streams (usually in the headwaters of large river systems) or sometimes lakes (Reed 1959; Reed and Moulton 1973; Scott and Crossman 1998), especially at higher altitudes where competition is not very intense (Becker 1983). For more information concerning the lake habitat requirements of longnose dace, refer to Bradbury et al. (1999).

Longnose dace are mainly bottom dwellers (Scott and Crossman 1998), usually found in clear or muddy running water (McPhail and Lindsey 1970). They are usually more active at night feeding and seek shelter under rocky substrates during the day (Culp 1989). All age groups occur in very shallow water, usually at depths <0.3 m and rarely >1.0 m and require overhead cover and shelter from the current (Edwards et al. 1983).

#### 3.6.2.1 Spawning, Incubation, and Emergence

Females are capable of spawning more than once during a reproductive season (Roberts and Grossman 2001). Peak spawning usually occurs from June to early July (McPhail and Lindsey 1970, northwest Canada; Gee and Machniak 1972; Brazo et al. 1978, Michigan; DeHaven et al. 1992, North Carolina; Gray and Dauble 2001). However, it may occur as early as May (Carlander 1969, Maryland) or as late as August (McPhail and Lindsey 1970, Alberta) depending upon water temperature. LGL Limited (1999) reported that there were no mature individuals collected during August electrofishing surveys within tributaries of Atikonak Lake, Labrador.

Spawning usually occurs in riffles <0.3 m in depth, velocities ranging from 0.3 to 0.6 m/s, and substrates comprised of large gravel, cobble, and rubble ranging from 5 to 20 cm in diameter (Bartnik 1970; Edwards et al. 1983; Aadland 1993; Scott and Crossman 1998). In a Manitoba stream, spawning and egg deposition was restricted to areas with natural depressions in the substrate (Bartnik 1970; 1973). While this habitat type is generally accepted within the literature there are some discrepancies. Greeley and Bishop (1933) reported longnose dace in a New York river, spawning at depths between 5-10 cm, over fine gravel in a strong current, while Gibbons and Gee (1972) found spawning redds in riffle areas within the Mink River, Manitoba at surface velocities ranging from 0.5-1.0 m/s over a mainly cobble substrate and depths of 7-35 cm. Bartnik (1973) noted that overhead cover and shelter from the current was always present at spawning sites located within a Manitoba stream. Although no nest is built during spawning, demersal, adhesive eggs are deposited among the substrate and guarded by one parent (Bartnik 1970; 1972; McPhail and Lindsey 1970).

Stream spawning of longnose dace has been reported at water temperatures >15°C (Bartnik 1970, Manitoba), 17°C (Becker 1983, Wisconsin), and 11.7°C (Brown 1971, Montana). The eggs hatch in 7 to 10 days at 16°C and the yolk sac is absorbed approximately seven days after hatching (McPhail and Lindsey 1970). Emergent larvae are pelagic (rising to the surface to inflate gas bladders) and inhabit shallow, relatively quiet (0.2-1.0 m/s) waters along stream margins (McPhail and Lindsey 1970; Gibbons and Gee 1972; Edwards et al. 1983; Scott and Crossman 1998).

#### 3.6.2.2 Young-of-the-Year/Nursery

The pelagic stage of young-of-the-year dace lasts from 2 weeks (Gee and Northcote 1963) to about 4 months before the benthic phase of the juveniles/adults commences (McPhail and Lindsey 1970). Gibbons and Gee (1972) reported that within 6 weeks after hatching longnose dace begin to move into faster and deeper water in a Manitoba river, while Gee and Northcote (1963) reported a move to swifter water within 2 weeks in the Fraser River, British Columbia.

Aadland (1993) reported that young-of-the-year were found most often in shallow pools having velocities <0.3 m/s and depths <60 cm, while Gibbons and Gee (1972) found they typically inhabit stream margins having mean velocities of 0-0.15 m/s, depths ranging from 7-25 cm and substrates comprised mainly of silt and sand until they attain a length of 25-30 mm. Once young-of-the-year attained a length of approximately 30 mm, Bartnik (1970) found they occupied water velocities >0.45 m/s. Gibbons and Gee (1972) also found that as they increase in size, they tend to occupy small rock riffles having water velocities between 0.45-1.0 m/s, mainly gravel/cobble substrate and depths of 7-35 cm as well as large rock riffles, which have mean velocities of 0.45-1.2, depths between 10-35 cm and mainly rubble/boulder substrate. In the lower Fraser River, young-of-the-year were caught in relatively swift flowing water (Gee and Northcote 1963).

Bartnik (1973) and Edwards et al. (1983) reported that young-of-the-year preferred areas with abundant overhead cover. During the fall, they have also been shown to seek shelter under flat stones within riffle areas (Gibbons and Gee 1972).

### 3.6.2.3 Juvenile/Adult

Around 1 year, longnose dace are approximately 3.8-6.4 cm long, while adults usually range from 6.4-11 cm in length (Trautman 1981). Habitat requirements of juvenile and adult longnose dace are similar (Edwards et al. 1983) and are therefore described together. The longnose dace is characteristic of clean, swift-flowing, gravel, rubble or boulder streams, at times inhabiting very turbulent waters (Becker 1983; Hubert and Rahel 1989; Johnson et al. 1992; Scott and Crossman 1998), but will occupy quiet, shallow water pools during the summer in the absence of competing species (Gee and Northcote 1963; Bartnik 1970; Gibbons and Gee 1972; Reed and Moulton 1973, Grossman and Freeman 1987).

Gee and Northcote (1963) captured juveniles in mainly shallow (<30 cm), slow flowing (<0.5 m/s) areas of the lower Fraser River. High water velocity seems to be a key habitat attribute for longnose dace (Johnson et al. 1992) as they are most common in water velocities >0.45 m/s (Bartnik 1970; Edwards et al. 1983) and have been reported at surface velocities as high as 1.9 m/s, usually within crevices between stones (McPhail and Lindsey 1970; Edwards et al. 1983). In Michigan, juveniles were reported at depths between 10-19 cm, velocities ranging from 0.25-0.5 m/s (avoided velocities <0.1 m/s) and boulder substrates (Mullen and Burton 1995; 1998).

Juveniles tend to complete their life cycle in large rock riffles, which have mean velocities of 0.45-1.2 m/s, depths of 0.1-0.35 m and mainly rubble/boulder substrates (Gibbons and Gee 1972). As they grow, however, they demonstrate an increasing preference for larger substrates and faster velocities (McPhail and Lindsey 1970; Mullen and Burton 1995). Gee and Northcote (1963) reported that in the Fraser River, British Columbia, juveniles sometimes move into deeper (>0.3 m) waters at night, while the larger adults did not. Both juveniles and adults within tributaries of Atikonak Lake, Labrador, were captured at depths of 20-25 cm (LGL Limited 1999). In Michigan, adults inhabit areas with faster currents (0.25-0.5 m/s), water depths between 10-30 cm and boulder substrates (Mullen and Burton 1995; 1998), while in Minnesota, they preferred fast riffles having velocities >0.6 m/s and depths <60 cm (Aadland 1993). In Wisconsin streams, longnose dace were found over the following substrates in order of decreasing frequency: gravel, rubble, sand, boulders, silt, mud, clay, bedrock and detritus (Becker 1983).

Juvenile and adult longnose dace are predominantly benthic, seeking refuge from the current between stones in coarse substrate (McPhail and Lindsey 1970; Gibbons and Gee 1972). Bartnik (1973) reported that shelter is important as dace become fatigued and lose their ability for coordinated motion after five minutes or so of swimming against a strong current. Mullen and Burton (1995) postulate longnose dace may have evolved their preference for fast water in response to competition from other species and/or higher food densities in the faster flowing areas.

In summer, longnose dace were found primarily in areas with high water velocities (0.25-0.45 m/s) and depths of 5-15 cm (Johnson et al. 1992), while during winter they became sedentary in quiet, shallow (15-30 cm) pools, or in shallow (15-30 cm), flat, sand/gravel areas adjacent to summer habitat (Becker 1983). Adults have been shown to seek shelter under cobble, rubble, or boulder substrates and submergent vegetation (Aadland 1993), especially in the fall and overwinter when water temperatures drop below $5^{0}$C (Gibbons and Gee 1972; Cunjak and Power 1986). In Ontario, they overwinter in areas of cobble and boulders (Cunjak 1996). Adults have also been shown to prefer areas with aquatic vegetation and overhead cover (Hubert and Rahel 1989; Aadland 1993). In North Carolina, longnose dace were found to occupy home ranges of approximately 14 m and the maximum distance traveled by an individual was 40 m (Hill and Grossman 1987).

Longnose dace have been captured at temperatures ranging from 12.8 to 21.1°C (Sigler and Miller 1963, Utah), 5.4 to 22.7°C (Edwards et al. 1983), and 11 to 19°C (tributaries of Atikonak Lake, Labrador) (LGL Limited 1999). Becker (1983) states that in Wisconsin, dace have withstood temperatures up to 27.8 °C for short periods of time. In the Humber River, Ontario, longnose dace were reported to prefer water temperatures around 20.6°C (Wichert and Lin 1996).

Longnose dace are usually mature by 2 years of age, with males maturing earlier than females (Bartnik 1970; McPhail and Lindsey 1970; Gibbons and Gee 1972; Brazo et al. 1978; Becker 1983). They rarely live longer than four years (Brazo et al. 1978), but a 5 year old individual was caught in the eastern United States (Reed and Moulton 1973).

### 3.6.3 Pearl dace (*Semotilus margarita*)

Throughout most of Canada and the United States, pearl dace occur in cool, clear headwater streams in the south and in bog and beaver ponds, creeks, and small lakes in the north (Scott and Crossman 1998). In Canada, the species ranges from Labrador to British Columbia and appears to be associated with the 1.7 to 4.4°C isotherm (Ryder et al. 1964; Loch 1969; Scott and Crossman 1998). Although pearl dace have been reported in the Churchill River, Labrador, there are no records of occurrence in Newfoundland (Scott and Crossman 1998). Despite its extensive range in Canada, there are few published accounts of its biology.

#### 3.6.3.1 Spawning, Incubation, and Emergence

Langlois (1929) reported that pearl dace spawning in Michigan streams took place in spring, at water temperatures ranging from 17.2 to 18.3°C. Tallman et al. (1984) also observed pearl dace spawning in tributaries during spring melt. According to Scott and Crossman (1998), spawning occurs in shallow waters. Langlois (1929) reported that spawning occurred in clear water, at depths of 0.46 to 0.61 m, in a weak or moderate current, over hard substrates. Similarly, McPhail and Lindsey (1970) reported that stream spawning occurred at depths of about 0.6 m over sand or gravel substrates in wide ranging currents. Although there is no nest building, males have been observed intermittently defending territories of about 2 m from the nearest competitor (Langlois 1929).

#### 3.6.3.2 Young-of-the-Year/Nursery

Tallman and Gee (1982) reported that age 0, 1, and 2+ dace were segregated by water depth in Brokenhead River, Manitoba and that younger fish generally fed higher in the water column than older fish. In May, young-of-the-year were most common in shallow pools (depths <0.5 m and velocity <0.05 m/s) (Tallman and Gee 1982; Johnson et al. 1992). From June to August, they were found mostly in shallow (<0.5 m), slow moving water (pools, <0.05 m/s or channels, 0.05 - 0.45 m/s), while in September, they began to appear in deeper (>0.5 m) sections of the streams (Tallman and Gee 1982). By November, young-of-the-year were found almost exclusively in deep pools (Tallman and Gee 1982).

#### 3.6.3.3 Juvenile/Adult

According to Becker (1983), pearl dace have a preferred water temperature of 16.2°C. From May to August, age 1 individuals were observed feeding up in the water column, while those age 2+ were feeding close to the bottom (Tallman and Gee 1982). In May, age 1 and 2+ fish were abundant in pools and channels, but not in riffles (Tallman and Gee 1982). During the summer, age 1 individuals occupied shallow pools (<0.5 m, <0.05 m/s) and deep channels (>0.5 m, 0.05-0.45 m/s), while age 2+ dace occurred in deep pools (>0.5 m, <0.05 m/s) and deep channels (>0.5 m, 0.05-0.45 m/s) (Tallman and Gee 1982). In November, age 1 and 2+ coexisted in deep pools (>0.5 m, <0.05 m/s) (Tallman and Gee 1982).

Although Loch (1969) reported that pearl dace attained sexual maturity at approximately 1 year of age and a length of 65 mm, Becker (1983) and Portt et al. (1988) found sexual maturity was usually attained by 2 years of age. Based on pearl dace sampled in Ontario, Loch (1969) proposed that age 2 individuals ranged from 75 to 95 mm in length and age 3 from 95 to 120 mm. A maximum size of 158 mm has been reported by Scott and Crossman (1998). Although females may live up to 4 years of age, males typically only live to age 3 (Stasiak 1978; Nelson and Paetz 1992).

## 3.7 Perch (Percidae)

### 3.7.1 Logperch (*Percina caprodes*)

The logperch is wide-ranging in North America, occurring from Labrador to Saskatchewan, south through the Mississippi River system to the Rio Grande River in Texas (Scott and Crosssman 1998; Grant et al. 2000). The only documented occurrence in Newfoundland and Labrador is within tributaries of Atikonak Lake, south eastern Labrador (Grant et al. 2000). It has also been captured in tributaries of Joseph Lake (west of Atikonak Lake), Labrador (R. Perry 2001, Inland Fisheries, St. John's, NL, Pers. Comm.)

Logperch are commonly found over gravel and sand in medium-sized rivers, but can occur almost anywhere from small, fast-flowing rock-bottomed streams to vegetated lakes (Page and Burr 1991). According to Becker (1983), they occur in swift water, quiet water of cut off pools in rivers, and open water of large lakes.

#### 3.7.1.1 Spawning, Incubation, and Emergence

Logperch spawn in late spring, usually commencing in June (Scott and Crossman 1998). Males gather in large schools, into which the females swim and pair with males releasing 10 to 20 demersal, adhesive eggs (Scott and Crossman 1998). Each female may spawn several times and with different males. No nests are constructed and the eggs are abandoned (Scott and Crossman 1998). Spawning occurs in sand and gravel riffle areas (Becker 1983).

Eggs and larvae develop over a wide range of temperatures; in Texas, development was recorded between 22 and 26°C (Hubbs 1961), while in Ontario, it was recorded at 8°C (Amundrud et al. 1974). Floyd et al. (1984) reported that in Drake's Creek, Kentucky, emergent logperch larvae were present for 16 weeks. Larvae were first collected on March 29 at 11.8°C and the last on July 8 at 20°C.

#### 3.7.1.2 Young-of-the-Year/Nursery/Juvenile

Larvae were most commonly associated with vegetated shorelines, pools, and rocky substrates (Floyd et al. 1984). Floyd et al. (1984) reported that in Drake's Creek, Kentucky, young-of-the-year logperch were most commonly encountered over gravel substrate under cover of roots and algae. Becker (1983) reported that older young-of-the-year were often associated with dense beds of vegetation in shallow water.

#### 3.7.1.3 Adult

After spawning, adults migrate to deeper waters (Becker 1983). In Wisconsin streams, adults occurred most frequently in pools or riffles (Becker 1983). Grant et al. (2000) captured adult logperch within tributaries of the Atikonak Lake watershed, Labrador, in relatively fast flowing riffle areas over a predominantly cobble substrate at water depths of 0.5 to 0.8 m and temperatures ranging from 13.8 to 18.6°C. In Ontario, logperch typically reach sexual maturity at 3 years of age (Portt et al. 1988), while according to Becker (1983), maturity generally occurs by age 2.

## 3.8 Pikes (Esocidae)

### 3.8.1 Northern pike (*Esox lucius*)

The northern pike has a circumpolar distribution in the northern hemisphere above $40^0$ N latitude (Toner and Lawler 1969; Scott and Crossman 1998). Its native North American range includes: Alaska, most of Canada south of the Arctic Circle, the drainages of the Missouri and Ohio Rivers, and the Great Lakes (Inskip 1982). It has been widely introduced outside its native North American range as a sport fish or control predator (Scott and Crossman 1998). In Canada, it occurs from Labrador to British Columbia, but excludes the Maritime provinces, including Newfoundland. They are found throughout southern Labrador from the southeast to Sandwich Bay (Black et al. 1986).

Northern pike are not adapted to strong currents and occur most frequently in lakes (Inskip 1982) where they inhabit backwaters and pools (Christenson and Smith 1965; Crossman 1978). In Canada, pike generally inhabit clear, cool to moderately warm, slow, meandering, heavily vegetated rivers or warm, weedy bays of lakes (McPhail and Lindsey 1970; Becker 1983; Scott and Crossman 1998). Pike inhabit areas containing aquatic vegetation throughout all stages of their life cycle (Ford et al. 1995; Inskip 1982) and have been found over a wide range of turbidity, although they are much more common in clear and only slightly turbid water (Becker 1983).

### 3.8.1.1 Spawning, Incubation, and Emergence

Northern pike are spring spawners, migrating to spawning areas around ice-out when the shallows are warmed to 8-12°C (Ford et. al 1995; Casselman and Lewis 1996; Scott and Crossman 1998). Spawning has been reported at temperatures ranging from 4.4-17.2°C (Clark 1950; Franklin and Smith 1963; Gammon 1986; Scott and Crossman 1998). They generally spawn during daylight hours in shallow, heavily vegetated floodplains of rivers, marshes, and lakes (Clark 1950; Franklin and Smith 1963; McCarraher and Thomas 1972; Scott and Crossman 1998; Bradbury et al. 1999), however, in the St. Lawrence River, New York, they were observed spawning at depths up to 2.6 m (Farrell et al. 1996). Sexes pair during spawning, with a larger female usually accompanied by one to three smaller males. They swim through and over vegetation intermittently releasing milt and adhesive eggs, which attach to the vegetation (Ford et al. 1995; Casselman and Lewis 1996; Scott and Crossman 1998).

Although there is no available information regarding the specific water velocities required by spawning northern pike, terms such as 'still waters', 'sluggish flows', and 'river backwaters or back eddies' are commonly used. Thus, flowing water is not required for spawning (Ford et al. 1995). Dryden and Jessop (1974) indicated that in a Canadian stream, strong currents (>1.5 m/s) have been shown to prevent spawning migrations. Although preferred spawning depths range from 0.1 to 0.7 m (averaging 0.2 to 0.4 m), with good year classes being associated with high water levels (Johnson 1957; Machniak 1975b; Inskip 1982; Becker 1983; Ford et al. 1995; Casselman and Lewis 1996), Farrell et al. (1996) observed northern pike spawning over depths ranging from 0.5-2.6 m in a New York river marsh. The type of bottom over which spawning occurs varies widely, but a soft, silt-filled rubble with decaying vegetation is common (Ford et al. 1995). According to Casselman and Lewis (1996), preferred spawning substrate is well oxygenated detritus and elaborate root systems of emergent vegetation, but has been reported over sand and mud substrates (Holland and Huston 1984; Scott and Crossman 1998).

Spawning has been reported over flooded emergent vegetation (Machniak 1975b; Becker 1983; Holland and Huston 1984) as well as submerged vegetation (McPhail and Lindsey 1970; Ford et al. 1995; Farrell et al. 1996). Shallow vegetated areas, such as flooded marshes, flooded terrestrial vegetation or weedy bays provide suitable spawning habitat provided that high water levels are maintained throughout the embryo and fry stage (McPhail and Lindsey 1970; Inskip

1982; Ford et al. 1995; Scott and Crossman 1998). Although grasses, sedges or rushes with fine leaves are preferred (Machniak 1975b; Inskip 1982; Becker 1983; Ford et al. 1995), any vegetation may be used. Vegetative hummocks and mats are typically adequate to entrap the eggs and suspend them above the substrate where anoxic conditions can develop (Alldridge and White 1980; Inskip 1982; Crossman and Casselman 1987; Casselman and Lewis 1996).

### 3.8.1.2 Young-of-the-Year/Nursery

Incubation time is inversely related to temperature (Lillelund 1966; Walker 1968). Average length of incubation is approximately 26 days at 6°C, 17 days at 8°C, 12 days at 10°C, 9 days at 12°C, 6 days at 14°C, and 5 days at 16 to 20°C (Swift 1965; Walker 1968).

After a short active period immediately following hatching, young-of-the-year attach themselves to submergent vegetation where they remain for 4 to 15 days until the yolk sac is absorbed and the swim bladder is filled with gas (Franklin and Smith 1963; Frost and Kipling 1967; Howard and Thomas 1970; Machniak 1975b; Inskip 1982; Ford et al. 1995). The close association of larval pike with vegetative cover provides a survival advantage by keeping larvae removed from the oxygen poor and hydrogen sulphide rich sediments typical of pike spawning grounds as well as providing cover from potential predators (Inskip 1982; Ford et al. 1995; Craig 1996).

Young-of-the-year average 7 to 9 mm in length at hatching and begin emigration from the spawning grounds once they attain a length of 15 to 20 mm (Frost and Kipling 1967; Forney 1968). Active feeding usually begins 9-10 days after hatching and young remain within the spawning area for several weeks (Machniak 1975b; Inskip 1982; Becker 1983; Ford et al. 1995; Scott and Crossman 1998). Growth and survival rates of young-of-the-year are temperature dependent (Inskip 1982). Optimal growth rates have been reported at water temperatures of 22-25°C (Casselman and Lewis 1996, Ontario; Bevelhimer et al. 1985, Ohio). Casselman and Lewis (1996) suggest that optimum temperature for growth decreases with age.

Nursery areas are generally contiguous with spawning areas and as the young-of-the-year grow their preferred depth increases (Machniak 1975b; Inskip 1982; Casselman and Lewis 1996). In the Ontario region, Casselman and Lewis (1996) observed that for every 12 mm increase in body length, young-of-the-year preferred water depths 10 cm deeper. Thus, as young-of-the-year grow during their first season, they move from shallow spawning areas to deeper water (1.0-2.5 m) (Casselman and Lewis 1996).

As pike grow, increased activity makes them more susceptible to predation (Casselman and Lewis 1996), therefore cover is critical to the survival of young-of-the-year during their first winter (Grimm 1989). Although young pike prefer submerged vegetation with some emergent and floating vegetation interspersed, woody debris and other structures can sometimes provide adequate cover (Johnson 1960; Inskip 1982; Casselman and Lewis 1996). In the Mississippi River, Holland and Huston (1984) observed that catches of young-of-the-year were three times higher in areas of submergent rather than emergent vegetation, and 10 times higher than areas without vegetation. They also reported that extremely dense beds of vegetation were avoided, presumably due to low dissolved oxygen levels which indicate that adequate water flows through vegetation must be maintained (Holland and Huston 1984). Based upon field surveys and laboratory experiments conducted in Ontario, results concluded that intermediate densities of vegetation are optimal and that young-of-the-year prefer a combination of submergent and emergent vegetation with densities ranging from 20 to 50% (Anderson 1993).

### 3.8.1.3 Juvenile/Adult

Most of the literature reviewed considers habitat use by juveniles and adults to be essentially the same. Although there are some reports of extensive migrations of juveniles, they generally remain sedentary for most of their early life, especially in areas where there is adequate food and cover available (Ford et al. 1995; Scott and Crossman 1998). Juveniles are typically found over a mud or silt bottom at depths <2.0 m and submerged vegetation often provides refuge (Inskip 1982; Ford et al. 1995).

Casselman (1978) reported that yearling northern pike grew most rapidly at temperatures between 19 to 21°C. Growth increased sharply at temperatures greater than 10°C, was still positive at 3 to 4°C, and ceased at 28°C. The upper lethal limit measured in laboratory conditions was 29.4°C (Casselman 1978) and over 30°C in the natural environment (Ridenhour 1957). Although no lower limit has been experimentally determined, Casselman (1978) reported that northern pike showed no apparent stress when subjected to temperatures as low as 0.1°C prior to freeze-up in Ontario Lakes. The optimum temperature decreases with increasing age as pike move from protected bays and backwaters with submerged vegetation into the deeper, cooler areas of lakes and rivers (Hokanson et al. 1973; Casselman 1978). Water depth distributions of northern pike are related to differences in temperature, dissolved oxygen, vegetation, and food availability (Inskip 1982).

Adults are generally found in relatively shallow water in summer (<4 m), but will sometimes move into areas as deep as 12 m providing it is relatively clear, cool and well oxygenated and contains some vegetative cover (Inskip 1982; Casselman and Lewis 1996). Although they do not exhibit strong substrate preferences (Inskip 1982; Casselman and Lewis 1996), their distribution is closely associated with the presence of aquatic vegetation, which is usually found on soft, silty, organic bottoms (Inskip 1982). According to Aadland (1993), adults were found most often in medium pool habitats (i.e., velocities <0.3 m/s and depths of 0.6-1.5 m) containing a mud, silt or organic bottom (Inskip 1982; Ford et al. 1995; Casselman and Lewis 1996). Both juveniles and adults have been shown to avoid habitat predominated by sand (Eklov 1997).

The ambush predation style of northern pike requires cover, usually in the form of aquatic macrophytes, tree stumps or fallen logs (Inskip 1982; Becker 1983; Ford et al. 1995). Complete vegetative cover is considered sub-optimal for adults, especially with respect to foraging efficiency (Savino and Stein 1989; Wright 1990; Ford et al. 1995). In general, foraging efficiency has been shown to decrease with increasing vegetation densities (Savino and Stein 1989). Unlike juveniles, adults prefer areas containing open water interspersed with moderately abundant vegetation comprising approximately 30-70 % cover (Inskip 1982; Grimm and Backx 1990; Casselman and Lewis 1996; Randall et al. 1996.) Chapman and Mackay (1984) reported that large northern pike preferred a mixture of open water and vegetated areas, while smaller individuals were restricted to more heavily vegetated areas.

The age of sexual maturity is dependent upon growth rate, which varies considerably based upon geographical range. Bruce and Parsons (1979) and Ryan (1980) reported that pike in Labrador mature at 3-5 years of age (approximately 40 cm in length). In southern Canada and the northern United States, pike mature at 2-4 years of age, whereas they mature at 5-6 years in northern Canada (Frost and Kipling 1967; Priegel and Krohn 1975; Scott and Crossman 1998). They are long-lived and may live more than 25 years in some areas (Miller and Kennedy 1948).

## 3.9 Salmonids (Salmonidae)

### 3.9.1 Arctic charr (*Salvelinus alpinus*)

The Arctic charr has the most northerly distribution of all anadromous and freshwater fishes (Walters 1955; Klemetsen et al. 2003). It has a circumpolar distribution and is found in inshore marine waters, lakes, and rivers around the northern hemisphere, including North America, northern Asia, northern Europe, Iceland, and Greenland (Scott and Crossman 1998).

In the northern part of its range, Arctic charr are mostly anadromous, but may also be confined to fresh water (landlocked) (Scott and Crossman 1998). Landlocked populations have been reported in insular Newfoundland, Labrador, New Brunswick, the Canadian Arctic archipelago, southeastern Quebec, Alaska (Scott and Scott 1988), and Norway (Power 1973). Landlocked charr usually occupy lakes which are inaccessible to the ocean, however, both landlocked and anadromous forms may occur in the same water body simultaneously (Johnson 1980; Gyselman 1984; Nordeng and Skurdal 1985; Langeland 1995). Although charr are found in streams, lakes and/or at sea, lacustrine populations are most common (Klemetsen et al. 2003). Apart from migration to and from sea, rather than migration to and from lakes, the habitat requirements of both anadromous and landlocked Arctic charr populations are similar. For more information on lacustrine habitat utilization, refer to Bradbury et al. (1999).

Anadromous Arctic charr reach their southern limit in insular Newfoundland (Scott and Scott 1988) at Pistolet Bay (Dempson 1982), though there have been isolated reports of Arctic charr in numerous Newfoundland river systems from the Northern Peninsula to the south coast. However, there is insufficient information available to determine if these isolated reports represent anadromous populations or landlocked forms that have wandered or been washed into estuarine areas (B. Dempson, 2001, Fisheries and Oceans Canada, St. John's, NL. Pers. Comm.).

Arctic charr display more diversity in morphology, life history and habitat use than most salmonids. This coupled with a lack of information regarding juvenile stages makes defining habitat preferences difficult unless they are stock specific (Barbour 1984; Sandlund et al. 1987; Scruton et al. 2000).

#### 3.9.1.1 Spawning, Incubation, and Emergence

It has been postulated that anadromous charr populations undertake annual migrations in spring from freshwater to the sea to feed, return to spawn in the fall, and remain until spring ice break-up (Johnson 1980). Beddow et al. (1998) reported that radio-tagged charr from Reid Brook, northern Labrador, immediately moved downstream after spawning, presumably to find suitable overwintering habitat. In some populations, fall spawners forgo the seaward feeding migration and remain in freshwater throughout the summer (Johnson 1989; Beddow et al. 1998). However, a seaward migration of maturing Arctic charr has been documented in northern Labrador (Dempson 1995). Spawning of anadromous Arctic charr in northern Labrador has also been reported adjacent to the inlet streams of lakes and ponds (Dempson and Green 1985).

Because spawning requires high-energy output, females often only spawn every two to four years and not all adults spawn in any given year (Sprules 1952; Grainger 1953; Gyselman 1984; Dutil 1986; Scott and Crossman 1998). Like many cold-water species, Arctic charr are slow growing, with growth rate decreasing in a northerly progression (Andrews and Lear 1956). The average age of sexually mature charr from the Fraser River, northern Labrador, was 5.2 years for males and 6.9 years for females (Dempson 1984).

Arctic charr populations undergo various types of migrations. Since they often spawn in lakes, migrations may be as simple as ontogenetic habitat shifts within a single lake (Klemetsen et al. 1989). Sometimes they may migrate between separate lakes within a river system (Näslund 1990) and migrations between river systems and the sea occur in the northern part of its range, such as northern Russia, northern Canada, Greenland, Iceland and North Norway (Nordeng 1983; Johnson 1989; Klemetsen et al. 2003).

In Newfoundland, spawning normally occurs from mid-October to mid-November, but may occur two weeks earlier in Labrador (Scruton et al. 1997). Maturing charr, predominantly females, tend to leave the ocean first, followed by the smaller and non-maturing adults and juveniles (Dempson and Kristofferson 1987; Johnson 1989). Dempson and Green (1985) reported that in Fraser River, Labrador, the upstream migration began in late July, extended into late September, and peaked during the last two weeks of October. Beddow et al. (1998) reported that for both Reid and Ikadlivik brooks, Labrador, the upstream spawning run began in mid-July, peaked in August, with spawning occurring the last week of September and the first week of October. Gyselman (1994) reported that anadromous Arctic charr tend to have a high site fidelity to their natal stream during spawning.

Males establish and guard territories, while the nest or redd is prepared by the females through clearing debris from the site. Females deposit their eggs in the redd, which are fertilized by the male (Scott and Scott 1988).

**Velocity**

Cunjak et al. (1986) reported that Arctic charr from the Koroc River, Quebec, were observed spawning in moderately strong surface velocities ranging from 0.22 to 0.48 m/s. In the Cumberland Sound area of Baffin Island, spawning was reported at velocities ranging from 0.2-0.7 m/s (Moore 1975a), while in two Norwegian streams, 75 to 80% of Arctic charr were encountered at velocities <0.1 m/s (Heggberget 1984).

### Temperature

Spawning is believed to be largely influenced by photoperiod and water temperature, as it is stimulated by lowering water temperatures during the final stages of egg maturation (Scott 1979). Dempson and Green (1985) observed spawning at 1 to 3°C in the Fraser River, Labrador and Beddow et al. (1998) reported that spawning occurred as water temperatures dropped from 7 to 1°C in Reid Brook, Labrador. Spawning was reported at temperatures between 2-7°C in eastern USSR and at a temperature of 0.5 °C in Baffin Island (Moore 1975a; 1975b).

Eggs incubate over winter, buried in gravel at temperatures of 0.0 to 2.2°C, while temperatures above 7.8°C are fatal (Scott and Scott 1988; Scott and Crossman 1998). Eggs are believed to hatch in early April, however, the emergence from the gravel does not occur until ice break-up in mid-July, at which point the fry are about 25 mm in length (Scott and Crossman 1998). Initial feeding occurs at temperatures of 3 to 16°C and the optimal temperature range for growth is 11 to 14°C (Jensen et al. 1989).

### Depth

Dempson and Green (1985) and Cunjak et al. (1986) found Arctic charr redds in the Fraser River, Labrador, at depths of 0.5 to 1.5 m, which is sufficient to keep the eggs safe from winter ice or in quiet pools (depths of 1.0-4.5 m) below rapids where no ice forms (Communications Directorate 1991; Scott and Crossman 1998). Moore (1975a) observed evidence of charr spawning in Baffin Island streams at depths ranging from 1 to 11 m. Lake spawning near inlet streams has been reported at depths of 1.5-2.0 m (Dempson and Green 1985) and 2.0-6.0 m (Gyselman 1984; Nordeng and Skurdal 1985).

### Substrate

Stream spawning of Arctic charr generally occurs in pools over gravel bottoms (Sprules 1952; McPhail and Lindsey 1970; Scott and Scott 1988; Scott and Crossman 1998). Cunjak et al. (1986) reported spawning in the Koroc River, Quebec, over heterogeneous substrates ranging from 1 to 15 cm in diameter (sand, gravel, cobble and very small rubble), while Dempson and Green (1985) reported spawning in the Fraser River, Labrador, over substrates ranging from fine and coarse sand to gravel which were 4-5 cm in diameter. In the Cumberland Sound area of Baffin Island, spawning was reported over substrates ranging from coarse sand to boulder-strewn gravel (Moore 1975a).

### Cover

The importance of cover during spawning was not quantified in the literature. This is likely due to the absence of instream and large shoreline vegetation in many northern climates.

### 3.9.1.2 Young-of-the-Year/Nursery

References with respect to riverine habitat requirements of young-of-the-year are limited. In aquarium situations, after young-of-the-year had absorbed the yolk sac, they remained close to the bottom of the tank, resting on the bottom or hiding under stones (Fabricius 1953; Fabricius and Gustafson 1954). Moore (1975b) reported for Baffin Island, that young-of-the-year were never encountered in saltwater and during the summer, they were normally found in schools along the shores of lakes, in mid-water column. However, a few individuals were occasionally found hiding among stones (assumed to be gravel, cobble and rubble) in streams where the overlying water velocity ranged from 0.1 to 0.5 m/s (Moore 1975b). In two Norwegian streams, Heggberget (1984) found young-of-the-year in shallow (<0.2 m), slow-flowing areas.

Emergent alevins from the Kigdlut-iluat River, Greenland (Nielsen 1961), and the Sagavanirktok River, Alaska (Yoshihara 1973), ranged in size from 2.0 to 2.5 cm in length. Dempson (1982) reported that Arctic charr within the Fraser River, Labrador, reached an average length of 3.9 cm during the first summer, with a range of 2.4 to 5.6 cm.

### 3.9.1.3 Juvenile

Juvenile Arctic charr grow slowly in their early years. Dempson (1982) and Dempson and Green (1985) reported that in the Fraser River, Labrador, charr length increments in the first two years of freshwater life averaged 2.5 cm annually, increasing to 3.5 cm annually at 3 to 4 years of age. The age and size of juveniles during their first seaward migration can vary significantly depending on geographical location. In the western Canadian Arctic, juveniles commonly move seaward for the first time at 3 or 4 years of age, but may be as young as 1 or 2 years (McCart 1980). Moore (1975a; 1975b) reported juvenile charr ranging in length from 10 to 19 cm (2 to 4 years of age) present in river mouths on Baffin Island. Dempson and Green (1985) reported that in Fraser River, Labrador, seaward migrating juvenile charr ranged in age from 3 to 4 years and 11.3 to 18.5 cm in length.

Juveniles congregate in estuarine river mouths during the summer, with many first-time migrants staying only two or three days (Gyselman 1984; Bouillon and Dempson 1989). They remain near river mouths feeding on stray food organisms near the saltwater-freshwater boundary or may make short feeding excursions into saltwater (Bouillon and Dempson 1989). Adams et al. (1988) reported that juvenile Arctic charr in the Koroc River, Quebec, were diurnal, spending many of the daylight hours hidden under stones, emerging only at night to feed.

#### Water Velocity

Heggberget (1984) reported that in two Norwegian streams, when Arctic charr were sympatric with Atlantic salmon and brown trout, 70 to 85 % of the charr were found at velocities <0.1 m/s. They also found that charr were the most abundant species at localities with the lowest velocities and were often located further from the banks in pools.

#### Temperature

Dempson and Kristofferson (1987) reported that in northern Labrador (Ikarut River), upstream migration of juvenile Arctic charr is triggered by periods of declining sea temperatures, and that the upstream run is essentially complete in September when the ocean temperature remains near 0°C. Since salmonids are unable to survive prolonged subzero temperatures (Brett and Alderice

1958), this migration may be a tactic to avoid unfavourable winter sea conditions (Northcote 1978). Jensen (1981) indicated that coastal water temperatures of 14°C at depths of 4 to 5 m might act as a thermal barrier in the distribution of anadromous Arctic charr into more southerly areas. Optimal temperatures for feeding range from 3 to 16°C, while optimal growth temperatures range from 11 to 14°C (Jensen et al. 1989).

**Depth**

Heggberget (1984) reported that in two northern Norwegian streams, 90% of juveniles were found at water depths <20 cm, although sometimes they occurred in pools. Night observations in the Koroc River, Quebec found juveniles in shallow water with mean depths of <20 cm (Adams et al. 1988). In the intertidal zone of Cumberland Sound, Moore (1975b) observed that juvenile charr less than 30 cm in length preferred depths of 1.0 m or greater, while those greater than 30 cm preferred depths of 2.0 m.

**Substrate**

Juvenile substrate preferences vary depending upon activity and time of day. For instance, in the Koroc River, Quebec, they preferred gravel during the day when active and rubble when resting/hiding. At night, Adams et al. (1988) reported that juveniles occupy positions in quiet near shore waters over sand.

**Cover**

Adams et al. (1988) found that coarse substrates (rubble/cobble) provide cover for juveniles.

### 3.9.1.4 Adult

Seaward migrations usually occur in the spring and generally coincide with the period of spring runoff and ice break-up in coastal rivers (Andrews and Lear 1956; Morrow 1980; Dempson 1982; Dempson and Green 1985). Scruton at al. (1997) suggested that this period may range from early May to early June in Newfoundland and from mid-May to the end of June in Labrador. In the Vardnes River, northern Norway the main downstream migration takes place from early May (start of ice break-up) to mid-June (Berg and Berg 1989). In Nauyuk system, Northwest Territories, nonspawning fish overwintered in Nauyuk Lake, moved to the sea in the spring as soon as the river opened and returned to the lake after 35-45 days (Gyselman 1984; Johnson 1989). In Nain and Tikkoatokak, Labrador, Dempson and Kristofferson (1987) found that Arctic charr spent 52 and 57 days, respectively at sea. Minimum estimates of the average length of time charr spend at sea were 8 to 9 weeks in Labrador (Dempson and Kristofferson 1987) and 6 to 8 weeks in the Northwest Territories (Gyselman 1984) and northern Norway (Mathisen and Berg 1968).

In the Fraser River, Labrador, first time migrants were typically 3-7 years of age (Dempson and Green 1985). According to Dempson and Kristofferson (1987), larger charr (both maturing and non-maturing) began to move downstream and enter the sea before smaller adults and juveniles. Similarly, maturing females were usually the first to leave the sea and enter rivers, followed by smaller and non-maturing adults, and juveniles (Dempson and Kristofferson 1987, Fraser River, Labrador; Johnson 1989, Norway). Johnson (1980) reported that in some Norwegian rivers the upstream run consisted mainly of non-maturing fish, while the majority of mature individuals remained in freshwater during the year in which they were going to spawn.

Dempson and Kristofferson (1987) reported that there was no relationship between distance travelled while at sea and fish size in northern Labrador or Cambridge Bay. Arctic charr tagged in Labrador during the spring outward migration leave the immediate vicinity of the river and distribute themselves throughout the bays and fiords, moving further away with the melting and retreating ice (Dempson and Kristofferson 1987). Tagging studies indicate that the mean distance travelled at sea was usually in the range of 40 to 70 km (Nielsen 1961, west Greenland; Moore 1975a; 1975b, Baffin Island; Dempson and Kristofferson 1987, Labrador), but can range from 250 km (Dempson and Kristofferson 1987, Labrador) to 940 km (Jensen and Berg 1977, Norway). There is considerable mixing of populations from individual rivers or subareas during the ocean phase, although the intermixing of populations from widely distributed areas is minimal (Dempson and Kristofferson 1987).

Large variation in age-at-length is a phenomenon common for Arctic charr populations from different geographical locations. For instance, in the Fraser River, Labrador, charr of modal length 43-48 cm can vary in age by as much as 8 years (Dempson and Green 1985). Mean age at maturity can also vary between populations. For instance, the mean age of maturity for females in Labrador rivers increases with latitude. From south to north, age of mature females has been reported as 5 years (Dempson and Green 1985; Fraser River), 7.9 years (Dempson 1982; Tikkoatokak Bay), and 10.2 years (Dempson 1982; Ramah Bay). The mean age of both male and female maturity has been reported as low as 4 to 6 years in the George River, northern Quebec (Gillis et al. 1982) and as high as 50% maturity by age 17 at Creswell Bay, Northwest Territories (Sekerak et al. 1976).

**Water Velocity**

In two Norwegian streams, Heggberget (1984) found that 70-85 % of charr were encountered at velocities <0.1 m/s, while Beddow et al. (1998) reported that adults were generally found at water velocities ranging from 0.5 to 1.0 m/s in Voisey's Bay streams. Heggberget (1984) also reported that charr were the most abundant species at localities with the lowest velocities and were often located in pools distant from banks.

**Temperature**

There is no evidence to suggest that the upstream movements of adult charr are related to temperature. Moore (1975a; 1975b) reported for Baffin Island, Canada, that the upstream movements of adult Arctic charr were not correlated to changes in stream water temperature, while Dempson and Kristofferson (1987) also reported that in northern Labrador, fjord temperatures were not correlated with adult upstream migrations. Arctic charr are unable to survive prolonged subzero temperatures (Brett and Alderice 1958). Thus, duration at sea may be limited by temperature, however, Dempson and Kristofferson (1987) reported that most charr in northern Labrador return to freshwater before sea temperatures fall to 0°C (winter sea temperatures in this area are below −1.7°C). Jensen (1981) indicated that in Norwegian coastal waters, temperatures of 14°C at a depth of 4 to 5 m might act as a thermal barrier in the distribution of anadromous Arctic charr into more southerly areas. Optimal temperatures for charr feeding range from 3 to 16°C, while optimal growth temperatures range from 11 to 14°C (Jensen et al. 1989).

#### Depth

Beddow et al. (1998) reported that in streams of Voisey's Bay, Labrador, adults were generally found in groups of at least ten individuals in pools ranging in depth from 1 to 2 m. Page and Burr (1991) reported that adults occur in deep runs and pools of medium to large rivers.

#### Substrate

In northern Labrador streams, adults were generally found in pools or in association with large boulders downstream of riffles (Beddow et al. 1998). Typically, adults were associated with boulders (40%), rubble (50%), and sand/gravel (10%) substrates.

#### Cover

Within the literature reviewed, there was no quantification of the importance of cover to adults. This is most likely due to the absence of instream and large shoreline vegetation in northern climes.

## 3.9.2 Anadromous Atlantic salmon (*Salmo salar*)

Atlantic salmon occur naturally along the east and west coasts of the North Atlantic Ocean from the Arctic Circle south to the Connecticut River (Scott and Crossman 1998; Klemetsen et al. 2003). Both anadromous (sea run) and freshwater resident forms (ouananiche) are found throughout Newfoundland and Labrador, ranging from northern Labrador to the south coast of Newfoundland (Scott and Scott 1988; Black et al. 1986).

### 3.9.2.1 Spawning, Incubation, and Emergence

Atlantic salmon typically remain at sea for 1-3 years before returning to their natal river to spawn for the first time (Porter 1975; Scott and Scott 1988; Klemetsen et al. 2003). They generally ascend rivers in the fall, however, the timing of upstream migration may occur from May to September in Newfoundland and July to August in Labrador (Porter 1975; Scruton et al. 1997). In Newfoundland, spawning typically occurs between mid-October and mid-November and may occur approximately two weeks earlier in Labrador (Porter 1975; Scruton et al. 1997).

Nesting sites are chosen by the female and are usually within a clean, well-aerated, gravel bottom riffle above a pool (Porter 1975; Danie et al. 1984; Scott and Scott 1988; Smith 1988; Gibson 1993; Stanley and Trial 1995; Scott and Crossman 1998). Spawning has also been reported at the tail of pools on the upstream edge of riffles (Danie et al. 1984; Smith 1988; Gibson et al. 1990; Stanley and Trial 1995; Scott and Crossman 1998; Scruton et al. 2000). The nest (redd) is created in the substrate by strong tail movements of the female (Scott and Scott 1988; Scott and Crossman 1998). Once the redd is complete, the female settles into the depression, the male aligns himself alongside, and the eggs and sperm are released. The fertilized eggs are covered by the female (using the previously displaced gravel) and left to incubate over winter. The female then rests and repeats the procedure over and over until spawning is complete, which may take up to a week for certain individuals (Scott and Scott 1988; Scott and Crossman 1998). Some male parr mature in freshwater (referred to as 'precocious males') and take part in spawning (Dalley et al. 1983; Gibson 1983; Myers 1984; Myers et al. 1986; Chadwick and Green 1985; Thorpe 1986). Some of these precocious male parr never migrate to sea (Dalley et al. 1983; Gibson 1983).

Some Atlantic salmon (usually females) survive to spawn a second or even up to five times (O'Connell et al. 2001a) and are often referred to as kelts. Kelts move downstream to rest in pools, immediately return to the ocean, or overwinter in freshwater, returning to the sea the following spring (Scott and Scott 1988). The number of repeat spawners can vary significantly among rivers or among years on a given river. Dymond (1963) reported the percentage of repeat spawners could vary from 5-34% in Canadian rivers. Ducharme (1969) identified kelts that had spawned four and five times within the Big Salmon River, New Brunswick. O'Connell et al. (2001b) reported a return rate of 7% for repeat spawners based on tagging studies carried out in Northeast Brook, Trepassey, Newfoundland, while Downton et al. (2001) estimated an average return rate of 20% yearly (range 6.9 to 39.3%) for Campbellton River, Notre Dame Bay.

The egg incubation period is normally four to five months, with hatching occurring between mid-April and early May in Newfoundland and mid-April to mid-June in Labrador (Porter 1975; Scruton et al. 1997).

### Water Velocity

Spawning has been reported at velocities ranging from 0.15-0.8 m/s: 0.31-0.46 m/s (Jones 1969); 0.15-0.5 m/s (mean 0.5 m/s) (Stanley and Trial 1995); 0.3-0.45 m/s (Gibson et al. 1990); 0.1-0.8 m/s (Scruton et al. 2000); 0.4-0.8 m/s (mean 0.56 m/s) (Heggberget et al. 1988); and 0.49-0.52 m/s (Danie et al. 1984). Other researchers have suggested that a midwater velocity of 0.31 to 0.55 m/s (range of 0.15–0.90 m/s) was preferred for spawning (Pratt 1968; Beland et al. 1982) and Jones (1959) reported that spawning ceased if velocities were reduced to 0.05–0.08 m/s.

### Temperature

Although Atlantic salmon may spawn at water temperatures between 3 and 11°C, temperatures are usually below 7°C (DeCola 1970; Peterson et al. 1977; Scruton et al. 2000). Egg mortality has been shown to increase at temperatures below 4°C and development may occur at a slower rate at temperatures as low as 0.5°C (Peterson et al. 1977; Moir et al. 1998). Baglinière et al. (1990) observed spawning in a French stream, principally at night, immediately following an increase in temperature from 6 to 9°C. Conversely, they observed a temperature decrease from 9 to 6°C from the start to the end of reproduction. Based upon habitat studies in the United States, spawning occurred between 4.4 and 10°C, with 6°C considered the optimum temperature for egg fertilization and incubation (Danie et al. 1984).

**Depth**

Spawning depths between 10 and 70 cm are most frequently noted within the literature (Pratt 1968; Sorokin 1971; Peterson 1978; Beland et al. 1982; Danie et al. 1984; deGraff and Chaput 1984; Heggberget et al. 1988; Scruton et al. 2000). During experimental stream tank trials, Jones (1959) observed that preferred spawning depths were rarely greater than 30 cm.

**Substrate**

Spawning substrates consist mainly of gravel and cobble (Warner 1963; Peterson 1978; Heggberget et al. 1988; Gibson et al. 1990; Bardonnet and Baglinière 2000; Scruton et al. 2000), while bottoms of mud, silt or sand are typically avoided (Porter 1975; Smith 1988). Sufficient substrate porosity is required to provide adequate oxygen and remove metabolites from developing eggs (Scrivener and Brownlee 1989). The permeability of sampled spawning gravel from New Brunswick streams was between <20 m/hr to >50 m/hr; fry did not emerge from gravel with a permeability of 6 m/hr (Peterson and Metcalfe 1981).

**Cover**

Overhead or emergent cover has not been reported to be associated with spawning site selection displayed by Atlantic salmon. However, cover in the form of interstitial spaces between gravel and cobble substrates is critical for the protection and development of pre-emergent alevins (Peterson 1978).

### 3.9.2.2 Young-of-the-Year/Nursery

Newly hatched young, referred to as alevins, usually remain within the substrate for several weeks until the yolk sac is absorbed. After emergence, alevins (now referred to as young-of-the-year, underlings, fingerlings, or fry) may remain within the vicinity of the redd until they reach a length of approximately 65 mm (Randall 1982). Most fry then disperse downstream and establish territories, usually occupying areas of slow flowing water initially and moving into faster flowing water, such as riffles or rapids, as they increase in size (Porter 1975; Danie et al. 1984; Smith 1988; Gibson et al. 1990; Stanley and Trial 1995).

**Water Velocity**

Young-of-the-year have been associated with relatively low water velocities (<0.4 m/s) (Elson 1967; Knight et al. 1981; Danie et al. 1984; Rimmer et al. 1984; Trial and Stanley 1984; deGraff and Bain 1986; Morantz et al. 1987). Gibson (1993) reported nose velocities within Newfoundland's southeast coast rivers of 0.13 m/s in riffles and flats and 0.06 m/s in pools, while Scruton and Gibson (1993) reported preferred velocities of 0.2-0.6 m/s. deGraff and Bain (1986) reported that nose velocities in two Avalon Peninsula rivers ranged from 0.07 to 0.21 m/s, and column velocities from 0.14 to 0.71 m/s. Young-of-the-year have been reported to overwinter in areas where mean water velocities are 0.4-0.5 m/s (Cunjak 1990). deGraff and Bain (1986) and Heggenes (1990) concluded that nose velocity was the principal variable defining habitat use.

### Temperature

Young-of-the-year were collected from southeast coast Newfoundland rivers within temperatures ranging from 10 to 19°C (Gibson 1993).

### Depth

Young-of-the-year tend to occupy shallow areas, often near stream margins (MacCrimmon 1954; Elson 1967; Symons and Héland 1978; Kennedy and Strange 1982; 1986; Gardiner 1984; Morantz et al. 1987; Scruton et al. 2000), however, this can vary significantly among streams as they may occur in water up to 1 m deep (Francis 1980; Knight et al. 1981; Baglinère and Champigneulle 1986; Rimmer et al. 1984; Trial and Stanley 1984; deGraff and Bain 1986; Morantz et al. 1987; Scruton et al. 2000). Symons and Héland (1978) found them in shallow (10-15 cm) pebbly riffles and densities in a Scottish stream were positively correlated with depths <19 cm (Egglishaw and Shackley 1982). In the Miramichi River, New Brunswick, Keenleyside (1962) found that young-of-the-year were more abundant in the upper (narrower) reaches of the river than in the lower (wider) reaches, usually at depths <50 cm. Gibson (1993) reported that in southeast Newfoundland rivers, young-of-the-year were encountered at depths ranging from 17.4 cm in riffles, 23.0 cm in flats, and 31.8 cm in pools. deGraff and Bain (1986) encountered them in two Avalon Peninsula streams at depths ranging from 29.1 to 40.7 cm. Young-of-the-year have been reported to overwinter in areas where mean water depths are 0.4-0.5 m (Cunjak 1990). Scruton and Gibson (1993) determined that the optimum habitat suitability index depth for young-of-the-year Atlantic salmon in Newfoundland was from 15 to 20 cm.

### Substrate

Young-of-the-year are generally associated with pebble or gravel substrates (Keenleyside 1962; Symons and Héland 1978; deGraff and Bain 1986; Gibson 1993). In Newfoundland rivers, young-of-the-year/fry have been found to be associated with pebble/cobble dominated substrate (Scruton and Gibson 1993). Gibson et al. (1990) postulated that the association of fry and young parr with gravel/pebble substrate may be a reflection of limited migration or displacement of fry from spawning habitat.

### Cover

Pickering et al. (1987) found salmon fry to have a high affinity for overhead cover, while Gibson et al. (1990) found salmon biomass to be negatively associated with overhanging cover. Young-of-the-year seek shelter in the substrate, especially when water temperatures drop below 10°C (Rimmer et al. 1983; Danie et al. 1984). Although some move beneath coarse substrate, such as rubble, in riffle-run habitats to overwinter (Cunjak 1990), many overwinter within redd excavations made that spawning season (Porter 1975; Cunjak 1990). In river systems where lacustrine habitats are common (e.g. NL) and/or suitable substrates for overwintering are locally unavailable, some young may enter deep pools or ponds (Cunjak 1990).

### 3.9.2.3 Juvenile

The juvenile classification can be subdivided into small parr (40-70 mm) and large parr (>70 mm) (Scott and Scott 1988; Heggenes 1990; Gibson 1993; Scruton et al. 2000). By the end of the first growing season, parr have eight to eleven narrow pigmented marks on both sides along the lateral line (referred to as parr marks).

In Newfoundland, parr remain in freshwater for 2 to 4 years, while in Labrador they may remain in freshwater for 3 to 6 years (Porter 1975). They can use both riverine and lacustrine habitats for rearing. In the spring (May and June), individuals which have attained a size of 12 to 20 cm lose their parr marks, become silvery (due to guanine deposits in the skin) and migrate to the sea as smolt (Porter 1975; Scott and Scott 1988; Scott and Crossman 1998). The minimum smolt age reported in North America is 2 years (Saunders and Schom 1985), while smolts as old as 8 years have been encountered in rivers of Ungava Bay, Quebec (Power 1969; Robitaille et al. 1986).

Large smolt move to sea earlier in the season than small smolt (Jonsson et al. 1990). Water temperature appears to be the stimulating factor for downstream migration (Jonsson and Ruud-Hansen 1985; McCormick et al. 1998; Antonsson and Gudjonsson 2002). In some populations, downstream migration and smolting occurs in the fall rather than spring (Youngson et al. 1983; Cunjak et al. 1989; Huntingford et al. 1992). Estuaries are often used by Atlantic salmon parr for rearing prior to undergoing smoltification (Cunjak et al. 1989; 1990; Cunjak 1992).

Older and larger parr are usually found in riffles that are deeper than 20 cm, with surface water velocities between 0.5 and 0.7 m/s, but occupy pools and lentic waters where interspecific competition and fish predation is low (Gibson et al. 1990). Older juveniles prefer deeper pools (2.0-4.0 m), steadies and ponds (Gibson 1973; Porter 1975; Danie et al. 1984; Gibson et al. 1990; Gibson et al. 1993; Bremset and Berg 1997) especially during floods, low water levels, high water temperatures and winter freezing (Porter 1975) or when interspecific competition and fish predation is low (Gibson et al. 1990). During summer and autumn, all age classes of juveniles are markedly more frequent in runs (i.e., water depths of 25-45 cm, velocity of 0.2-0.4 m/s and substrates comprised of boulder, rubble, cobble, and gravel with no sand, silt or detritus) than in either riffles or pools (Rimmer et al. 1983).

In winter, juveniles generally move into areas characterized by increased water depth, reduced water velocity, and larger substrate than their preferred summer habitat (Cunjak 1996; Whalen et al. 1999). Juveniles also typically switch from being active throughout the diel cycle in summer to being predominantly nocturnal in winter (Rimmer and Paim 1990; Gries et al. 1997; Valdimarsson et al. 1997; Hiscock et al. 2002a), thus spending the day in interstitial spaces beneath the substrate, emerging at night to forage (Gibson 1978; Rimmer and Paim 1990; Fraser et al. 1993, 1995). However, in West Salmon and Stoney rivers, Newfoundland, juveniles were active throughout the diel cycle, with peaks in activity shortly before sunrise and after sunset (Hiscock et al. 2002b; Robertson et al. 2003). Several other authors have also reported similar nighttime peaks in activity for juvenile salmonids (Gibson 1978; Rimmer and Paim 1990; Heggenes et al. 1993; Riehle and Griffith 1993).

## Water Velocity

A number of studies have suggested that larger parr occupy faster water than young-of-the-year (MacCrimmon 1954; Keenleyside 1962; Wankowski and Thorpe 1979; Rimmer et al. 1984), while others have reported the opposite (Saunders and Gee 1964; Elson 1967; Chadwick and Green 1985; Morantz et al. 1987; Cunjak et al. 1989; Heggenes and Saltveit 1990). Variation in the literature may reflect differences in habitat availability among study sites and the influence of competition or predation by other fish species (Scruton et al. 2000). Gibson (1973) and Gibson et al. (1993) stated that slow-flowing lentic habitats may be occupied by juveniles in the absence of competitors or predators. Large (>10 cm) parr from two southeast Newfoundland rivers were encountered at nose velocities ranging from 0.13 m/s (pool and flat) to 0.20 m/s (riffle), while small (6-10 cm) parr were encountered at slightly lower nose velocities ranging from 0.06 m/s (pool) to 0.11 m/s (flat) to 0.20 m/s (riffle) (Gibson 1993). Mean nose velocities for Atlantic salmon parr collected from two Avalon Peninsula streams ranged from 0.11 m/s to 0.19 m/s (deGraff and Bain 1986). In developing habitat suitability curves for Newfoundland, Scruton and Gibson (1993) found that the optimum velocity for parr ranged from 0.1 to 0.5 m/s. Based upon a review of available data, Heggenes (1990) concluded that parr could be found in velocities ranging from 0.05 to 1.0 m/s.

Atlantic salmon parr are less buoyant than other salmonids and tend to remain upon the substrate, which permits stability in faster water (Saunders 1965; Sosiak 1982). In winter, they often move into areas with slow water velocities (typically in pools), seeking shelter in coarse substrate (Rimmer et al. 1983; Cunjak 1988; Scruton et al. 2000). According to Cunjak (1990), young salmon (5-15 cm FL) overwinter primarily in areas where mean water velocities are 0.4-0.5 m/s. In Northeast River, Newfoundland, Hiscock et al. (2002a) found that during winter, active juveniles preferred areas with higher water velocities than inactive fish. Since increased flow is associated with increased invertebrate drift (Wankowski and Thorpe 1979; Fausch 1984), selecting faster velocities while active may give fish access to more prey.

## Temperature

Jensen et al. (1989) reported that the lower temperature limit for juvenile growth in Norwegian rivers is approximately 7°C. At water temperatures less than 8-10°C, juveniles seek shelter in the substrate within riffle areas or move into pools (Gibson 1978; Fraser et al. 1993, 1995). Gibson (1978) suggests that this sheltering behaviour may reflect an inability to completely adapt to lower temperatures or may simply imply that it is more energy efficient to remain inactive at lower temperatures. Gibson (1988) reported that at 24°C more parr were encountered in pools than in riffles. Gardiner and Geddes (1980) and Rimmer et al. (1985) postulated that there is a critical threshold temperature that will trigger sheltering behaviour when water temperatures drop in the fall. There is evidence to suggest that there may be geographical variation in this threshold temperature. Juvenile Atlantic salmon in the British Isles were reported to take shelter at temperatures of 5 to 7°C (Gardiner and Geddes 1980), while sheltering seems to occur at temperatures of 9 to 10°C in eastern Canada (Gibson 1978; Rimmer et al. 1985).

### Depth

Parr have been encountered in shallow (<50 cm) riffles (Keenleyside 1962; Saunders and Gee 1964; Maitland 1965; Jones 1975; Danie et al. 1984; Morantz et al. 1987; Scruton et al. 2000) as well as deeper (>50 cm) pools and riffles (Lindroth 1955; Gibson 1966; Elson 1967; Symons and Héland 1978; Heggberget 1984; Scruton et al. 2000). Large (>10 cm) parr from two southeast Newfoundland rivers were encountered at depths ranging from 56.8 cm (pool) to 32.3 cm (flat) to 24.1 cm (riffle) (Gibson 1993). Small (6-10 cm) parr from the same rivers were encountered at depths ranging from 41.6 cm (pool) to 28.1 cm (flat) to 22.5 cm (riffle) (Gibson 1993). deGraff and Bain (1986) reported that parr in two Avalon Peninsula streams were found at mean water depths ranging from 38.3 cm to 43.5 cm. In developing habitat suitability curves for Newfoundland, Scruton and Gibson (1993) found the optimum depth to range from 15 to 25 cm. In Northeast River, Newfoundland, juveniles who occupied shallow habitats (riffles and runs) during summer and fall tended to move into deeper habitats (glides, pools and small lakes) during the winter (Hiscock et al. 2002a). According to Cunjak (1990), young salmon (5-15 cm FL) overwinter primarily in areas where mean water depths are 0.4-0.5 m.

### Substrate

Juveniles are usually associated with a coarse gravel/cobble substrate (Gibson 1993), although they have been found in areas containing a wide range of substrate types (Heggenes 1991). In Newfoundland rivers, juveniles exhibit a preference for boulder dominated substrates (Scruton and Gibson 1993). During summer and fall, Rimmer et al. (1983) observed all age classes of juveniles over substrates comprised of boulder, rubble, cobble, and gravel with no sand, silt or detritus (Rimmer et al. 1983). During winter, juveniles tend to be associated with larger substrates (Gibson 1978; Rimmer et al. 1983; Hearn and Kynard 1986; Cunjak 1988). Gibson et al. (1990) stated that the apparent preference for coarse substrates may be determined by other variables such as water velocity, territoriality, or turbulence. In Northeast River, Newfoundland, Hiscock et al. (2002a) found that during winter, juveniles preferred gravel-cobble substrates when active at night and appeared to be burrowing into cobble-rubble-boulder substrates when inactive during the day.

### Cover

Scruton and Gibson (1993) found that habitat suitability was negatively correlated with increasing cover in Newfoundland rivers. Gibson (1978) and Heggenes (1990) reported that a preference for turbulent waters may be related to white water cover, although increased water velocities may play a role in this type of habitat selection. Rimmer et al. (1983) found that shelter is often provided by undercut banks, deep pools, surface water turbulence and rocky substrate. Gibson and Power (1975) reported that overhanging cover attracted Atlantic salmon parr in shallow water, but not in deeper water. As water temperatures drop below $10^0$C, young salmon seek shelter under coarse substrate (Rimmer et al. 1983; Gibson et al. 1990; Scruton et al. 2000) or move to pools (Gibson et al. 1990). Young salmon (5-15 cm FL) move beneath coarse substrates, such as rubble, in riffle-run habitats to overwinter (Rimmer et al. 1983; Cunjak 1990; Scruton et al. 2000). The optimum habitat suitability criteria for juveniles in Newfoundland was determined to be in the range of 0 to 10%, with a marked decline in suitability above 80% cover (Scruton et al. 2000).

#### 3.9.2.4 Adult

Anadromous Atlantic salmon may mature as parr, 1-3 sea-winter fish (mature after spending one to three winters at sea), or in rare instances, at older sea ages (Klemetsen et al. 2003). During upstream migration, adults cease feeding and alternate between periods of active swimming and resting, often in sheltered pools (Bardonnet and Baglinière 2000). Returning adults are referred to as grilse after spending one winter at sea, and salmon if they have spent two or more years at sea (Porter 1975; Scott and Scott 1988). In Newfoundland, Atlantic salmon have been shown to undergo consecutive and alternate spawning (Dempson et al. 2001; O'Connell et al. 2001b). After they have spawned, salmon turn black in colour and are referred to as kelts.

**Water Velocity**

When adults enter the mouth of a river, hydraulic factors become increasingly important (Bardonnet and Baglinière 2000). Clarke et al. (1991) determined that upstream movement of salmon is in response to flow events, and that low flow periods will delay entry. Up-estuary movements are primarily nocturnal and tend to occur during ebb tides (Smith and Smith 1997). Adults require a minimum stream velocity of 0.3 to 0.6 m/s to continue upstream movement (Weaver 1963).

**Temperature**

At sea, adults prefer temperatures ranging from 4-12°C (Scott and Scott 1988). Saunders et al. (1975) established –0.7°C as the lower lethal temperature for adults in seawater of 30 ppt. Garside (1973) reported an upper lethal temperature of 27.8 °C at sea, although they may survive exposure to higher temperatures for brief periods (Scott and Scott 1988).

Radio tags applied to postspawning kelts in a number of Newfoundland rivers indicate that during the seaward migration and subsequent return to freshwater, fish were exposed to a range of temperatures from 0 to 20°C (Reddin et al. 1999). It is not uncommon for adults to be exposed to temperatures higher than 20°C (even as high as 27°C) in Newfoundland rivers in July-August (O'Connell et al. 2001b). According to Coutant (1977), Atlantic salmon prefer water temperatures around 16.0°C.

**Depth**

The literature reviewed indicates that the distribution of adults in freshwater does not appear to be correlated with water depth. Due to alternating swimming and resting periods associated with upstream movement, the quality and quantity of available pool habitat appears to be a more important habitat feature (Hawkins 1988; Bardonnet and Baglinière 2000). However, initial attempts to evaluate the relative quality of holding pools suggest that a minimum depth of 0.9 m is required (Moreau and Moring 1993).

According to Komadina-Douthwright et al. (1997), the majority of kelts in the Miramichi River overwintered within the lower reaches, below the head of tide and those that overwintered in pools appeared to position themselves in areas with less frazil ice deposition and lower water velocities. It was also suggested that pools located close to bridges, point sources of runoff, the confluence of tributaries, and small islands might protect Atlantic salmon kelts from frazil ice accumulation in winter and moving ice during spring break-up, as kelts were found either overwintering in these areas, or moved to them during ice-out in the river (Komadina-Douthwright et al. 1997).

**Substrate**

Other than spawning substrate requirements, no information exists within the literature reviewed regarding adult substrate requirements.

**Cover**

The literature indicates a relative paucity of information with respect to cover requirements of adults. Moreau and Moring (1993) state that instream cover should be more than 20% of the total area of holding pools. Large boulders and other stream obstructions provide eddies and slack water where adults may rest (Danie et al. 1984).

### 3.9.3 Freshwater resident Atlantic salmon (*Salmo salar*)

Some Atlantic salmon populations remain in freshwater their entire life-cycle even though there may be no physical obstruction preventing seaward migration and are referred to as landlocked or resident Atlantic salmon or ouananiche (Scott and Crossman 1964; 1998; Scott and Scott 1988). There are well-established populations of ouananiche in many of the inland ponds, lakes, rivers, and streams of Newfoundland (Andrews 1966), ranging from the Great Northern Peninsula (Barbour et al. 1979), the Avalon Peninsula (Chaput and Astle 1985) and western Labrador (Ryan 1980). Ouananiche may or may not be either geographically or genetically distinct from coexisting anadromous Atlantic salmon (Hutchings 1986; Berg 1988). Dwarf populations of ouananiche have also been reported from several Newfoundland localities (Bruce 1976; Barbour et al. 1979; Gibson et al. 1996).

#### 3.9.3.1 Spawning, Incubation, and Emergence

The life history of ouananiche is similar to anadromous Atlantic salmon except adults remain in lakes, where they spawn along rocky shorelines (Scott and Crossman 1964; Cowan and Baggs 1988; Scruton et al. 1997) or migrate into tributary streams to spawn (Scott and Crossman 1964; 1998; Hutchings 1986; Einarsson et al. 1990). In Newfoundland, spawning typically occurs between late September and early November (Leggett 1965; Lee 1971; Bruce 1976; Beak Consultants Ltd. 1981; Scruton et al. 1997) and between mid-September and October in Labrador (Wiseman 1972; Scruton et al. 1997). Scott and Crossman (1964) stated that spawning activity is usually stimulated by increased flows within tributary streams, while Laughton (1991) and Hawkins and Smith (1986) found that within a Scottish river system, spawning migrations began at all stages of a spate event, even though movements were most common after the peak.

Hawkins and Smith (1986) also reported that some ouananiche appeared to move only on falling flow rates, which suggests that fish having spent a long time in the river may be unwilling or unable to ascend the fastest flow rates.

According to Gibson et al. (1996), landlocked salmon apparently spawned in shallow (mean depth of 10-18 cm) riffle areas over a cobble substrate in a tributary of the Bristol Cove River in south eastern Newfoundland. Water temperatures at the time ranged from 6-8$^{0}$C (Gibson et al. 1996). Ouananiche have also been observed spawning in substrates containing up to 18% fines (sand, silt and clay) with little apparent effect on subsequent egg survival (Scruton et al. 2000). In Newfoundland, spawning has also been reported along lake shorelines (Leggett 1965; Cowan and Baggs 1988; Scruton et al. 1996a) and in moving water, usually above outlet streams and near the mouths of inlet streams (Leggett 1965; Leggett and Power 1969; Havey and Warner 1970; Beak Consultants Ltd. 1980; Einarsson et al. 1990; Scruton et al. 1996a).

#### 3.9.3.2 Young-of-the-Year/Nursery/Juvenile

Hatching and emergence usually occurs between early April and mid-June in Newfoundland and from mid-May to mid-June in Labrador (Scruton et al. 1997). Fry are typically found in shallow riffles of small streams over pebble/cobble substrates (Scruton and Gibson 1993; Stanley and Trial 1995; Gibson et al. 1996). Young-of-the-year and juveniles generally occupy riffle areas in tributary streams (Leggett and Power 1969; Wiseman 1973; Gibson et al. 1996), where they may remain for 2-3 years before moving into lakes (Leggett 1965; Leggett and Power 1969; Havey and Warner 1970; Wiseman 1971a). In Newfoundland, young-of-the-year and juveniles were found at depths ranging from 0.3-1.5 m and velocities of 0.1-1.0 m/s (Gibson et al. 1996). Stanley and Trial (1995) found that the most suitable current velocity for fry was 0.1-0.3 m/s and 0.1-0.4 m/s for parr, while the most suitable depths were 10-40 cm for fry and 20-50 cm for parr.

#### 3.9.3.3 Adult

Most stream spawning ouananiche return to their lake of origin after spawning (Scott and Crossman 1964; Havey and Warner 1970; Scruton et al. 1996b), although some may overwinter in tributary pools, returning to the lake the following spring (Scott and Crossman 1964; Havey and Warner 1970). Recent radio-telemetry investigations within a Newfoundland hydroelectric reservoir system have shown that ouananiche will overwinter in both the deep warmer waters of ice-covered lakes as well as in the fast-flowing ice-free waters of inlets, outlets, and canals (Scruton et al. 1997).

Ouananiche mature at 2-3 years of age (Leggett 1965; Lee 1971; Leggett and Power 1969), with males usually maturing first (Leggett and Power 1969). Some male parr, referred to as 'precocious parr', mature early and engage in spawning activities (Gibson 1983). Ouananiche up to 14 years old have been collected in Newfoundland (Pippy 1966).

### 3.9.4 Brook trout (*Salvelinus fontinalis*)

Brook trout are native to eastern North America and widely distributed throughout Newfoundland and Labrador (Scott and Crossman 1964; 1998). They have been reported from northern (Black et al. 1986) and southern Labrador (Bruce 1974; Ryan 1980) and are thought to exist within all Newfoundland freshwater ecosystems (Scott and Crossman 1964). Some brook trout populations may spend their entire life cycle in freshwater, while others are anadromous, spending one or two months feeding at sea in relatively shallow coastal waters within the vicinity of their natal stream (Scott and Crossman 1964; Morrow 1980; Power 1980; Ryan 1988; Scott and Scott 1988). At sea, brook trout often form small schools and have been observed moving within 8 km of their natal river (Scott and Scott 1988).

Within Newfoundland and Labrador, lakes and ponds are utilized for spawning, overwintering, and feeding (Dempson and Green 1985; Cowan and Baggs 1988; McCarthy 1996) (refer to Bradbury et al. 1999 for more information on lake utilization). Although movements between fresh and salt water can occur throughout the year (O'Connell 1982), peak seaward migration typically occurs in May or June in Newfoundland (O'Connell 1982) and June or July in Labrador (Scruton et al. 1997). Apart from migration to and from the sea, the life histories of both the anadromous and non-anadromous (resident) forms are similar (Scott and Crossman 1964), so for the purposes of this report they are combined.

Raleigh (1982) characterized optimal brook trout riverine habitat as clear, cold spring-fed water; a silt-free rocky substrate in riffle-run areas; an approximate 1:1 pool-riffle ratio with areas of slow, deep water; well vegetated stream banks; abundant instream cover; and relatively stable water flow, temperature regimes and stream banks.

#### 3.9.4.1 Spawning, Incubation, and Emergence

Spawning typically occurs between late September and early November in Newfoundland (Frost 1940; Scott and Crossman 1964; Wiseman 1969; 1970; 1971; 1972; O'Connell 1982) and Labrador (Dempson and Green 1985). Brook trout usually spawn in shallow headwater streams with a gravel substrate (Scott and Crossman 1964; 1998; Wiseman 1970; 1971; Raleigh 1982; Ryan 1988; Ford et al. 1995), but also utilize lake shorelines (Wiseman 1970; Wurtsbaugh et al. 1975; Fraser 1982; Dempson and Green 1985; Cowan and Baggs 1988; Ford et al. 1995; Quinn 1995; McCarthy 1996), areas of upwelling groundwater (Hazzard 1932; Benson 1953; Webster and Eiriksdottier 1976), and submerged woody debris in lake areas with sufficient upwelling (Fraser 1982). For more information on lake spawning, refer to Bradbury et al. (1999).

Males usually arrive first at the spawning grounds and often outnumber the females (Scott and Crossman 1998). The female (assisted by the courting movements of the male) clears away debris from the substrate to create a redd. The eggs are extruded into the redd in batches by the female, which are then fertilized by the male. Although one male and one female take part in the spawning act, they may each repeat the procedure with other mates throughout the spawning period (Scott and Scott 1988). In northern populations, repeat spawning is common with males spawning annually and females spawning in alternate years (or annually if food resources permit gonadal development) (Power 1980; O'Connell 1982). Redd superimposition rates as high as 60% have been reported within brook trout spawning areas (Curry and Noakes 1995). Eggs incubate in the substrate over winter and hatch between April and mid-June in Newfoundland (Baggs 1989; Scruton et al. 1997) and mid-May to mid-June in Labrador (Scruton et al. 1997).

After hatching, the young-of-the-year (alevins) remain within the redd until the yolk sac is absorbed (Williams 1981; Ryan 1988; Scott and Scott 1988).

### Water Velocity (Groundwater Upwelling)

In the literature reviewed, groundwater upwelling (as opposed to water velocity) was identified as probably being the most critical factor in redd site selection (Webster and Eiriksdottier 1976; Raleigh 1982; Snucins et al. 1992; Witzel and MacCrimmon 1983; Fraser 1985; Gunn 1986; Curry and Noakes 1995; Curry et al. 1995). Groundwater upwelling is beneficial in that it provides protection from freezing and carries dissolved oxygen to and metabolic wastes away from developing embryos (Reiser and Wesche 1977; Fraser 1982; 1985; Matthess 1982; Curry et al. 1995). Spawning brook trout are also known to be able to locate new areas of upwelling groundwater, suggesting that gradients created by discharging groundwater may be used for homing to spawning areas (Webster 1962; Carline 1980; Curry and Noakes 1995). The importance of groundwater upwelling with respect to brook trout spawning has not been documented in Newfoundland and Labrador.

Witzel and MacCrimmon (1983) reported that the majority of brook trout in southeastern Ontario streams spawned at velocities of 0.3 m/s or less. Spawning velocities have been reported in ranges from 0.01 to 0.92 m/s in Oregon streams (Smith 1973) and 0.03 to 0.34 m/s in Wyoming streams (Reiser and Wesche 1977). Brook trout redds have been located at the following mean water velocities: 0.11 m/s in Oregon streams (Smith 1973), 0.16 m/s in Wyoming streams (Reiser and Wesche 1977), and 0.18 m/s in Ontario streams (Witzel and MacCrimmon 1983). Reiser and Bjornn (1979a) suggest that the flow rate through substrate during incubation should be greater than 0.01 m/s.

### Temperature

Spawning has been reported at temperatures ranging from 4 to 10°C (Greely 1932; Hazzard 1932; Smith 1941; Needham 1961; McAfee 1966a; Power 1980). In Newfoundland, spawning temperatures have been shown to range from 4 to 10°C (Scott and Crossman 1964) and 4.4 to 9.4°C (Scruton 1986). Optimum temperatures for egg incubation range from 4.5 to 11.5°C (MacCrimmon and Campbell 1969). Within Canadian streams, 50% of alevins emerge from the redd in 56 days at 7.1°C and 19-27 days if the temperature is between 9.8 and 19.5°C (McCormick et al. 1972). Power (1980) reported that males in the Netherlands fail to produce viable sperm above 19°C and egg production in females is optimal at temperatures near 10 °C, with spawning often not occurring at temperatures above 16°C.

### Depth

Brook trout have been reported to spawn at depths between 0.1-0.3 m (Smith 1973, Oregon; Reiser and Wesche 1977, Wyoming; Witzel and MacCrimmon 1983, Ontario).

### Substrate

In Newfoundland, spawning has been reported to occur in shallow headwater streams having mainly gravel substrates (Scott and Crossman 1964; 1998; Scott and Scott 1988; Ryan 1988). Other than O'Connell (1982) who reported spawning over a sand/silt/gravel substrate within an Avalon Peninsula river, the literature reviewed did not contain any information on the preferred substrates of riverine spawners in Newfoundland and Labrador. Reiser and Wesche (1977) observed in Wyoming streams that the optimum substrate size for embryo survival was in the range of 0.3 to 5.0 cm (gravel and small cobble). Witzel and MacCrimmon (1983) determined the preferred spawning substrate size within southwestern Ontario streams was in the range of 0.3 to 8.0 cm in diameter (gravel and small cobble). Burns (1970) observed that incubation survival was reduced in California streams as the percent of material less than 2.5 mm in diameter increased. In general, as the amount of sand in spawning gravel increases, especially above 15-20%, there is an overall reduction in the percentage of alevins that emerge (Becker 1983; Ford et al. 1995). However, brook trout have been found to spawn over silt and detritus providing there is groundwater seepage (Witzel and MacCrimmon 1983). Because embryos are typically located in the upper 30 cm of substrate they can be susceptible to freezing mortality during winter if the redds are exposed (Curry et al. 1991; Snucins et al. 1992).

### Cover

In southwest Ontario streams, redds were within 0.5, 1.0, and 1.5 m of cover (most commonly submerged logs and tree branches) 83, 94, and 96% of the time, respectively (Witzel and MacCrimmon 1983).

## 3.9.4.2 Young-of-the-Year/Nursery

### Water Velocity

Cunjak and Green (1983) captured young-of-the-year brook trout from two streams on the Avalon Peninsula at nose velocities ranging from 0.02 to 0.38 m/s (mean 0.11-0.21 m/s). Cunjak and Power (1986) reported that young-of-the-year from three southern Ontario streams were found at mean nose velocities ranging from 0.03 to 0.06 m/s in summer and 0.02 to 0.07 m/s (range 0.02 to 0.23 m/s) in winter. Griffith (1972) reported that preferred nose velocities in Idaho streams ranged from 0.08 to 0.1 m/s with a maximum of 0.2 m/s, while Scherer et al. (1984) stated that in a Manitoba woodland stream, velocities between 0.1-0.2 m/s were preferred. According to Johnson et al. (1992) and Ford et al. (1995), young-of-the-year appear to prefer water velocities <0.1 m/s.

### Temperature

McCormick et al. (1972) stated that temperature is an important limiting factor for growth and distribution of young brook trout. For young-of-the-year, temperatures from 9.8 to 15.4°C were considered suitable, 12.4 to 15.4°C optimal, and temperatures greater than 18°C detrimental (McCormick et al. 1972; Peterson et al. 1979; Barton et al. 1985; Meisner 1990). In a laboratory study, the optimum temperature was determined to range from 8 to 12°C (Peterson et al. 1979). Depending upon the acclimatization temperature, the upper lethal limits are between 21 and 25.8°C (Brett 1940).

### Depth

Griffith (1972, northern Idaho) and Williams (1981, Quebec) reported brook trout alevins were usually found at depths of 25 to 50 cm. Young-of-the-year have been observed and/or captured at depths of 10 to 20 cm in a Manitoba stream (Scherer et al. 1984), 5-30 cm in a Pennsylvania stream (Johnson et al. 1992), 20 to 67 cm in three Ontario streams (Cunjak and Power 1986), and 14 to 73 cm in two Avalon Peninsula streams (Cunjak and Green 1983).

### Substrate

Upon emergence, young-of-the-year disperse into shallows along the edge of streams, in suitable eddies or even mid-stream in slower currents, over a gravel, cobble, rubble substrate (Johnson et al. 1992; Ford et al. 1995). They have also been reported in relatively silt-free areas over a mainly cobble, rubble, boulder substrate (Bustard and Narver 1975; Raleigh 1982; Cunjak and Power 1986), but have been found in areas containing sand and organic fines (Johnson et al. 1992). For streams in the United States, a relatively silt-free substrate within the range of 10 to 40 cm in diameter (cobble, rubble, and boulder), occupying more than 10% of the total habitat, is considered adequate for young-of-the-year and small juvenile brook trout (Raleigh 1982).

### Cover

In Wyoming streams, Wesche (1980) reported that young-of-the-year and small juveniles (<15 cm in length) were associated more with instream cover (mostly rubble substrate) than overhead stream bank cover, and that an area of cover at least 15% of the total stream width is required. Boussu (1954) reported that aquatic vegetation is an important form of cover for young salmonids. Cunjak and Green (1983) observed in two Avalon Peninsula streams that young-of-the-year and juveniles showed a strong preference for cover (where available), but that the presence of competing species and/or lack of available cover can result in shifts of habitat utilization.

Young-of-the-year usually overwinter in shallow, low velocity areas, seeking shelter under rubble (Everest 1972; Bustard and Narver 1975; Cunjak and Power 1986). Cunjak and Power (1986) investigating south western Ontario streams also found that during winter there was a preference for young-of-the-year to hold position beneath instream cover such as coarse substrates, vegetation, and debris. Bustard and Narver (1975) reported that use of smaller diameter rocks for cover during winter might result in increased mortality due to substrate shifting.

### 3.9.4.3 Juveniles

**Water Velocity**

The range of water velocities suitable for juveniles has been identified as 0-0.45 m/s, with an optimum range of 0.06-0.21 m/s (Jirka and Homa 1990). Although many juveniles will occupy the slowest available water (Wickham 1967; Wesche 1974), they have also been reported holding in velocities up to 1.5 m/s (Jirka and Homa 1990). Griffith (1972) reported mean nose velocities in an Idaho stream ranging from 0.08-0.09 m/s, with a maximum of 0.24 m/s. Cunjak and Power (1986) found juveniles in three southern Ontario streams occupied mean nose velocities ranging from 0.05 to 0.15 m/s in summer and 0.05 to 0.18 m/s in winter (range 0.02 to 0.23 m/s). Cunjak and Green (1983) reported mean nose velocities for juveniles in two Avalon Peninsula streams ranging from 0.01 to 0.49 m/s.

**Temperature**

Water temperature is a critical limiting factor for brook trout distribution (MacCrimmon and Campbell 1969), and it is generally accepted that temperature preferences do not differ between juveniles and adults (Jirka and Homa 1990). Temperatures in the range of 0 to 24°C are considered suitable for survival, but the optimum temperature range for feeding and growth is 11 to 16°C (Jirka and Homa 1990).

**Depth**

Depth preference is dependent on several factors including, fish size, season, and level of activity (Jirka and Homa 1990). In southern Ontario streams, Cunjak and Power (1986) found that smaller fish occupy shallower water than larger fish, and smaller fish will also use shallower water during winter. They reported juveniles were found at mean nose depths ranging from 36.7 to 91.9 cm in summer, and 42.4 to 95.4 cm in winter (Cunjak and Power 1986). Research findings to date have resulted in the acceptance of an optimal depth range for both juvenile and adult brook trout of 20 to 40 cm (Jirka and Homa 1990). Juveniles have been shown to occasionally seek depths up to 1.3 m as a means of escape or during foraging in the absence of predators and larger competitors (Jirka and Homa 1990) and during the winter, they have been shown to occupy slow, deep (>2 m) steadies (Cunjak and Power 1986). In Pennsylvania, 1+ individuals were found at depths ranging from 10 to 40 cm (Johnson et al. 1992).

**Substrate**

In the literature reviewed, information on substrate preference of juveniles was somewhat contradictory. In the Miramichi River, New Brunswick, Keenleyside (1962) reported that juveniles were found over a variety of substrates, ranging from clean gravel and cobble in turbulent waters to sandy bars near deeper pools. They were associated with a cobble/gravel substrate in western New York State (Kendall and Dence 1927; Dence 1928), while in the King's River Basin, California, Hanson et al. (1987) reported that a predominantly sandy substrate was preferred. Johnson et al. (1992) reported that juvenile brook trout from a northern Pennsylvania stream occupied areas with a large cobble/small boulder substrate. Scherer et al. (1984)

observed juveniles within a Manitoba woodland stream over a wide variety of substrates ranging from cobble and small boulders to sand and silt. The variation in substrate preferences within the literature indicates that other habitat variables, such as temperature, water velocity, depth, cover, and the presence or absence of predators or competitors may play an important role.

**Cover**

Brook trout are often found near cover, and this habitat variable may limit production in streams (Boussu 1954; Lewis 1969; Hunt 1971; Fausch and White 1981; Cunjak and Power 1986; 1987; Lambert and Hanson 1989). Wesche (1980) reported that in Wyoming streams, small juveniles (<15 cm in length) were associated more with instream cover (cobble, rubble, submerged vegetation, etc.) than overhead stream bank cover. Small juveniles (<15 cm in length) have been associated with cover in the form of undercut banks, surface water turbulence, rocky substrate, logs, large woody debris, brush cover, pools and overhanging vegetation (McPhail and Lindsey 1970; Wesche 1980; Raleigh 1982; Jirka and Homa 1990; Ford et al. 1995; Scruton et al. 2000). Raleigh (1982) concluded that an area of cover ≥15% of the total stream width is adequate for juveniles.

### 3.9.4.4 Adult

Although brook trout typically mature at 3 years of age, some individuals may mature at age 2 (Portt et al. 1988; Scott and Crossman 1998). Brook trout are relatively short-lived and seldom live longer than 5-8 years of age (Scott and Crossman 1998). Waters (1983) found that brook trout populations were often displaced by brown trout in lowland streams and Gibson (2002) stated that salmon parr have negative effects on brook trout in riffles.

**Water Velocity**

Adult water velocity preferences are dependent upon many factors including, age (size), presence/absence of cover, and season (Cunjak and Power 1986; Smith and Aceituno 1987; Jirka and Homa 1990). Griffith (1972) reported that nose velocities in Idaho streams usually ranged from 0.07-0.11 m/s, with a maximum of 0.25 m/s. He also found little difference between nose velocities among different age-classes. In a Wyoming study, 95% of all brook trout observed were associated with nose velocities of less than 0.15 m/s (Wesche 1974). Cunjak and Green (1983) observed mean nose velocities for over yearlings (which may be juveniles or adults, the only stipulation was that they had spent at least one year in the stream) in two Avalon Peninsula streams ranged from 0.08 to 0.2 m/s (range 0.01 to 0.49 m/s). Cunjak and Power (1986) reported that in southern Ontario streams, positions in winter were characterized by slower water velocities and greater overhead cover. During winter, brook trout appear to select areas with maximum velocities <0.15 m/s and pools with low current velocity are considered important (Chisholm et al. 1987).

There is a demonstrated relationship between the annual flow regime of a stream and the quality of brook trout habitat. The most critical period is typically the base flow (low flows during late summer to winter). A base flow ≥55% of the average annual daily flow is considered excellent, 25 to 50% fair, and <25% poor (Wesche 1974; Binns and Eiserman 1979; Wesche 1980; Raleigh

1982). Gibson (1993) stated that in an Avalon Peninsula stream, brook trout biomass had a negative relationship to maximum flood height, indicating that habitats with more stable stream flows had higher production.

### Temperature

The reported upper and lower temperature limits for adults vary; this most likely reflects local and regional acclimation differences. Hynes (1970) reported that the upper tolerable limit is raised approximately 1°C for every 7°C rise in acclimation temperature up to 18°C. Water temperature is a critical limiting factor for distribution (MacCrimmon and Campbell 1969), and it is generally accepted that temperature preferences do not differ between juveniles and adults (Jirka and Homa 1990). Temperatures in the range of 0 to 24°C are considered suitable for survival, but the optimum temperature range for feeding and growth ranges from 11 to 16°C (MacCrimmon and Campbell 1969; Jirka and Homa 1990). Cherry et al. (1977) reported that brook trout had a preferred water temperature around 16.0°C.

### Depth

Adult preference for water depth is dependent upon fish size, season, presence/absence of cover, and activity (feeding, spawning, etc.) (Jirka and Homa 1990). Brook trout are generally found at depths ranging from 6 to 90 cm, with an optimum range of 18 to 40 cm (Jirka and Homa 1990). Scherer et al. (1984) encountered adults at depths of 20 to 85 cm in a Manitoba woodland stream, while Chisholm et al. (1987) reported adults at depths up to 1.1 m in a Wyoming stream. Smith and Aceituno (1987) found that adults preferred a depth of 50 cm in a California stream. During winter, brook trout appear to select areas with maximum depths <50 cm (Chisholm et al. 1987).

### Substrate

In general, adults are encountered over the whole range of substrates from mud to bedrock, but are mainly associated with clean substrates ranging from gravel to boulder (Keenleyside 1962; Chisholm et al. 1987; Jirka and Homa 1990; Scruton et al. 2000). In a Pennsylvanian stream, adults were found most frequently over gravel substrates (Magoulick and Wilzbach 1997). During winter, brook trout were found predominantly in areas containing sand or silt substrate, however, some were found over rocky substrates (Chisholm et al. 1987).

### Cover

Adults are often associated with cover, which is sometimes considered a factor limiting trout production (Boussu 1954; Lewis 1969; Hunt 1971; Fausch and White 1981; Cunjak and Power 1986; Lambert and Hanson 1989). Cover can be provided by overhanging vegetation, submerged vegetation, undercut banks, instream objects (woody debris, roots, and large boulders etc.), rocky substrates, depth, and water surface turbidity (McPhail and Lindsey 1970; Giger 1973; Becker 1983; Raleigh 1982; Kozel and Hubert 1989; Ford et al. 1995).

Canopy cover is important in maintaining shade for stream temperature regulation and in providing allochthonous materials to the stream, however, too much shade can restrict primary productivity. About 50 to 75% midday shade is considered to be optimal for small brook trout streams, although shading becomes less important as stream gradient and size increases (Raleigh 1982). Enk (1977) reported that in two Michigan streams, trout biomass and number of adults were significantly correlated with bank cover. Cunjak and Green (1983) reported that in two Avalon Peninsula streams, as brook trout increase in size they tend to move from shallow stream margins to deeper water (pools) with undercut banks and other forms of cover.

## 3.9.5 Brown trout (*Salmo trutta*)

The brown trout is indigenous to Europe, North Africa and western Asia (MacCrimmon et al. 1970) and was introduced into North American waters in the late 1800's (Scott and Crossman 1998). They were first imported to Newfoundland from Scotland in 1886, with further importations from Germany and England in 1892 and 1906 (Andrews 1965). They have spread from their original introductions in ponds within the St. John's area and successful sea-run populations are widely distributed throughout eastern Newfoundland, including the Avalon and Burin peninsulas, Trinity Bay, and Bonavista Bay (Scott and Crossman 1964; O'Connell 1982; Gibson and Cunjak 1986).

Brown trout exist in both anadromous and freshwater resident forms (Scott and Scott 1988), however, since the stream life history characteristics of both are similar, for the purposes of this report they will be combined. Anadromous brown trout can spend two to four months or up to two or more years at sea before they migrate into rivers to spawn (Went 1962; Jensen 1968; O'Connell 1982; Jonsson and Gravem 1985; Ryan 1988; Scott and Scott 1988; Jonsson and Jonsson 2002). Upon returning to freshwater, brown trout often stray to places other than their river of origin (Ryan 1988).

Since brown trout are absent from certain rivers adjacent to areas having abundant brown trout populations, it would appear that distribution is dependent on a combination of climate, habitat variables, and water chemistry (Gibson and Cunjak 1986; Gibson 1988). Habitat requirements are similar to those of brook trout (Ryan 1988; Scott and Scott 1988; O'Connell and Dempson 1996), except brown trout have higher tolerances and will occupy streams or ponds with warmer and/or more turbid water (Scott and Scott 1988; Scott and Crossman 1998). For more information on lacustrine habitat requirements of brown trout, refer to Bradbury et al. (1999).

Raleigh et al. (1986) described optimal brown trout riverine habitat as being characterized by clear, cool to cold water; a relatively silt-free rocky substrate in riffle-run areas; a 50-70% pool to 30-50% riffle-run habitat combination with areas of slow, deep water; well-vegetated, stable stream banks; abundant instream cover; and relatively stable annual water flow and temperature regimes.

### 3.9.5.1 Spawning, Incubation, and Emergence

Brown trout have been reported to spawn from early October to mid-December (Kellett 1965; Liew 1969; Lee 1971; Wiseman 1971b; O'Connell 1982; Beard and Carline 1991; Scruton et al.

1997). They typically spawn in streams (Hansen 1975; Raleigh et al. 1986; Haraldstad and Jonsson 1983; Jonsson 1985; Jonsson and Gravem 1985; Ryan 1988; Scott and Scott 1988; Clapp et al. 1990), however, lake spawning along rocky shorelines has also been observed (Eddy and Surber 1960; Borgeson 1966; Daly 1968; Liew 1969; Braband et al. 2002).

The female digs a redd in the substrate (Haury et al. 1999), the eggs are deposited, fertilized by the male, and covered by the female with stones and gravel within minutes (Scott and Scott 1988). Females spawn only a portion of their eggs at a time so this procedure may be repeated a number of times until spawning is complete (Scott and Scott 1988). The area of redds and the size of the egg pocket are proportional to the size of the spawners (Ottaway et al. 1981; Crisp and Carling 1989), and the largest individuals spawn in the deepest areas with the highest water velocities (Ottaway et al. 1981). Large females also spawn on coarser gravel and bury their eggs deeper than smaller individuals (Fleming 1996).

**Water Velocity**

Water velocities over redd sites in areas outside Newfoundland have been reported to range from 0.10 to 0.75 m/s (Hooper 1973; Smith 1973; Waters 1976; Berg 1977; Reiser and Wesche 1977; Nihouarn 1983; Shirvell and Dungey 1983; Witzel and MacCrimmon 1983; Fragnoud 1987; Heggberget et al. 1988; Crisp and Carling 1989; Grost et al. 1990; Beard and Carline 1991). Raleigh et al. (1986) in developing a habitat suitability curve in the United States recommended a velocity tolerance range of 0.15 to 0.9 m/s and an optimal range of 0.4 to 0.7 m/s for spawning.

**Temperature**

Fall spawning has been observed at water temperatures of 6 to 7°C in English streams (Frost and Brown 1967; Mills 1971), 6 to 12.8°C in a California stream (Hooper 1973), 2 to 10.5°C in a French stream (Baglinière et al. 1979), and 3 to 13°C in southwest Ontario streams (Witzel and MacCrimmon 1983).

The following optimal temperature ranges have been reported for incubation and emergence: 7 to 12°C (Frost and Brown 1967), 6.6 to 12.8°C (Markus 1962), and 2 to 6°C (Alabaster and Lloyd 1980). Raleigh et al. (1986) in developing a habitat suitability index model for the United States suggested that optimal incubation temperature is 2 to 13°C, with a tolerance range of 0 to 15°C.

**Depth**

Water depths at redd sites have been reported in the range of 6.4 to 91.4 cm (Raleigh et al. 1986), including 28.3 to 60.3 cm in the Yellowstone River (Berg 1977); a mean of 45.7 cm in the Brule River, Wisconsin (O'Donnell and Churchill 1943); 6.4 to 18.3 cm (Reiser and Wesche 1977); 24.4 to 45.7 cm in Idaho (Waters 1976); a mean of 38.3 cm for large rivers in Sweden (Heggberget et al. 1988); 5 to 75 cm in New Zealand (Shirvall and Dungey 1983); a mean of 20.5 cm in eastern France (Fragnoud 1987); a mean of 16 cm in Wyoming streams (Grost et al. 1990); and 10.8 to 80.2 cm in southern Ontario streams (Witzel and MacCrimmon 1983). Reiser and Wesche (1977) postulate that depth, beyond a minimal depth of approximately 15 cm, does not significantly affect the selection of brown trout redds or subsequent embryo survival.

### Substrate

Raleigh et al. (1986) found that brown trout prefer a spawning substrate of 1 to 7 cm in diameter (mainly gravel), but will utilize substrates ranging from 0.3 to 10 cm (gravel, small cobble) (Stuart 1953; Frost and Brown 1967; Hooper 1973; Berg 1977; Reiser and Wesche 1977; Beard and Carline 1991). Witzel and MacCrimmon (1983) indicated that trout in southern Ontario streams preferred a mean substrate size of 6.9 cm in diameter (cobble). Heggeberget et al. (1988) reported a mean substrate particle size of 11.5 cm (cobble) for large rivers in Sweden, Shirvall and Dungey (1983) reported a mean substrate particle size of 14 cm (rubble) in New Zealand rivers, and Fragnoud (1987) and Nihouarn (1983) reported a substrate particle size range of 2 to 64 cm and 2 to 50 cm (gravel through boulder), respectively for rivers studied in France. Ottaway et al. (1981) concluded that brown trout will spawn in areas where the substrate is sufficiently fine to be moved.

The suitability of the substrate for emergence and survival of embryos depends upon both water velocity and dissolved oxygen concentration (Raleigh et al. 1986). Substrate size is important in determining survival to emergence, with survival decreasing as the amount of fine sediment increases (Witzel and MacCrimmon 1983). Based on the effects of fines on other salmonid species, Raleigh et al. (1986) postulated optimum spawning substrate conditions for brown trout are $\leq$5% fines with $\geq$30% fines resulting in low survival of embryos and emerging fry.

### Cover

Embryos overwinter within the interstitial redd gravels and emerge in the early spring (Raleigh et al. 1986). In south western Ontario streams, Witzel and MacCrimmon (1983) reported that redds were within 0.5, 1.0, and 1.5 m of cover (usually logs and tree branches) 68, 79, and 84% of the time, respectively. It was suggested that this nearby cover enhances the probability of survival of dispersed young-of-the-year. Baglinère et al. (1979) noted in the Scorff River, France, that brown trout redds were concentrated in undercut banks that provided protection during high flows.

### 3.9.5.2 Young-of-the-Year/Nursery

Eggs hatch in the spring usually between mid-April and mid-May (Raleigh et al. 1986; Ryan 1988; Scruton et al. 1997) and the larvae, called alevins, feed on the yolk which they carry in a sac underneath their belly for several weeks (Klemetsen et al. 2003). Alevins (~ 20 mm in TL) swim up from the gravel when most of the yolk is consumed and start feeding in or near the spawning area (Klemetsen et al. 2003). These alevins are generally stationary or move with weak swimming movements close to the bottom (Gaudin and Hèland 1995). After several days, swimming becomes more secure and they congregate in areas with moderate current, generally behind an obstacle such as a stone or large pebble (Hèland 1977; 1978). Thus, within a week of emergence, individuals have dispersed into suitable habitats (Elliot 1966; Mortensen 1977).

Young-of-the-year are aggressive and territorial from the first day of emergence (Kalleberg 1958; Mills 1971; Hèland 1999; Lahti et al. 2001). The first aggressive behaviour is expressed between young-of-the-year during confrontations while searching for holding positions or capturing prey (Gaudin and Hèland 1995). During the first summer, fry often remain in their natal stream (Elliot 1986), moving around to obtain food and find shelter against predators and high water currents (Heggenes and Traaen 1988; Hèland et al. 1995). During winter, Elliot (1986) observed that young-of-the-year tended to move from riffles to pools.

### Water Velocity

Gaudin and Hèland (1995) found that in both natural and artificial streams studied in France, young-of the-year preferred holding position in currents <0.20 m/s. Harris et al. (1992) reported that they preferred water velocities ranging from 0 to 0.18 m/s. Mäki-Petäys et al. (2000) observed in experimental flume tests conducted in Finland a preference for velocities of 0.3 m/s or less in summer and 0.2 m/s in winter. Cunjak and Power (1986) reported that in three Ontario streams, young-of-the-year occupied mean nose velocities of 0.14 m/s in summer and 0.02 to 0.05 m/s in winter. They also noted a trend over three years of observations that preferred velocities were lower in winter than in summer. Heggenes and Traaen (1988) noted in Norwegian rivers that as water temperature increased, preferred water velocities increased as well.

### Temperature

Markus (1962) reported that for hatchery-reared brown trout, young-of-the-year mortality was high at temperatures less than 4.5°C, while growth was best at 12.8°C. He proposed an optimum temperature range of 6.7 to 12.8°C. In Virginia streams, Brown (1973) reported that the optimal temperature for feeding ranged from 7 to 15°C. Temperatures <4.5°C have been found to inhibit dispersal and reduce aggressive behaviour of young-of-the-year in U.S. streams (Raleigh et al. 1986). Spass (1960) reported an upper lethal temperature of 25.5°C for European young-of-the-year.

### Depth

Young-of-the-year are usually found in shallow water, with an optimum depth between 10 and 30-40 cm (Lindroth 1955; Baglinière and Champigneulle 1982; Fragnoud 1987; Heggenes 1988a; Heggenes at al. 1998). They tend to occupy shallower water than juveniles and are often found near stream margins (Lindroth 1955; Jones 1975; Bohlin 1977; Harris 1991). This is particularly true at night when they move into shallow stream margins to avoid predation by larger fish (Harris et al. 1992). Cunjak and Power (1986) reported mean nose depths ranging from 42.0 to 46.2 cm in Ontario streams.

### Substrate

After emergence, young-of-the-year occupy mainly rocky substrates (Raleigh et al. 1986) and tend to prefer gravel and cobble substrates, while avoiding fines (Baglinière and Champigneulle 1982; Glova and Duncan 1985; Fragnoud 1987).

**Cover**

Euzenat and Fournel (1976) observed that redds in the Scorff River, France were located close to shelter ninety percent of the time. This shelter, in the form of undercut banks, submerged vegetation or still and deep areas provided critical cover for recently emerged young-of-the-year. In south western Ontario streams, Witzel and MacCrimmon (1983) reported that redds were within 0.5, 1.0, and 1.5 m of cover (usually logs and tree branches) 68, 79, and 84% of the time, respectively. Hartman (1963) observed in a stream aquarium that a substrate particle size of 10 to 40 cm (cobble, rubble and boulder) provides refuge and winter cover for young-of-the-year and smaller juveniles. In Idaho, Griffith and Smith (1993) reported that young-of-the-year seek cover under cobble and boulder substrates in shallow (<0.5 m) river margins during winter.

### 3.9.5.3 Juvenile

Many of the references reviewed considered the habitat of young-of-the-year and juveniles to be similar. However, confusion existed within the literature with respect to distinctions between young-of-the-year (also referred to as alevins or 0+), juveniles (also referred to as fry or 1+), and adults ($\geq$2+). Many authors made no distinction and simply combined all age classes, while others referred to the trout's life stage, but did not provide information with respect to age or length class within the study group.

Juveniles exhibit considerable variability in habitat utilization. In the Osa River, eastern Norway, juveniles migrate from their natal river to a larger river for feeding (Jonsson and Sandlund 1979). In this instance, trout use smaller tributaries for spawning and nursery grounds and migrate to a larger river for feeding. In three rivers within central Norway, juvenile brown trout were found most frequently in deeper (2.0-4.0 m) pools (Bremset and Berg 1997). This is consistent with the general understanding that brown trout prefer pool habitats to riffle habitats (Gibson 1966; Jones 1975), especially older individuals (Baglinière and Champigneulle 1982; Kennedy and Strange 1982; Heggenes et al. 1995). Others have found that young migrate from their natal stream into lakes as they grow (Arawomo 1981; Haraladstad and Jonsson 1983; Schei and Jonsson 1989; Forseth et al. 1999; Jonsson et al. 1999). Typically, in this situation feeding occurs mainly in the lakes, while spawning and rearing takes place within the inlets and outlets. Anadromous juveniles migrate to estuaries or coastal areas for feeding and return to freshwater for spawning and overwintering (Jensen 1968; Berg and Berg 1987; Jonsson and Jonsson 2002).

In spring, smolts and larger fish that spend the winter in fresh water often migrate to estuaries for feeding. In northern Norway, this downstream migration occurred mainly during April and May (Berg and Berg 1987; Berg and Jonsson 1989), early March into June for a Danish stream (Rasmussen 1986), end of April to mid-May in southern Sweden (Bohlin et al. 1993), and mid- to late May in mid-Norway (Hembre et al. 2001).

**Water Velocity**

Heggenes (1988a) observed in Norwegian streams that the nose velocity for juveniles is generally less than 0.2 m/s, with a range between 0.1 to 0.3 m/s (Heggenes and Saltveit 1990). However, Heggenes and Saltveit (1990) also noted that within the habitat occupied the mean column velocity is usually within the range of 0.2 to 0.5 m/s. In Wyoming streams, Wesche (1980) reported that juveniles prefer velocities less than 0.15 m/s. Greenberg et al. (1996) reported that in a Swedish river juveniles preferred water velocities <0.3 m/s. Glova and Duncan (1985) observed in New Zealand rivers that juveniles (>55 mm in length) occupied white water habitat with velocities greater than 0.3 m/s. Mäki-Petäys et al. (1997) observed in Finnish streams that juveniles (4-22 cm in length) occupied mean water velocities ranging from 0.1 to 0.8 m/s. They also noted that there were no significant differences in preferred velocities between size classes and that large juveniles preferred higher velocities in summer than winter. Cunjak and Power (1986) observed in southern Ontario streams that juveniles occupied mean nose velocities ranging from 0.05 to 0.17 m/s. Roussel et al. (1999) observed in a tributary of the River Scorff, France, that juvenile brown trout occupied deeper, slower flowing pools at night (mean velocity of 0.34 m/s) and shallower, fast flowing riffles during the day (mean velocity of 0.04 m/s). Gibson and Cunjak (1986) reported that in three rivers on the Avalon Peninsula of Newfoundland, the mean water velocity preferred by juveniles was 0.08 m/s with a range of 0.02 m/s (pools) to 0.25 m/s (riffles).

### Temperature

In laboratory experiments, Elliot (1975; 1981) found that the optimal temperature range for juveniles was 4-19°C, optimum growth occurred at 13°C, and mortality occurred above 25°C. Tebo (1975) reported that maximum growth occurred at 19°C during the North Carolina summer. Frost and Brown (1967) and Brown (1973) reported that good growth in Virginia steams occurred between 7 and 19°C, with optimal growth at 12°C. Spaas (1960) reported a mean upper short-term lethal temperature of 29°C for European juvenile brown trout, while Raleigh et al. (1986) determined the optimum temperature to be 7 to 19°C, with a range of 0 to 27°C.

In Finnish streams, Mäki-Petäys et al. (1997) observed a distinct winter habitat shift to deeper areas with slower water velocities when water temperatures dropped below 10°C, while Heggenes and Dokk (2001) found the switch to occur when temperatures dropped below 8°C and Greenberg et al. (1996) reported that it occurred as early as August in the Swedish River Vojmån at water temperatures of 12°C. They suggest that the temperature at which the winter habitat shift occurs may be related to population densities or other factors such as light intensities. Anadromous trout often migrate to sea during the fall and winter to overwinter. In Scotland, Pemberton (1976) found that brown trout migrated to sea in August where they remained until late spring, while in the River Imsa, Norway both mature and immature individuals migrated to sea from September throughout January (Jonsson and Jonsson 2002).

### Depth

Glova and Duncan (1985) reported that juveniles in a New Zealand stream preferred depths greater than 30 cm. Heggenes and Saltveit (1990) observed that juveniles in Norwegian streams could be found at depths ranging from 30 cm to 1 m, but avoided shallow areas with depths less than 20 cm. Heggenes (1988b) also reported a preference for depths of 10 to 25 cm, while Greenberg et al. (1996) found preferred depths of 30 to 90 cm in a Swedish stream. Roussel et al. (1999) reported that in the River Scorff, France, juveniles preferred water depths ranging from 25 to 45 cm during the day and 40 to 55 cm at night. Mäki-Petäys et al. (2000) observed in a Finnish stream, preferred depths of 5 to 35 cm, 40 to 60 cm, and 50 to 75 cm for small (4-9 cm length), medium (10-15 cm), and large (16-22 cm) juveniles, respectively. Cunjak and Power (1986) reported that in southern Ontario streams juveniles were observed at mean nose depths of 43.0 to 75.6 cm, with depth increasing during the winter. Gibson and Cunjak (1986) reported that juveniles in streams of the Avalon Peninsula of Newfoundland were found at mean depths ranging from 49.4 cm to 72.1 cm. They also reported that in the absence of competing species, brown trout utilized more available habitat and were commonly seen in shallow open water.

**Substrate**

There appeared to be a lot of confusion within the literature reviewed with respect to substrate preferences of juvenile brown trout. Many references loosely used terminology such as 'large boulders', 'gravel', 'pebble', etc. without quantifying substrate dimensions. It was also evident that there was a lot of variability with respect to habitat availability among streams. For example, one author may cite bedrock as a preferred substrate for a certain length class of trout, while in another paper the authors indicate there was no bedrock habitat available in their streams. Thus the preferred substrate reported in some cases may be more of a reflection of habitat availability as opposed to habitat preferences.

Greenberg et al. (1996) reported that in the River Vogmån, northern Sweden, small (2-6 cm) juveniles exhibited a weak preference for pebble substrate, medium-sized (7-11 cm) trout showed a weak preference for boulders, and large-sized (12-35 cm) individuals had a weak preference for gravel. The authors also note that both medium and large juveniles avoided sand and silt substrates. Mäki-Petäys et al. (1997) reported that in a Finnish stream during summer, all size classes preferred a relatively small substrate (small cobble to large gravel), but during winter, larger juveniles shifted their preference towards coarser substrates (large cobble to boulders). Bohlin (1977) observed in a Swedish stream that larger juveniles preferred pools with rocky substrates, while smaller juveniles (and young-of-the-year) preferred shallow, smooth-bottomed riffles. Heggenes and Saltveit (1990) observed in a Norwegian stream that juveniles were most commonly encountered above or upon cobble and boulder substrate.

**Cover**

Cunjak and Power (1986) reported that in southern Ontario streams juveniles were located beneath some type of cover (broken water, logs, boulders, macrophytes, undercut banks, etc.) 95% of the time in winter and summer. Greenberg et al. (1996) reported that in a Swedish stream, the use of overhead cover increased with increasing body size, while the use of instream cover decreased. Smaller juveniles (2-11 cm in length) were noted to be under or near instream cover, while larger (12-35 cm) juveniles were more commonly associated with overhead cover. They speculate that the preferred use of overhead cover by larger individuals may aid in avoiding terrestrial predation. Raleigh et al. (1986), based upon a comprehensive literature review, recommended that an area of cover $\geq$15% of the total stream area will provide adequate cover for juveniles. In contrast to the studies mentioned above, Mäki-Petäys et al. (1997) reported that in a Finnish stream, juveniles occupied habitats with little cover throughout the year, but particularly avoided cover during the winter. However, they did report a shift towards coarser substrates in winter, which will provide a fair degree of cover within the interstitial crevices. Bremset (2000) found that during winter, brown trout seek shelter in interstitial spaces in the substrate during daylight, but may hold position on or close to the bottom in slow flowing water during the night while feeding.

### 3.9.5.4 Adult

In the Great Lakes area, brown trout typically mature at 3 years of age (Minns et al. 1993), while in Newfoundland, they generally mature at 2-6 years of age (Liew 1969; Lee 1971; O'Connell 1982; MacKinnon 1998). In Newfoundland, brown trout rarely live longer than 10 years (Wiseman 1971b; Ryan 1988), although several anadromous individuals 11 to 13 years of age have been captured (Williams 1963; O'Connell 1982). Adults exhibit seasonal trends in habitat choices. Clapp et al. (1990) reported that in a Michigan stream, during the spring and summer months, they are usually found downstream in cold waters with suitable spawning substrates, while in the fall and winter they usually occupy upstream waters with slower velocities and deeper water (Clapp et al. 1990). They also observed that large (>400 mm) adults typically alternate between sites, spending two or three days in one area before moving, usually at night, to another section of the river.

#### Velocity

Most of the references reviewed state that older brown trout prefer relatively slow water velocities (≤0.15 m/s) (Bohlin 1977; Wesche 1980; Baglinière and Champigneulle 1982; Egglishaw and Shackley 1982; Heggenes 1988c; Clapp et al. 1990), however, they have also been observed in faster-flowing, turbulent areas (Karlström 1977; Baglinière and Champigneulle 1982). Cunjak and Power (1986) reported that in southern Ontario streams, adults occupied deeper and faster flowing habitats than juveniles. Therefore, although they prefer deep, slow water, if this habitat is limited they appear to shift to shallower, faster water. Näslund et al. (1998) reported that in a Swedish stream the presence of sympatric, intensely competing species, such as northern pike, can result in adults spending their life cycles in fast, riffle-type habitat. Gibson and Cunjak (1986) reported that in three streams on the Avalon Peninsula of Newfoundland, adults generally occurred in deeper, slower water than sympatric Atlantic salmon and younger brown trout. They also reported that in the absence of competing species, brown trout will utilize all available habitats.

#### Temperature

Water temperature is considered to be a critical factor in determining the suitability of a stream for habitation (Raleigh et al. 1986). The upper lethal temperature for adults has been determined as 27.2°C (Needham 1969) and 25°C (Charlon 1969). Optimal temperature requirements for growth and survival are 12 to 19°C (Frost and Brown 1967; Mills 1971; Brown 1973; Tebo 1975), with a temperature tolerance range of 0 to 27°C (Maciolek and Needham 1952; Mills 1971). Minns et al. (1993) reported a preferred water temperature of 21.1°C within the Great Lakes area. Laboratory tests conducted by Jensen et al. (1989) reported an optimal temperature range of 4 to 19°C for feeding and 13°C for growth. When water temperatures drop below 7°C, brown trout will seek shelter in slow-flowing, deep environments, with cover (Chapman and Bjornn 1969; Bjornn 1971; Cunjak and Power 1986).

### Depth

Adult depth preference is usually in the range of 20-50 cm, although they have been observed at depths greater than 1.0 m (Bohlin 1977; Egglishaw and Shackley 1977; Karlström 1977; Baglinière and Champigneulle 1982; Shirvell and Dungey 1983; Gibson and Cunjak 1986; Heggenes 1988c; Clapp et al. 1990). Shirvell and Dungey (1983) observed that they can change their depth preference depending upon their activity; adults were correlated with an optimal depth of 65 cm during feeding and 32 cm during spawning. Gibson and Cunjak (1986) reported that in three streams on the Avalon Peninsula, adults generally occurred in deeper, slower water than sympatric Atlantic salmon and younger brown trout. Clapp et al. (1990) reported that in a Michigan stream, the deepest sections (46 to 60 cm) were utilized as daytime refuge sites from high temperatures.

### Substrate

Within the literature reviewed, information on adult substrate preference was sparse and somewhat contradictory. It has been postulated (Rincon and Lobon-Cervia 1993) that water velocity, depth, and shelter are more important than substrate in determining habitat use among adults. Baglinière and Champigneulle (1982) and Fragnoud (1987) observed in French rivers that adults preferred a substrate of large stones and boulders. Jowett (1990) reported that in New Zealand rivers, there was a negative preference for sand substrate, while Clapp et al. (1990) reported that large (≥400 mm) brown trout in a Michigan stream were associated with silt.

### Cover

Cover and shelter is recognized as one of the essential components of adult habitat (Hartman 1963; Lewis 1969; Devore and White 1978; Cuinat 1980; Nielsen 1986; Raleigh et al. 1986; Wesche et al. 1987; Mesick 1988; Jowett 1990; Haury and Baglinière 1990) as they seek cover more than any other trout species (Raleigh et al. 1986). Instream cover includes deep water, riffle areas, submerged vegetation (macrophytes and terrestrial debris), boulders, undercut banks, and so on. Overhead cover can be provided by riparian vegetation (overhanging shoreline grasses, trees, and shrubs), while large trees that extend across a width of stream provide canopy cover.

In Danish streams, Nielsen (1986) reported that the amount of cover can account for more than 70% of the variation in brown trout density among streams. Boussu (1954) was able to manipulate adult abundance and biomass in a stream by adding or removing brush cover and undercut banks. Aarestrup and Jepsen (1998) observed in a Denmark river a preference for positions close to undercut banks. Clapp et al. (1990) reported that in a Michigan stream, sampling quadrants occupied by adults contained higher amounts of cover than control quadrants.

## 3.9.6 Lake trout (*Salvelinus namaycush*)

Lake trout, the largest of the charr, are widely distributed in northern North America, ranging in Canada from Labrador to British Columbia (Scott and Crossman 1998). Lake trout are found throughout southern Labrador, except for the southeast, but do not occur in Newfoundland (Ryan 1980; Black et al. 1986; Scott and Crossman 1998). In its southern range, the species is essentially an inhabitant of deep cold lakes, however, in the north it is abundant in shallow tundra lakes and large clear rivers (Loftus 1958; McPhail and Lindsey 1970; Morrow 1980; Scott and Crossman 1998).

#### 3.9.6.1 Spawning, Incubation, and Emergence

Throughout most of Canada, spawning occurs mainly in October, sometimes as early as September in the north or as late as November in the south (Scott and Crossman 1998). It is not uncommon for lake trout to spawn intermittently, every two or three years (McPhail and Lindsey 1970; Machniak 1975c; Marcus et al. 1984). Although spawning occurs mainly in lakes, riverine spawning has been recorded sporadically. For example, Dymond (1926) reported a lake trout in Lake Pinion, Ontario, which ascended a number of tributaries at spawning time. Loftus (1958) described spawning runs in the Montreal and Dog rivers and other tributaries of Lake Superior, while Paterson (1968) reported spawning populations in an Alberta lake outlet stream. Scott and Wheaton (1954) also reported lake trout spawning at the mouth of Hay River, Northwest Territories. The shortfall with most of the literature is that except for Loftus (1958), there were no details provided on spawning habitat requirements. In addition, a recent paper by Gunn (1995) questions some of the older Great Lake river spawning references as they were based on anecdotal information from fisherman regarding the presence of mature fish at these sites. Furthermore, the opportunity to study river spawning within the Great Lakes is now limited because most of the riverine stocks are extinct.

According to Loftus (1958), spawning was reported to occur within tributaries of Lake Superior from September to November over a substrate of large boulders interspersed with coarse gravel in eddies. Paterson (1968) reported spawning over substrates ranging from 3-8 cm in diameter (cobble) and at depths of 15-50 cm. Spawning has also been reported over mainly rocky substrates (gravel, cobble, rubble and boulders), while areas containing sand, silt, mud, detritus and vegetation were avoided (Machniak 1975c; Martin and Olver 1980; Marcus et al. 1984; Ford et al. 1995). Spawning usually occurs at depths <60 cm (Machniak 1975c; Martin and Olver 1980; Marcus et al. 1984). Spawning in lakes has been reported to occur within a temperature range of 8.9 to 13.9°C (Scott and Crossman 1998) at depths ranging from 15 cm to >100 m, but for the most part spawning occurs at depths between 5 and 10 m (Martin and Olver 1980; Thibodeau and Kelso 1990; Ford et al. 1995).

According to Loftus (1958), lake trout enter and leave rivers during the night, with most having returned to the lake by midnight, where they remain in deep water off the river mouth until the next evening. Paterson (1968) reported that lake trout in an Alberta lake entered the outlet stream at dusk, with peak spawning occurring between 9 and 10 p.m., and most of the trout had returned to the lake by morning. Based upon lake spawning accounts, males usually enter the spawning area first and clean the rubble and rocks of silt (Martin 1957). One or two males may spawn with a single female, or a group of males and females may spawn together, extruding eggs and sperm over a coarse substrate (Scott and Crossman 1998). Eggs fall between the substrate crevices where they will incubate for 4-5 months over the winter, usually hatching in mid-March or April in Labrador (Scruton et al. 1997; Scott and Crossman 1998). However, Paterson (1968) reported that a stream spawning population in Alberta hatched between December and March, and hatching in Cedres Brook, Quebec occurred before mid-January (Machniak 1975c).

#### 3.9.6.2 Young-of-the-Year/Nursery

Newly hatched larvae typically undergo early development within the protection of rocky substrate on the spawning grounds (Machniak 1975c). Within a month of emergence, fry begin moving from the spawning area towards their nursery lake (Paterson 1968; Machniak 1975c; Marcus et al. 1984; Ford et al. 1995). In lake spawning populations, they may remain in spawning areas for several weeks to three months before moving to deeper water when temperatures exceed 15 °C (Martin and Olver 1980; Peck 1982; Morrow 1980; Ford et al. 1995; Scott and Crossman 1998).

#### 3.9.6.3 Juvenile/Adult

Within the literature reviewed, it appears that juveniles and adults generally have similar habitat requirements. There were no references found that specifically described juvenile riverine habitat. Miller and Kennedy (1948) reported that juveniles were found in shallow water along a boulder shoreline of Great Bear Lake. DeRoche (1969) reported that juveniles in a Massachusetts lake were inshore, darting among boulders until water temperatures reached 7.8°C in May. When temperatures reached 10°C none were seen in shallow water, but were captured in trawls at depths up to 30 m.

According to Machniak (1975c), adults disperse widely from the spawning grounds once spawning is complete. Laboratory studies suggest that 12°C is the preferred temperature of adults, with a range from 8 to 15°C (Johnson 1975) and an upper lethal limit of 23.5°C (Gibson and Fry 1954). According to Petersen et al. (1979), lake trout have a preferred temperature of 11.0°C.

Sexual maturity is usually attained by age 6 or 7 (Scott and Crossman 1998). In Labrador, lake trout have been reported to mature at 6 to 11 years of age (Bruce and Parsons 1979; Ryan 1980; Bruce 1984), while in the Great Lakes area sexual maturity usually occurs by age 5 (Portt et al. 1988).

### 3.9.7 Lake whitefish (*Coregonus clupeaformis*)

Lake whitefish are widely distributed throughout North America from the Atlantic coast westward across Canada and the northern United States, to British Columbia, the Yukon Territory, and Alaska (Scott and Crossman 1998). They are distributed throughout southern Labrador, (Bruce 1974; Parsons 1975; Beak Consultants Ltd. 1979; Black et al. 1986; Scott and Crossman 1998; LGL Limited 1999), but are apparently absent from the Fraser River and more northern areas (Bruce et al. 1979). In Labrador, a slow growing, early maturing dwarf form of the species has been sporadically reported (Bruce 1975a; b; 1984; Parsons 1975; Bruce and Parsons 1979; Ryan 1980). For the purposes of this report, the habitat requirements of both the normal and dwarf forms were combined.

Lake whitefish are not native to the island of Newfoundland (Scott and Crossman 1998), but were introduced into Hogan's Pond and Murray's Pond on the Avalon Peninsula in 1886 (Chen 1968). Scott and Crossman (1964) reported that in 1960, lake whitefish were captured in Hogan's Pond and adjoining Mitchell's Pond, indicating that not only was the original introduction a success, but the species managed to naturally propagate to another area.

Although lake whitefish are primarily lake dwellers, they may also be present in large rivers and brackish water (McPhail and Lindsey 1970; Ford et al. 1995; Scott and Crossman 1998). Spawning occurs primarily in lakes, but also in rivers and smaller tributary streams (Bryan and Kato 1975; Machniak 1975a; Ford et al. 1995). Although the usage of riverine habitat is commonly mentioned in the literature, there is very little information presented on specific habitat requirements. Given the general lack of information, the following summary was in part based upon research carried out in lakes. For a more detailed review of the lacustrine habitat requirements, refer to Bradbury et al. (1999).

### 3.9.7.1 Spawning, Incubation, and Emergence

Spawning typically occurs between October and December, although the spawning season can extend from mid-September to late January throughout its geographic range, with northern populations generally spawning earlier (Lindsey et al. 1970; Machniak 1975a; Ford et al. 1995; Scruton et al. 1997). In Labrador, according to Scruton et al. (1997) spawning occurs from mid-September to the end of October, while Ryan (1980) reported that it occurs from October to November. Spawning duration is usually about one week, but can be spread out as long as a month (Machniak 1975a). In extreme northern latitudes, spawning may be intermittent, only occurring every 2-3 years (Scott and Crossman 1998), depending upon trophic conditions and length of the growing season (Kennedy 1953; Johnson 1976; Ford et al. 1995).

Lake whitefish undertake migrations to spawning grounds, ascending rivers or moving into the shallows of lakes when water temperatures cool to 4.5-10°C (MacKay 1963; Ford et al. 1995). There is some evidence that lake whitefish home to the same spawning grounds year after year (Machniak 1975a; Ford et al. 1995). In Labrador, spawning migrations are reported to occur from early September to mid-October (Scruton et al. 1997). River spawners generally utilize shallow (0.1 to 1.0 m) (Ford et al. 1995) riffles or rapids with a gravel/cobble substrate (Hinks 1943; Fabricius 1950; Fenderson 1964; Machniak 1975a). Although sand provides a suitable spawning substrate in lakes (McCrimmon 1956; Bidgood 1972) it has not been associated with river spawning (Machniak 1975a). Mud substrates are generally avoided by both lake and river spawners (Ford et al. 1995), however, lake whitefish in the Yukon have been observed spawning over silt and emergent vegetation in water which had little current and was 2.0-2.5 m deep (Bryan and Kato 1975). Fabricius (1950) reported that the flexibility of spawning locations (and the ability to switch from lakes to rivers, if necessary) indicates spawning is more closely linked to substrate type than water flow.

Because spawning occurs after dark, there is limited information available on spawning behaviour. Females randomly broadcast eggs over the bottom, which are then fertilized by males (Hart 1930, Lake Ontario; Morrow 1980; Scott and Crossman 1998). Adults typically move downstream after spawning and the eggs are left unattended to incubate and hatch the following spring (Reist and Bond 1988). Relatively low incubation temperatures ranging from 0.5 to 12°C have been reported for successful egg development (Ford et al. 1995). Optimum temperatures for incubation have been reported in the range of 4 to 6°C (Tait 1973) and 6°C (Brooke 1975). Hatching will not occur at temperatures above 12°C (Price 1940; Tait 1973; Brooke 1975). Brooke (1975) reported median hatch occurred in 42 days at 10°C and 185 days at 0.5°C. In Labrador, incubation occurs from mid-September to mid-June and hatching from mid-May to mid-June (Scruton et al. 1997).

#### 3.9.7.2 Young-of-the-Year/Nursery/Juvenile

Larvae are free-swimming and exhibit great mobility immediately after hatching. In Lake Huron, Faber (1970) observed larvae congregated along steep shorelines at depths less than 10 m, while Reckahn (1970) reported them at depths of 0.3 to 1 m near aquatic vegetation. Larval whitefish generally leave shallow inshore waters by early summer and move into deeper water (Scott and Crossman 1998). Reckahn (1970) and Hoagman (1973) reported that larvae tolerate temperatures between 12 and 20°C, with an optimum of approximately 14°C, while Coutant (1977) reported an upper lethal temperature of 26.6°C for juveniles.

In the Mackenzie River in northwestern Canada, most young-of-the-year are quickly displaced downstream by spring floods, reaching the delta or estuary by late May or June (Hatfield et al. 1972; Reist and Bond 1988). The delta lakes and channels, estuaries, coastal areas and backwater eddies of the Mackenzie River are the primary nursery areas utilized by young (Jessop and Lilley 1975; Bond and Erickson 1985; Reist and Bond 1988).

#### 3.9.7.3 Adult

Comparison of the growth rates in different regions of North America have shown that lake whitefish grow faster in the southern portion of their range (Van Oosten and Hile 1949; Kennedy 1953) than in northern latitudes (Rawson 1947; Kennedy 1954; Healey 1975). The preferred temperature range is from 8 to 14°C, with optimum growth at 11.9°C (Qadri 1968; Coutant 1977).

Age and size at maturity varies among populations depending on degree of harvesting by commercial and recreational fisheries, latitude, and productivity of the water body (Healey 1975). Typically, individuals from harvested populations grow faster and mature sooner than unexploited populations (Healey 1975). Lawrence et al. (1984) found that anadromous lake whitefish grow slower and do not live as long as resident populations. In all populations, males usually mature at a younger age, and die earlier than females (Scott and Crossman 1998). The earliest mature male and female whitefish (age 2 and 3, respectively) were reported from Lake Michigan (Mraz 1964) and Lake Eerie (Van Oosten and Hile 1949). In Labrador, whitefish from the lower Churchill River, Orma Lake and Michikamau Lake have been reported to mature at age 5 (Ryan 1980; Bruce 1984). Populations of dwarf lake whitefish known to occupy Gabbro and Ossokmanuan lakes in southwestern Labrador were approximately 60% mature at age 2 (Bruce 1984). The oldest recorded individual was estimated to be 28 years of age (Kennedy 1963), however, 16 years is the most commonly observed maximum age (Ford et al. 1995; Scott and Crossman 1998). The maximum reported age from the Lower Churchill River was 21 years (Ryan 1980).

Outside the spawning period, adults appear to show no preference for substrate type (Ford et al. 1995). Within the Mackenzie River watershed, adults have been found to overwinter at depths of 0.6-20 m (Jessop and Lilley 1975).

### 3.9.8 Pink salmon (*Oncorhynchus gorbuscha*)

The anadromous pink salmon is native to the Pacific and Arctic oceans, the Bering and Okhotsk seas, and the Sea of Japan (Scott and Crossman 1998). Transplants from southern British Columbia to the North Harbour River, St. Mary's Bay, Newfoundland were initiated in 1959 (Blair 1968) and by 1966 over 15 million eggs had been transplanted (Lear 1975). Initially, while transplants were still occurring, yearly adult returns were encouraging, however, since 1969 the returns of the progeny of naturally spawning fish has steadily declined (Lear 1975). By 1978-79 there were no recorded spawning adults returning to the North Harbour River (Dempson 1980).

Since the late 1960's there have been sporadic reports of pink salmon captured in the commercial Arctic charr fisheries of northern Labrador (Lear 1975; Dempson 1980). It is not known whether these fish are strays from the North Harbour River stocking program or a Russian transplantation program initiated in 1956 in the Baltic and White seas (Kossov et al. 1960; Lear 1975; Dempson 1980). Although the North Harbour River stocking program has been deemed a failure, and there have been no recent records in Newfoundland (R. Porter, 2001, Fisheries and Oceans Canada, St. John's, NL. Pers. Comm.), it is possible that isolated populations of naturally producing pink salmon may exist in certain areas of the province (Dempson 1980).

#### 3.9.8.1 Spawning, Incubation, and Emergence

Although some adults return to their natal rivers to spawn (Sheridan 1962), the rate of straying among pink salmon is believed to be much higher than in any other species of salmon (Bonar et al. 1989). Adults which return to their natal rivers usually do so between June and September (Aro and Shepard 1967), when water temperatures range from 8 to 14°C (Pritchard 1939; Hunter 1959) and flows are above normal (Pritchard 1939). Although spawning usually takes place in freshwater close to the sea or in intertidal areas (Bonar et al. 1989) as upstream migration is usually limited by their inability to navigate over steep falls or high velocity stream sections (Heard 1991), it has also been commonly reported between 70 to 500 km upstream in large rivers (Godfrey et al. 1954; Scott and Crossman 1998).

Spawning usually occurs from mid-July to late October (Sheridan 1962; Neave et al. 1967; Kwain and Lawrie 1981; Scott and Crossman 1998) over gravel/cobble substrates ranging in diameter from 1.3 to 10.2 cm (Lucas 1959; Collings 1972), at depths of 15 to 53 cm (Hourston and MacKinnon 1957), water velocities of 0.2-1.0 m/s (Collings 1972), and water temperatures between 7.2 and 12.8°C (Reiser and Bjornn 1979b). In the Steel River, a tributary of Lake Superior, nests were located at the upstream end of riffles over pebble/gravel substrates, at depths of 22-110 cm, and water velocities ranging from 0.05-0.16 m/s (Kwain and Lawrie 1981).

McNeil and Ahnell (1964) reported that spawning beds were comprised of cobble (54%), gravel (32%) and sand (14%) in south eastern Alaska. According to Heard (1991), pink salmon typically avoid spawning in quiet deep water, pools, areas of slow current or heavily silted or mud-covered substrates.

During spawning, females, guarded by dominant males, prepare redds by displacing gravel with vigorous tail movements (Scott and Crossman 1998). Eggs and sperm are deposited in the redd, which is then partially covered by gravel (Scott and Crossman 1998). Females may construct more than one nest and males may spawn with more than one female (Wickett 1959; Scott and Crossman 1998). Females will usually guard the nest as long as they are able, although spawning adults usually die within a few days or weeks of spawning (Neave 1966; Heard 1991; Scott and Crossman 1998).

Incubation times are temperature dependent (Carl et al. 1959) with hatching occurring from late December to late February (Neave 1966; Scott and Crossman 1998) within a preferred temperature range of 4.4 to 13.3°C (Reiser and Bjornn 1979b).

### 3.9.8.2 Young-of-the-Year/Nursery

After hatching, the alevins remain in the substrate for several weeks until the yolk sac is absorbed (Bonar et al. 1989). Emergence may occur as early as February, but peak emergence usually occurs during April and May (Neave 1966). Immediately after emergence, young-of-the-year begin to move downstream towards the sea (Levy and Northcote 1982; Scott and Crossman 1998). Migration usually occurs at night, although schools have been observed moving downstream during daylight hours (Scott and Crossman 1998). Some may remain in fresh water for several months before finally moving to the open sea (Levy and Northcote 1982; Scott and Crossman 1998).

At sea, active migration is interspersed with longer inactive periods (Healey 1967). It has been theorized that migration at sea may be related to salinity gradients (Baggerman 1960; McInerney 1964; Leggett 1977) or the use of tidal flows and food gradients (Hurley and Woodall 1968; Leggett 1977). By the fall, young-of-the-year are usually 10 to 20 km offshore (Neave 1966). The upper lethal water temperature has been determined as 23.9°C, with a preferred range of 12 to 14°C (Brett 1952).

### 3.9.8.3 Juvenile/Adult

In an Ontario tributary of Lake Superior, most 2 and 3 year old pink salmon were caught at or near the water surface at depths <10 m, where they appeared to be opportunistically feeding (Kwain and Lawrie 1981).

In the marine environment off British Columbia, pink salmon generally move northward, migrating rapidly up to 850 km offshore (Hart 1973). The distribution at sea is not well known; gillnet and longline catches are usually made at depths of 6 to 7 m although some have been caught at depths up to 36 m (Manzer and LeBrasseur 1959; Neave 1953; 1966). The upper lethal water temperature is 25.8°C, with a preferred range of 5.6 to 14.6°C and an optimal temperature of 10.1°C. Countant (1977) reported that pink salmon have a preferred water temperature of 11.7°C. After spending about 18 months at sea, adults begin to return to natal streams to spawn (Bonar et al. 1989). Occasionally, high current velocities in excess of 2.1 m/s may exceed the swimming ability of ascending adults (Krueger 1981).

Pink salmon usually mature at 2 years of age, although 3-year-old spawners have been occasionally reported (Anas 1959; Turner and Bilton 1968; Alexandersdottir and Mathisen 1983).

### 3.9.9 Rainbow trout (*Oncorhynchus mykiss*)

Rainbow trout were introduced into eastern North America (MacCrimmon 1971; MacCrimmon and Gots 1972; Scott and Scott 1988). The first recorded introduction in Newfoundland occurred in 1887 when trout from California were placed into Long Pond on the Avalon Peninsula (Frost 1938; Scott and Crossman 1964). Stocking of Avalon Peninsula ponds and other areas of Newfoundland including Notre Dame Bay and the Corner Brook area continued sporadically into the early 1900's (Scott and Crossman 1964; Andrews 1965; Chadwick and Bruce 1981; Porter 2000).

Established freshwater resident populations have been reported from several small watersheds on the Avalon Peninsula, four small streams near Clarenville, Shalloway Pond Brook in Placentia Bay, and a watershed at Tilt Cove on the Baie Verte Peninsula (Porter 2000). The populations within Shalloway Pond Brook and the Clarenville streams are known to have an anadromous component (Porter 2000). Populations reported from the south and west coasts of Newfoundland (Dempson et al. 1999; 2000) are thought to be related to escapements from estuarine aquaculture operations in Nova Scotia and Bay d'Espoir and do not constitute naturally reproducing populations (Porter 2000). Mullins and Porter (2002) reported a small population of rainbow trout in Trout River, which is the first confirmed rainbow trout population in western Newfoundland. There are no records of rainbow trout occurring in Labrador.

Rainbow trout can be subdivided into three basic ecological forms: (1) anadromous or steelhead; (2) resident stream; and (3) resident lake or reservoir dwelling (Raleigh et al. 1984). All three forms utilize streams and rivers for spawning. For a description of the lacustrine habitat requirements of rainbow trout, refer to Bradbury et al. (1999). The freshwater habitat requirements of stream dwelling trout and steelhead trout are essentially the same (Raleigh et al. 1984) and will be combined for the purposes of this review. Any differences in habitat requirements will be noted in the appropriate sections.

Rainbow trout are commonly reported as the least acid resistant of all salmonids; their lower tolerance limit is a pH of 5.5-6.0 (Grande et al. 1978). MacCrimmon (1971) has suggested that low pH may be the reason for unsuccessful introductions of rainbow trout in certain parts of North America and Europe. From Raleigh and Duff (1980): "Optimal rainbow trout habitat is characterized by clear, cold water; a silt free rocky substrate in riffle-run areas; an approximately 1:1 pool-to-riffle ratio, with areas of slow, deep water; well vegetated stream banks; abundant instream cover; and relatively stable water flow, temperature regimes, and stream banks."

### 3.9.9.1 Spawning, Incubation, and Emergence

Steelhead and lake-dwelling rainbow trout migrate from the sea and lakes, respectively into their natal streams to spawn (Greeley 1933; Scott and Crossman 1998). Throughout its native range, spawning occurs from January to July depending upon location (Raleigh et al. 1984) and spawning of certain hatchery-reared strains can occur at any time of the year (Behnke 1979). Unlike other native salmonid species in Newfoundland that spawn in the fall, rainbow trout typically spawn in the spring from late March to mid-May depending upon location and weather conditions (Frost 1938; 1940; Scruton et al. 1997).

Spawning has been reported in small tributary streams, larger streams, and lakes (Lindsey et al. 1959; Hartman et al. 1962; Scott and Crossman 1998). Preferred spawning sites are usually characterized by fine gravel in a riffle above a pool. The female excavates a redd in the gravel, deposits eggs, which are fertilized by an attendant and aggressive male, and then covers them with displaced gravel (Scott and Scott 1988; Scott and Crossman 1998). The female may repeat this pattern a number of times with the same or different males (Scott and Scott 1988). In Newfoundland, depending upon location and weather conditions, egg incubation occurs from mid-April to the end of June, and hatching occurs from mid-June to mid-August (Scruton et al. 1997; Scott and Crossman 1998).

#### Water Velocity

Withler (1966) reported that for Pacific coast steelhead trout, a freshet condition is usually required to initiate an upstream spawning migration. Hanel (1971) observed in an Oregon river that steelhead trout only migrated upstream when water velocities were above seasonal levels. Reiser and Bjornn (1979a) state that water velocities of 3.0 to 4.0 m/s or greater may hinder upstream migrations. Raleigh et al. (1984) suggested an optimal water velocity range of 0.3 to 0.9 m/s for spawning. The optimal water velocity above redds is between 0.3 and 0.7 m/s and velocities <0.1 m/s or >0.9 m/s are considered unsuitable (Delisle and Eliason 1961; Thompson 1972; Hooper 1973; Raleigh et al. 1984).

#### Temperature

In Oregon, upstream steelhead migration ceased at water temperatures outside the range of 4 to 18°C (Hanel 1971). Reiser and Bjornn (1979a) report that a sudden drop in water temperature may cause spawning activity to cease. Reingold (1968) reported that in an Oregon stream, water temperatures of 2 to 10°C delayed ripening of adults and impaired the viability of eggs. Scott and Crossman (1998) stated that spawning usually occurs between 10 and 15.5°C. Egg incubation time varies inversely with temperature, with hatching usually occurring within 4 to 7 weeks (Scott and Crossman 1998). Hatching occurs in 19 days at 15°C, 31 days at 10°C, and 80 days at 5°C (Embody 1934). Calhoun (1966) found that a water temperature of 7 to 13°C was suitable, while 11°C was optimal for egg incubation.

### Depth

Thompson (1972) reported that a minimum depth of 18 cm was required for steelhead spawning migration. Bovee (1978) reported that steelhead most commonly spawn at depths averaging 36 cm within a range of 15 to 61 cm. Based upon a literature review, Raleigh et al. (1984) suggested a spawning depth preference ranging from 15 cm to 2.5 m.

### Substrate

McPhail and Lindsey (1970) reported that rainbow trout in north western Canada usually spawn in gravel areas at the head of riffle areas just below pools. Optimal spawning substrate size is ultimately dependent upon the size of the spawners. Orcutt et al. (1968) reported that rainbow trout redds in Idaho streams were located in gravel 1.5 to 6.0 cm in diameter for trout <50 cm in length and substrates ranging from 1.5 to 10 cm in diameter (gravel/cobble) for trout >50 cm in length. Suitable incubation substrate has been reported to range from 0.3 to 10.0 cm in diameter with less than 5% fines (Delisle and Eliason 1961; McNeil and Ahnell 1964; Orcutt et al. 1968; Hooper 1973; Duff 1980; Raleigh et al. 1984).

### Cover

Within the literature reviewed, there was no mention of the importance of cover to spawning. However, it is reasonable to assume that the presence of instream or riparian cover assists in maintaining cool water temperatures within spawning tributaries, aids in bank stabilization (thereby reducing potential sedimentation), and probably functions to some degree in predator protection.

## 3.9.9.2 Young-of-the-Year/Nursery

Young-of the-year remain in the gravel for about two weeks after hatching (Scott and Crossman 1998) and emerge 45 to 75 days after egg fertilization, depending upon water temperatures (Calhoun 1944; Lea 1968). After emergence, they move from spawning to rearing/riffle areas using one of three different strategies, including: (i) movement downstream to a larger river, lake, or ocean; (ii) movement upstream from an outlet river to a lake; and (iii) dispersion within the spawning stream to rearing areas of low velocity and cover (Raleigh and Chapman 1971; Scott and Crossman 1998). Lake-dwelling trout may return to the lake immediately, wait until the fall, or spend 1-3 years in the stream before migrating (Scott and Crossman 1998). Stream residents remain within their respective streams, while steelheads usually migrate to sea after 2-4 years (Raleigh et al. 1984; Scott and Crossman 1998).

### Water Velocity

Young-of-the-year in streams prefer shallower water and lower velocities than the other life stages (Miller 1957; Horner and Bjornn 1976). Velocities up to 0.3 m/s have reportedly been used, however, velocities less than 0.08 m/s are preferred (Griffith 1972, Idaho; Horner and Bjornn 1976, Idaho). Johnson and Kucera (1985) reported that in Idaho, steelhead trout were found at stream velocities <0.2 m/s. Cunjak and Green (1983) reported that in three Avalon

Peninsula streams, rainbow trout were encountered at nose velocities from 0.02 to 0.38 m/s (mean 0.16 m/s). In a California stream, Baltz et al. (1991) reported that young-of-the-year preferred mean velocities of 0.06 m/s.

### Temperature

Bell (1973) reported that the preferred water temperature for steelhead trout ranged from 7.2 to 14.5°C, with an optimum of 10°C and an upper lethal limit of 23.9°C. Mantelman (1958, Minnesota) reported a preferred temperature range of 13 to 19°C. In British Columbia streams, Ford et al. (1995) reported that rainbow trout preferred an optimal temperature range of 10 to 14°C, with an upper lethal temperature of about 24°C.

### Depth

In three Avalon Peninsula streams, young-of-the-year were encountered at nose depths ranging from 18-69 cm (mean 37 cm) (Cunjak and Green 1983). Griffith (1972) observed in Oregon streams that young-of-the-year preferred shallower water (8 to 36 cm deep), stayed closer to refuge areas than adults, and moved to deeper, faster water as they grew. Johnson and Kucera (1985) and Everest and Chapman (1972) reported that in Idaho streams, steelhead trout were found at water depths <20 cm. Baltz et al. (1991) reported that young-of-the-year rainbow trout in California streams were encountered at mean depths of 23 cm. Bustard and Narver (1975) stated that resident rainbow trout overwinter in shallow areas of low velocity near stream margins. A pool area of 40 to 60% is assumed to provide optimal habitat.

### Substrate

Young-of-the-year rainbow trout remain within the spawning gravel for about two weeks after hatching (Scott and Crossman 1998). For overwintering purposes, Hartman (1965) and Everest and Chapman (1972) reported that young-of-the-year and small juveniles require substrates ranging from 10 to 40 cm in diameter (cobble, rubble, boulder) and use of smaller substrates may be detrimental to survival due to the increased potential for substrate shifting (Bustard and Narver 1975). In Idaho, Johnson and Kucera (1985) reported that steelhead trout in streams underwent a transition to larger substrates in the fall/winter. According to Raleigh et al. (1984), an area of suitable substrate comprising more than 10% of the total habitat is considered to be sufficient and presence of more than 10% fines within the substrate greatly reduces its value. Bradford and Higgins (2001) reported that in British Columbia, as light levels fell to night time levels, young-of-the-year moved to stream margins and were often resting on sand or silt substrates.

### Cover

After emergence, cover is critical for survival and is usually provided by interstices between rocks, vegetation (aquatic and riparian), submerged debris and increased depth or surface turbulence (Everest and Chapman 1972; Griffith 1972; Raleigh et al. 1984). Griffith (1972) reported that rainbow trout are usually encountered within 1 m of refuge areas. During winter, Everest and Chapman (1972) found that juvenile rainbow trout in two Idaho streams were encountered 15 to 30 cm deep in the substrate, while Bustard (1973) and Bustard and Narver (1975) reported that young-of-the-year were associated with rubble within shallow, low velocity areas of a British Columbia stream.

### 3.9.9.3 Juvenile/Adult

Since the habitat requirements of both juveniles and adults are similar (Raleigh et al. 1984; Barnhart 1986), they were combined for the purpose of this report and differentiated where appropriate. It is important to note that the ecological niches of juvenile rainbow trout and Atlantic salmon are similar; each prefers riffle habitats within steep gradient, coldwater streams (Keenleyside 1962; Hartman 1965; Gibson 1966; Everest and Chapman 1972). Consequently, rainbow trout have been known to compete with Atlantic salmon, sometimes displacing them from pools (Gibson 1981; Hearn and Kynard 1986). Gibson (1981) reported that juvenile rainbow trout were more aggressive than juvenile Atlantic salmon and were able to displace individuals of similar or slightly larger size from preferred locations. Larson and Moore (1985) provided evidence that rainbow trout also displaced brook trout to headwater reaches in many southern Appalachian streams.

Sexual maturity is usually attained at 3 to 5 years of age, with males often maturing a year earlier than females (Scott and Scott 1988; Scott and Crossman 1998). In Newfoundland, rainbow trout usually mature at 3 to 4 years of age (Lee 1971). The minimum size of sexually mature rainbow trout captured in Trout River was 180 mm (Mullins and Porter 2002), which is consistent with values for other populations in Newfoundland of 203-254 mm (Scott and Crossman 1964) and 150-250 mm (Scott and Scott 1988).

#### Water Velocity

Cunjak and Green (1983) reported that in three streams on the Avalon Peninsula, Newfoundland, over yearling trout were observed at nose velocities averaging 0.25 m/s, with a range from 0.02 to 0.69 m/s. Raleigh et al. (1984) and Rose (1986) stated that larger juveniles (5 to 13 cm in TL) mainly occupy water velocities between 0.10-0.12 m/s and a maximum of 0.22 m/s. Baltz et al. (1991) reported that in a California stream, juvenile and adult rainbow trout preferred mean velocities of 0.11 and 0.15 m/s, respectively, while in a Washington stream, Beecher et al. (1993) found that steelhead parr (~7.5-20 cm in TL) occupied velocities ranging from 0.21-0.27 m/s. The general pattern is that within any given system the older, larger fish prefer areas with higher water velocities. Adult steelheads prefer stream flows above normal seasonal levels (freshet) during upstream migrations (Withler 1966; Hanel 1971; Everest 1973).

#### Temperature

Metabolic rates of juvenile rainbow trout are highest at temperatures between 11 and 21°C, with an optimal temperature between 15 and 20°C (Dickson and Kramer 1971). Wagner (1974) and Adams et al. (1975) reported that in juvenile steelhead streams, water temperatures should stay below 13°C (optimum 7 to 10°C) from March until June in order for smoltification to occur. In streams of the Pacific Northwest it has been observed that juvenile steelhead become inactive and hide in available cover when water temperatures drop below 4°C (Chapman and Bjornn 1969; Bustard and Narver 1975).

The upper and lower lethal temperatures for adult rainbow trout are 25 and 0°C, respectively (Black 1953; Lagler 1956; McAfee 1966b; Bidgood and Berst 1969; Hokanson et al. 1977). Growth in the laboratory has been shown to cease at 23°C (Hokanson et al. 1977). Stream-dwelling rainbow trout select temperatures between 12 and 19.3°C (Garside and Tait 1958; Bell 1973; Cherry et al. 1977; McCauley et al. 1977), with most activity occurring between 15 and 20°C (Dickson and Kramer 1971). When the temperature preference (<18°C) of lake-dwelling rainbow trout (May 1973) is factored in, the optimal temperature range of adult rainbow trout is assumed to be within the range of 12 to 18°C, with optimal growth at 10 to 14°C (Raleigh et al. 1984; Carlander 1969). In Ontario lakes, Portt et al. (1988) reported that rainbow trout have a preferred water temperature of 11.3°C.

### Depth

Baltz et al. (1991) reported that juvenile and adult rainbow trout in California streams were encountered at mean depths of 44 and 47 cm, respectively, while Everest and Chapman (1972) reported that in two Idaho streams, most yearling steelhead occupied riffles 60-75 cm deep. Bovee (1978) reported that juvenile steelhead usually occur at water depths of 25 to 50 cm. Wesche (1980) found that in a large Wyoming stream the abundance of trout ≥15 cm in length increased with water depth and most were at depths of at least 15 cm. Cunjak and Green (1983) reported that over yearling rainbow trout from three streams on the Avalon Peninsula, Newfoundland were encountered at an average depth of 53 cm with a range of 26 to 95 cm. In a Washington stream, Beecher et al. (1993) found that steelhead parr (~7.5-20 cm TL) occupied depths ranging from 24 cm to 2.0 m. Depth preferences of stream-dwelling adult rainbow trout can vary depending upon water temperature, dissolved oxygen levels, food availability, interspecies competition, and amount of cover. Lewis (1969) reported that adults moved into deeper water in winter.

### Substrate

Other than spawning, adults show little consistency in their preference for substrate. The presence of large amounts of fine sediment within the substrate can significantly reduce invertebrate production, thus limiting the carrying capacity of a stream (Pennak and Van Gerpen 1947). Reiser and Bjornn (1979a) reported that aquatic insect production was highest in substrates comprised largely of coarse gravel and rubble and Hynes (1970) found that aquatic invertebrates were most abundant and diverse in riffle areas with rubble substrate and on submerged aquatic vegetation. In British Columbia, Bradford and Higgins (2001) reported that as light levels fell to night time levels, juveniles moved to stream margins and were often found resting on sand or silt substrates. In a Pennsylvanian stream, adults were found most frequently over gravel substrates (Magoulick and Wilzbach 1997).

### Cover

Cover is an essential component of rainbow trout streams. Boussu (1954) was able to increase or decrease the abundance and biomass of trout in stream sections by adding or removing artificial brush cover and/or undercut banks. Cover provides shelter from predators, regulates stream temperatures through shading, and can provide overwintering habitat (Raleigh et al. 1984; Barnhart 1986; Scott and Crossman 1998). Cover may be provided by overhanging vegetation, submerged vegetation, undercut banks, instream objects (debris piles, logs, large boulders, etc.), pool depth, coarse substrates, and surface turbulence (Giger 1973). During summer, cover is primarily used for predator avoidance and resting (Raleigh et al. 1984), while during the winter it is used to avoid physical damage from ice scouring (Hartman 1965; Chapman and Bjornn 1969) and conserve energy (Chapman and Bjornn 1969; Everest and Chapman 1972). Bustard (1973) and Bradford and Higgins (2001) found that use of substrate as cover increased during the winter. Hartman (1965) and Bustard and Narver (1975) reported that 1+ steelhead prefer deeper pools during winter. A cover area of 25% of the total stream is considered adequate for adults, while 15% is adequate for juveniles (Raleigh et al. 1984).

## 3.9.10 Round whitefish (*Prosopium cylindraceum*)

Round whitefish are widely distributed in lakes and ponds throughout their southern range and rivers in their northern range as well as brackish waters, from northern North America to north eastern Asia (McPhail and Lindsey 1970; Becker 1983; Scott and Crossman 1998). In Canada, its range encompasses northern New Brunswick, Labrador, and Ungava west through Quebec, Ontario, and north westward from northern Manitoba through the Northwest Territories and northern British Columbia (Scott and Crossman 1998). Although round whitefish have been reported from the Churchill (Beak Consultants Ltd 1979; Ryan 1980) and Atikonak river systems in Labrador (LGL Limited 1999), it has not been reported from Labrador's southeast coast, north of the Fraser River (Bruce et al. 1979), in Labrador's brackish waters (Backus 1957) or the island of Newfoundland.

### 3.9.10.1 Spawning, Incubation, and Emergence/Young-of-the-Year/Nursery

Although normally a lake species, round whitefish will move considerable distances against strong currents during the spawning run (Becker 1983). Spawning can take place in the shallow inshore areas of lakes, at river mouths, or occasionally in rivers (McPhail and Lindsey 1970; Scott and Crossman 1998; Bradbury et al. 1999).

Spawning occurs in the fall, from mid-October to late December depending upon geographical location and local conditions of water temperature, day length, etc. (Harper 1948; Normandeau 1969; Bryan and Kato 1975; Becker 1983; Scott and Crossman 1998). Spawning within the East Ashnik River, Yukon Territory occurred from the first to the third week of November (Bryan and Kato 1975); in October-November within the Pyasina and Anadyr' Rivers in Russia (Berg 1948); and possibly as early as late August in the Driftwood River, northern Yukon Territory (Bryan 1973). Spawning within the East Ashnik River occurred during the day at depths from 0.7 to 2.5 m, currents <0.6 m/s, and water temperatures ranging from 1.4 to 1.6°C (Bryan and Kato 1975). Bryan (1973) reported that in Yukon Territory streams, spawning occurred over a variety of substrates ranging from mud to gravel and boulders, but there appeared to be a preference for gravel substrates based upon the abundance of fry captured in these areas. McPhail and Lindsey (1970) also reported spawning over silt and potamogeton. Eggs and sperm are broadcast over the substrate and no parental care is provided for the young (Scott and Crossman 1998).

Normandeau (1969) reported that round whitefish eggs within Newfound Lake, New Hampshire, hatched in April after 140 days at a water temperature of 2.2°C. Normandeau (1969) also reported that upon hatching, fry remained on the bottom, but when disturbed they took shelter underneath rubble and large rocks. In Alaska, Suchanek et al. (1984) reported that young seek cover from cobble or boulders, debris and overhanging vegetation at water depths ranging from 5 cm to 3 m (optimal 5-15 cm) in relatively calm areas. In an Alaskan stream, larvae were found in backwater areas and shallow shoreline areas where water velocity was either nil or slight and substrate was comprised of sand or mud (Lee 1985). Morrow (1980) noted that dispersal from spawning areas is usually complete in 2 to 3 weeks. McKinley (1984) reported that larvae within an artificial stream enclosure demonstrated a significant preference for sand when resting on the bottom.

### 3.9.10.2 Juvenile/Adult

LGL Limited (1999) reported that immature juveniles (0+, 1+, and 2+ years) were captured during electrofishing surveys within tributaries of Atikonak Lake and Atikonak River, south western Labrador. They were captured at depths ranging from 12 to 75 cm, water temperatures between 7.9 to 18.5°C, and substrates of mud, sand, gravel, cobble, rubble, and small boulders (LGL Limited 1999). The highest catch rates were in areas of slow water velocity in steadies and backwaters, at depths ranging from 18 to 60 cm, temperatures between 13.9-16.3°C, and substrates of fine gravel and sand (LGL Limited 1999). In an Alaskan stream, juveniles were found in highest densities over silt substrates, at velocities of 0.2 m/s and depths up to 45 cm, but were also present in low numbers over sand, gravel and rubble substrates (Lee 1985).

Ryan (1980) reported that gillnet catches of mature specimens in the Churchill River system, Labrador were higher in fast-flowing sections than in steadies or backwaters. These distributions possibly indicate that juveniles prefer slow steadies and backwater habitat until they reach maturity, after which they prefer faster flowing sections of the main channel. According to Lee (1985), round whitefish tend to move into deeper and faster water as they grow. In Alaska, adults were found at optimal water velocities ranging from 0.6-0.9 m/s and were reported using the following cover types in order of most to least preferred: cobble and boulder, undercut banks, overhanging vegetation, debris/deadfall, submergent and emergent vegetation, rubble and large gravel (Suchanek et al. 1984).

Coutant (1977) reported that round whitefish have a preferred water temperature of 17.5°C. Armstrong et al. (1977) reported that in the Great Lakes region, round whitefish usually mature in their third or fourth year, while in New Hampshire it occurs in their fourth or fifth year (Normandeau 1969). MacKay and Power (1968) reported that males in northern Quebec mature between ages 4-7, while females mature from 3-6 years. The maximum age reported for this species is 14 years (Van Oosten 1932).

# 3.10 Sculpins (Cottidae)

## 3.10.1 Mottled sculpin (*Cottus bairdi*)

The mottled sculpin is a benthic species that ranges widely, but discontinuously through North America from the Tennessee River system of Georgia and Alabama in the south, to Labrador in the north, to the Great Lakes basin and parts of the Missouri and Columbia River systems in the west (Scott and Crossman 1998). In eastern Canada, the mottled sculpin is confined to mainland areas, occurring throughout the Churchill (Black et al. 1986) and Atikonak river systems (LGL Limited 1999) of Labrador, north through Ungava Bay, Quebec (Scott and Crossman 1998). They occur in cool, headwater streams and lakes across Canada (Becker 1983; Scott and Crossman 1998), but do not usually occur as far up headwater streams as the slimy sculpin (Scott and Crossman 1998). Although typically a stream-dwelling species it is also a common inhabitant of large lakes (Becker 1983).

### 3.10.1.1 Spawning, Incubation, and Emergence

Spawning occurs in the spring, with the timing dependent upon geographical location (Scott and Crossman 1998). Spawning has been reported to occur between March and May in North Carolina (DeHaven et al. 1992), mid-May in Ontario (Ricker 1934), late May in Alaska (Craig and Wells 1976), early April to early May in Wisconsin (Ludwig and Norden 1969), and late April in Minnesota (Petrosky and Waters 1975). Most spawning occurs at night (Savage 1963; Brown and Downhomer 1983). Water temperatures during spawning have been reported as 10°C (Koster 1936, New York), 8.9 to 13.9°C (Ludwig and Norden 1969, Wisconsin), and 3.5°C (Craig and Wells 1976, Alaska). Hybridization has been reported between mottled and slimy sculpins (Strauss 1986).

Males select the nest sites which are usually located in cavities under rocks and ledges, in crevices among large gravel (5-8 cm), or in tunnels within loam material, at an average depth of 22 cm, in areas with sufficient current to prevent siltation (Ricker 1934; Koster 1936; Ludwig and Norden 1969; Downhomer and Brown 1979; Becker 1983; Scott and Crossman 1998). Nest substrate usually consists of small gravel, although rock, sand, and silt may also be present (Ludwig and Norden 1969). Females (usually more than one) enter the nest cavity and turn over, depositing adhesive eggs on the nest ceiling, which are then fertilized, aerated, and guarded by a single male (Savage 1963; Downhomer and Brown 1980; Becker 1983; Scott and Crossman 1998).

Egg incubation time varies with geographical location and temperature (Scott and Crossman 1998). Hatching times have been reported as 17 days at 11.1 to 12.8°C (Ludwig and Norden 1969), 20 days at 13 to 15°C, and 30 days at 8 to 18°C (Sublette et al. 1990).

### 3.10.1.2 Young-of-the-Year/Nursery

Growth rates can vary significantly with geographical location. Northern populations tend to grow more slowly and live longer, but reach smaller maximum sizes than fish in the more southern latitudes (Craig and Wells 1976). Craig and Wells (1976) reported that young-of-the-year attained lengths of 19 to 24 mm before freeze-up in an Alaskan stream, while van Vliet (1964) and Petrosky and Waters (1975) reported a length of 45 to 50 mm in Saskatchewan and Minnesota streams, respectively.

Fry, as well as larger individuals, seem to distribute themselves in streams in accordance with the coarseness of the substrate (i.e., larger individuals are found in cobble areas, whereas smaller individuals are found in areas characterized by more finely divided materials) (Downhomer and Brown 1979). In a Pennsylvanian stream, van Snik Gray and Stauffer (1999) observed young-of-the-year over cobble and rubble substrates at depths <18 cm and velocities <0.3 m/s. According to Scott and Crossman (1998), young-of-the-year have been observed over mud at depths of 5-25 cm. Becker (1983) found that some small mottled sculpin obtain protection by hiding in quiet water near shore where they stir up clouds of silt which settles and covers them.

#### 3.10.1.3 Juvenile/Adult

Within the literature reviewed, there was no distinction between the habitat requirements of juveniles and adults. During the summer, mottled sculpin typically only occur in the coldest streams, usually occupying water temperatures between 11 and $16^{0}$C (Petrosky and Waters 1975). According to Wismer and Christie (1987), mottled sculpin prefer water temperatures around $16.6^{0}$C.

Although Pederson (1980) reported that sculpin were free-swimming and active during the day, Becker (1983) and Greenberg (1991) reported that they hid under rocks and large vegetation. Regardless of observed daytime activity, it is generally accepted that they are more active at night (Pederson 1980; Becker 1983; Scott and Crossman 1998). Gerking (1953) reported that within stream movements appeared to be random, exhibiting no preference towards upstream or downstream. Mottled sculpin are also relatively sedentary benthic fishes, typically moving <55 m throughout the year (Bailey 1952; McCleave 1964; Brown and Downhomer 1980; Grossman and Freeman 1987; Hill and Grossman 1987; Freeman and Stouder 1989). Hill and Grossman (1987) reported a home range estimate of 13 m for mottled sculpin in North Carolina.

Since stream-dwelling sculpin are usually found in pools and medium to fast riffles within the vicinity of cover such as vegetation, gravel or rubble, Becker (1983) suggested that their distribution is likely more dependent upon available shelter than substrate type. According to Matheson and Brooks (1983), however, water velocity seems to be the most important variable when distinguishing among habitat use of sculpins. Mottled sculpin seem to prefer substrates comprised mainly of sand, cobble, and rubble (Becker 1983; Grossman and Freeman 1987; Greenberg 1991; Scott and Crossman 1998; van Snik Gray and Stauffer 1999). In Wisconsin streams, mottled sculpin were encountered most frequently in clear or slightly turbid water at depths of 10 to 50 cm, over substrates of sand (23%), gravel (22%), silt (16%), rubble (12%), mud (12%), boulders (8%), detritus (5%), bedrock (1%), and clay (1%) (Becker 1983). In Pennsylvanian streams, van Snik Gray and Stauffer (1999) observed mottled sculpins over cobble and rubble substrates, at depths <16 cm and velocities <0.4 m/s, while in eastern Tennessee, they were observed over mainly rubble substrates, at a mean depth of 50 cm and velocities <0.31 m/s (Greenberg 1991). They have also been found beneath rubble and boulders in streams when water temperatures drop below $5.0^0C$ in the fall (Cunjak and Power 1986; van Snik Gray and Stauffer 1999).

In North Carolina, Hill and Grossman (1987) reported that mottled sculpins occupied areas having average velocities of 0.25 m/s and depths <70 cm, while Facey and Grossman (1992) reported mean nose velocities ranging from 0.4-0.9 m/s. Behavioural observations indicate that sculpin are poor swimmers and tend to hold position by clinging to the substrate, or by using their enlarged pectoral fins to generate downward pressure as water flows over them (Facey and Grossman 1990). Although field enclosure experiments demonstrated that mottled sculpins of all sizes generally preferred the same depths (12-32 cm), small sculpins (<50 mm SL) tended to use shallower habitats in the presence of larger conspecifics (Freeman and Stouder 1989). Downhomer and Brown (1979) suggested that the presence of adult sculpins in riffles could discourage young-of-the-year from occupying these areas due to predation risk.

Although the age at sexual maturity is similar for both sexes (Craig and Wells 1976), there is sexual dimorphism in size (Downhomer et al. 1983). Age at maturity varies geographically, occurring at 3-4 years of age and lengths of 65-75 mm in an Alaskan stream (Craig and Wells 1976); 1-2 years of age and lengths of 70 mm in the Montreal River (van Vliet 1964); 1-2 years of age and a minimum length of 41 mm in North Carolina (Grossman et al. 2002); and age 2 and a length of 75 mm in Minnesota (Petrosky and Waters 1975). The life span of mottled sculpins has been found to range from 2+ years in Delaware (Rohde and Arndt 1981), 3+ years in Wisconsin (Ludwig and Norden 1969), 4+ years in Washington (Patten 1971), 5+ years in Montana (Bailey 1952) and 7+ years in North Carolina (Grossman et al. 2002).

### 3.10.2 Slimy sculpin (*Cottus cognatus*)

Slimy sculpin occur from northern North America to extreme north eastern Siberia (Scott and Crossman 1998). In eastern Canada, it occurs in scattered mainland localities in New Brunswick and Labrador and north through most of Quebec to Ungava (Scott and Crossman 1998). There are no records from Nova Scotia, Anticosti Island or the island of Newfoundland. In Labrador, the slimy sculpin has been reported from the Churchill and Fraser river watersheds (Black et al. 1986), and Northwest River (Scott and Crossman 1998).

The species typically inhabits deep oligotrophic lakes, or swift, rocky-bottomed streams (Becker 1983) and often occurs in small springs as well as headwater pools and riffles (Becker 1983; Scott and Crossman 1998). The habitat occupied varies greatly depending upon available substrate and temperature (Scott and Crossman 1998). Cold water temperatures are preferred and the species is commonly found in association with trout or salmon (Becker 1983). Slimy sculpin have very small home ranges and do not migrate great distances (Morrow 1980; Morgan and Ringler 1992). There was little information within the literature reviewed with respect to the riverine habitat requirements of slimy sculpin.

#### 3.10.2.1 Spawning, Incubation, and Emergence

Slimy sculpin spawn in the spring, shortly after ice break-up (Scott and Crossman 1998). Koster (1936) reported that spawning occurred in May at a temperature of 10°C in Fall Creek, New

York, early May at a temperature of 8°C in the Montreal River, Saskatchewan (van Vliet 1964), late April in Valley Creek, Minnesota (Petrosky and Waters 1975), and late May and early June at temperatures of 3.5°C in an Alaskan stream (Craig and Wells 1976).

Nests are located in cavities under rocks and ledges, in crevices among large gravel (5-8 cm), or in tunnels within loam material, at an average depth of 22 cm, in areas with sufficient current to prevent siltation (Koster 1936; Scott and Crossman 1998). Nest substrate usually consists of small gravel although rock, sand, or silt may also be present (Ludwig and Norden 1969). Females (usually more than one) deposit adhesive eggs on the nest ceiling, which are then fertilized, aerated, and guarded by a single male (Savage 1963; Becker 1983; Scott and Crossman 1998). Van Vliet (1964) reported hatching occurred in the Montreal River, Saskatchewan in about four weeks at a temperature of 8°C. Upon hatching, young fall to the bottom of the nest where they remain for 3-6 days until the yolk sac is absorbed (Koster 1936).

### 3.10.2.2 Young-of-the-Year/Nursery

In a Pennsylvania stream, Johnson et al. (1992) reported that young-of-the-year were encountered mostly at water depths <15 cm, water velocities <0.2 m/s, were strongly associated with a gravel/cobble substrate and areas having <10% cover. In a Pennsylvanian stream, van Snik Gray and Stauffer (1999) also observed young-of-the-year under cobble/rubble substrates, at depths <18 cm and velocities <0.3 m/s.

### 3.10.2.3 Juvenile/Adult

In Pennsylvania streams, Johnson et al. (1992) reported that juveniles/adults occurred at depths ranging from 5 to 25 cm, water velocities of 0.1 to 0.3 m/s, were strongly associated with cobble/rubble substrates and preferred areas with >10% cover (Johnson et al. 1992), while van Snik Gray and Stauffer (1999) observed them at depths <21 cm, velocities <0.3 m/s, and cobble/rubble substrates. In New York streams, Baldigo and Lawrence (2001) reported that slimy sculpin were common over gravel and fine-grained substrates at velocities of 0.43-1.72 m/s, while in British Columbia they were commonly reported over cobble and smooth stones with little cover available except the substrate (Hughes and Penden 1984). In Tanana River, Alaska, Mecum (1984) observed juveniles and adults over substrates comprised mainly of silt, gravel and cobble, at depths between 0-40 cm and velocities ranging from 0-0.9 m/s, although they tended to prefer gravel substrates at depths between 20-30 cm and velocities of 0.4-0.5 m/s. According to van Snik Gray and Stauffer (1999), slimy sculpin frequently occur under cobble and rubble substrates.

Becker (1983) reported that in southwest Wisconsin streams, slimy sculpin were most frequently encountered near small springs, headwater pools, and riffles. Common stream characteristics include: 0.5 to 3.0 m in width; average depth of 13 cm; moderate to fast current; substrates of bedrock, boulder, rubble, gravel, sand, and silt; and substantial instream cover (McPhail and Lindsey 1970; Becker 1983). Based upon laboratory experiments, Otto and Rice (1977) determined that for slimy sculpin acclimated at 5 and 15°C, the preferred temperatures were 9 and 12°C, respectively, with an optimum of 10°C. They also determined that the upper lethal temperature ranged from 18.5 to 23.5°C and the ultimate lethal temperature was 26.5°C.

According to Symons et al. (1976), the upper lethal and preferred temperatures of slimy sculpin acclimated at 20°C were 25°C and 13°C, respectively.

Age at maturity has been reported to range between 2-4 years; 2 years of age in Valley Creek, Manitoba (Petrosky and Waters 1975); 3 years in the Montreal River, Saskatchewan (van Vliet 1964), 3 years in the Great Lakes area (Minns et al. 1993), and 4 years in the Chandalar River, Yukon (Craig and Wells 1976). The average life expectancy is between 4-6 years, although there are records of 7-8 year old individuals (Craig and Wells 1976; Sonnichsen 1981; McDonald et al. 1982; Becker 1983).

## 3.11 Smelt (Osmeridae)

### 3.11.1 Rainbow smelt (*Osmerus mordax*)

Rainbow smelt are primarily an inshore anadromous species that occur within bays and estuaries from its northern limit in the Hamilton Inlet area of Labrador southward to New Jersey (Scott and Scott 1988). There is also a landlocked form that exists in lakes (Scott and Scott 1988; Scott and Crossman 1998) which may occur in either normal or dwarf forms (Bruce 1975a; Whelan and Wiseman 1975). Landlocked smelt have been reported from many parts of insular Newfoundland (Bigelow and Schroeder 1963; Scott and Crossman 1964; Murawski and Cole 1978). The literature review indicated that the riverine habitat requirements of anadromous and landlocked forms were indistinguishable, so for the purposes of this report they will be considered together. For information on lacustrine habitat requirements of rainbow smelt, refer to Bradbury et al. (1999).

#### 3.11.1.1 Spawning, Incubation, and Emergence

Spawning has been reported in both lakes and rivers. In the Soviet Union, individuals spawning in lakes were typically first time spawners (1+ and 2+), while repeat spawners more commonly spawned in rivers (Ivanova and Polovkova 1972). Shoreward movement towards estuaries and streams usually begins prior to ice break-up (McKenzie 1964). Marcotte and Tremblay (1948) and McKenzie (1964) reported that in Gaspé, Quebec and the Miramichi River, New Brunswick, prespawning smelt arrive at estuarine water temperatures of 4-5°C, but do not enter smaller upstream tributaries until temperatures reach 6-7°C. A number of other authors report spawning occurring at a minimum water temperature of 2°C, including: the Elbe River, Germany (Ehrenbaum 1894); Lake Champlain (Greene 1930); and streams in New Hampshire (Hoover 1936). In Newfoundland, migration and spawning occurs from mid-April to mid-June, while in Labrador it occurs from early May to mid-June (Scruton et al. 1997). Temperature at peak spawning varies geographically, usually occurring at water temperatures from 4-9°C on the east coast of North America (Clayton 1976), but has been reported to occur at temperatures of 10-15°C in the Miramichi River (McKenzie 1964).

Anadromous smelt typically spawn in the lower reaches of streams and rivers (Templeman 1966) and near the mouths of rivers, mainly above tidal influence (McKenzie 1964; Scott and Crossman 1964; Nhwani 1973; Murawski and Cole 1978; Morrow 1980; Scott and Scott 1988; Buckley 1989). Some, however, migrate 0.8-1.6 km up streams and others make migrations of up to 24 km (Becker 1983). A single female, sometimes accompanied by two males, releases adhesive eggs into the water usually at night (Scott and Crossman 1998). Eggs sink to the bottom immediately after they are released and become attached to the substrate by a short pedicel (stalk) formed from the outer shell membrane (Rupp 1965). This enables eggs to sway in the water, thereby ensuring good aeration (Morrow 1980; Scott and Crossman 1998). Many individuals die after spawning, but those that survive spawn again the next year, at least in southern populations (McKenzie 1964; Morrow 1980; Scott and Crossman 1998).

Spawning has been reported at depths of 0.1 to 1.3 m (Murawski et al. 1980) over a variety of substrates, including gravel, sand, mud, pebble, cobble, submerged logs and aquatic vegetation, however, gravel appears to be preferred (Rupp 1959; Ivanova and Polovkova 1972; Nhwani 1973; Morrow 1980; Murawski et al. 1980; Buckley 1989; Scott and Crossman 1998). Clayton (1976) reported that spawning site selection was influenced more by water velocity than substrate or depth preferences in the Parker River, Massachusetts. Sutter (1980) found a positive relationship between survival and increasing water velocities up to 0.6-0.8 m/s in a Massachusetts stream and Hulbert (1974) reported that smelt prefer to deposit eggs in areas with high velocities. In Newfoundland, landlocked smelt have been reported to spawn at depths of 0.6-1.2 m and the eggs have been deposited on debris and rocks (Bruce 1975a). Immediately after spawning, those adults that survive move back to the ocean or the lake from where they originated (Morrow 1980; Bond 1982; Scott and Crossman 1998). Spent smelt have been observed descending from spawning tributaries of the Miramichi River in May and June (McKenzie 1964; Chadwick et al. 1985).

Smelt sometimes spawn offshore on gravel shoals before reaching freshwater, especially if they encounter stormy weather or physical obstructions (Rupp 1965; Leim and Scott 1966; Scott and Crossman 1998). In coastal waters, smelt usually spawn at night with most returning to the estuary during the day, although some males may remain hidden under rocks and undercut banks (McKenzie 1964; Clayton 1976).

Incubation times vary with water temperature and range from 29 days at 6-7°C, 25 days at 7-8°C, 19 days at 9-10°C, 11 days at 12°C, and 8 days at 16.5°C (McKenzie 1964; Cooper 1978). Lillelund (1961) reported that the upper temperature tolerance for eggs was in the range of 17.7-20.7°C. In Newfoundland, eggs typically incubate from mid-April to mid-July and hatch between mid-May and mid-July (Scruton et al. 1997). In Labrador, incubation occurs from early May to mid-July, while hatching occurs between early June and mid-July (Scruton et al. 1997).

#### 3.11.1.2 Young-of-the-Year/Nursery

Newly hatched larvae are 5 to 6 mm in length and the yolk sac is absorbed by the time they are 7 mm long (McKenzie 1964; Clayton 1976; Cooper 1978; Buckley 1989). After hatching, larvae drift downstream to either estuarine areas or lakes (McKenzie 1964; Morrow 1980; Scott and Scott 1988; Bond 1982; Becker 1983; Scott and Scott 1988; Buckley 1989; Nellbring 1989; Scott and Crossman 1998). The upper Miramichi estuary provides a major nursery ground for smelt (Hanson and Courtenay 1995; Locke and Courtenay 1995). McKenzie (1964) reported that in the Miramichi River, New Brunswick, larvae were located in bottom layers during the day and surface layers at night, allowing them to take advantage of selective tidal transport in maintaining position within the estuary. Laprise and Dodson (1989) reported that older larvae used tidal currents more efficiently and were usually located further upstream.

#### 3.11.1.3 Juvenile/Adult

Rainbow smelt are essentially a schooling, pelagic fish, inhabiting mid-water areas of lakes or inshore coastal waters (Leim and Scott 1966; Scott and Scott 1988; Scott and Crossman 1998). As anadromous smelt grow they are found in waters of increasing salinity and by August they inhabit lower portions of estuaries or nearshore coastal waters where they are associated with sand/gravel substrates (Buckley 1989; Scott and Crossman 1998) and eelgrass beds (Crestin 1973). Smelt begin to school at about 19 mm in length, moving into shallow water at night and returning to deeper channels during the day (Belyanina 1969). Smelt are likely one of the least migratory diadromous fish since there is minimal exchange of smelt populations between neighbouring large embayments (McKenzie 1964; Frechet et al. 1983).

During the summer, adults may move out of the estuary and occupy a narrow coastal zone within 2 km of shore, at depths less than 6 m (Bigelow and Schroeder 1953a; Buckley 1989). As water temperatures begin to drop in the fall, juveniles move further up the estuary, concentrating in channels where they mix with adults (McKenzie 1964; Clayton 1976). In the fall, smelt return to estuaries from marine areas (McKenzie 1964) and have been shown to overwinter in estuaries (Buckley 1989; Hanson and Courtenay 1995) or coastal areas (Bond 1982; Haldorson and Craig 1984). According to Chaput (1995), activity within the Miramichi estuary during winter is dominated by smelt and tomcod which can tolerate sub-zero water temperatures (Ewart and Fletcher 1990). In the Miramichi River, smelt have been reported to school in late winter in preparation for upstream spawning migrations in early April (Chaput 1995).

Wismer and Christie (1987) reported that rainbow smelt have a preferred water temperature of 15°C. According to Morrow (1980), smelt usually mature at 2 years of age. In Newfoundland, they mature at 1-2 years of age (Bruce 1975a), while in other areas, the majority of smelt mature at 2-3 years of age (McKenzie 1964; Murawski 1976). Attainment of sexual maturity is size related, therefore fish in more southerly populations tend to grow faster and mature earlier and smelt in marine populations usually grow faster than those in freshwater populations (Buckley 1989).

## 3.12 Sticklebacks (Gasterosteidae)

### 3.12.1 Blackspotted stickleback (*Gasterosteus wheatlandi*)

The blackspotted stickleback is a North American species found mainly in coastal marine waters, tidal pools, brackish waters, and occasionally in freshwater (Wootton 1976; Worgan and FitzGerald 1981; Scott and Scott 1988). It has been reported from the shores of northern Newfoundland, south to New York (Scott and Crossman 1998), but not in Labrador. Some freshwater populations have been reported from Newfoundland (van Vliet 1970).

#### 3.12.1.1 Spawning, Incubation, and Emergence/Young-of-the-Year/Nursery

Spawning occurs in brackish waters in the spring (Wootton 1976; Scott and Scott 1988) and has been reported to last from early May to the end of June in Rivière des Vases, Quebec (Craig and FitzGerald 1982). Spawning territories include: a sandy or coarse mud substrate, abundant rooted aquatic vegetation, a solid vertical surface provided by stones or sunken logs, and thread-like plant debris and algae suitable for nest construction (McInerney 1969). Spawning males construct a nest of thread-like algae and available plant material at depths of 5 to 60 cm during low tide (McInerney 1969; Scott and Scott 1988). Eggs are fertilized within the nest and males provide care during incubation by repairing nests and aerating the eggs through fanning with their pectoral fins (McInerney 1969; Scott and Scott 1988). Prior to hatching, males have been observed adding an extra 'loose' layer of plant material to nests, presumably to provide emergent fry with a safe area in which to move about (McInerney 1969). McInerney (1969) also observed that during the nursery phase, males would retrieve any wandering fry and return them to the nest.

In Newfoundland, Methven et al. (2001) found that young-of-the-year blackspotted stickleback utilized shallow (<1.2 m) subtidal areas having substrates comprised mainly of small rocks and gravel as nursery grounds.

#### 3.12.1.2 Juvenile/Adult

Under laboratory conditions, blackspotted sticklebacks were found to prefer water temperatures between 11-14°C (Lachance et al. 1987). Coad and Power (1973c) reported that in a Quebec estuary, blackspotted stickleback survived summer water temperatures up to 25°C. Audet et al. (1986) reported that in a Quebec tidal creek, adults immediately returned to estuaries after breeding. Within a Newfoundland subtidal area, blackspotted stickleback were captured at depths <1.2 m over a substrate comprised mainly of small rocks and gravel throughout most of the year except winter (Methven et al. 2001). In the marine coastal environment, they were reported to lead a semi pelagic existence and were commonly found in association with floating seaweed (Scott and Crossman 1998). Perlmutter (1963) noted that in the waters of Long Island, New York, they were captured at depths of 0.8 m over a coarse gravel substrate.

Since all authors commonly report on only one size class (age 1), it is assumed that blackspotted stickleback spawn the year after birth and die shortly after breeding (Wootton 1976; Worgan and FitzGerald 1981; Ward and FitzGerald 1983; Scott and Crossman 1998). In Newfoundland and other parts of the Atlantic coast, maximum lengths of 64 mm and 76 mm, respectively have been recorded for blackspotted stickleback (Scott and Crossman 1998).

### 3.12.2 Fourspine stickleback (*Apeltes quadracus*)

Fourspine sticklebacks are a euryhaline species found only on the east coast of North America, from the Gulf of St. Lawrence and Newfoundland south to Virginia (Scott and Scott 1988; Scott and Crossman 1998). Although it is primarily a marine species and usually restricted to a narrow coastal zone, it is also present in brackish and estuarine waters and sometimes occurs in freshwater (Blouw and Hagen 1981; Scott and Scott 1988). They usually occur in vegetated areas with calm water and are rarely found in swift currents or along coastlines exposed to strong wave action or large tidal flux (Blouw and Hagen 1981). Highest densities are found in brackish estuaries and lagoons (Blouw and Hagen 1981). In Newfoundland, fourspine stickleback have been collected from brackish and estuarine waters along the west coast of the island (Scott and Crossman 1964; van Vliet 1970), the western Avalon Peninsula in Placentia Bay (Scott and Crossman 1964; Garside 1970; Lewis 1978) and St. Mary's Bay (Hanek and Threlfall 1970). Freshwater populations have been reported from Pennsylvania (Nelson 1968a), New Brunswick (Scott and Crossman 1959), Nova Scotia (Scott and Crossman 1964), and Newfoundland (Dadswell 1972a; Rombough et al. 1981; Campbell 1992). Freshwater populations in Newfoundland have been reported from lakes on the northwest coast (Dadswell 1972a), on the tip of the Northern Peninsula (Rombough et al. 1981), and a pond on the eastern Avalon Peninsula (Campbell 1992).

### 3.12.2.1 Spawning, Incubation, and Emergence/Young-of-the-Year/Nursery

Spawning occurs in late spring or early summer (May to July) in intertidal areas for anadromous species and along shorelines for freshwater dwellers (Wootton 1976; Worgan and FitzGerald 1981; Scott and Scott 1988; Scott and Crossman 1998). Males and females appear simultaneously on the spawning grounds and the males construct nests (Scott and Scott 1988; Scott and Crossman 1998). Cup-shaped nests are constructed in the branches or on the stems of plants in shallow water using small twigs and aquatic plants bound together by a kidney secretion (Hall 1956; Rowland 1974a; Wootton 1976; Courtenay 1983; Scott and Scott 1988). Rowland (1974a; b) reported that nests may be constructed at the substrate level or 20 cm or more above the substrate depending on available vegetation.

Although no particular substrate has been associated with spawning in the field, laboratory experiments indicated that *Fucus* sp. covered with brown filamentous algae was rejected in favour of clean *Fucus* sp. which in turn was rejected in favour of eelgrass, *Zostera* sp. (Courtenay and Keenleyside 1983). Courtenay (1985) reported that nests built upon the banks of intertidal pools can be exposed at low tide. Females deposit clutches of 15 to 50 eggs within the nest, which are fertilized, aerated, and guarded by the male (Rowland 1974a; Wallace and Selman 1979; Craig and FitzGerald 1982; Courtenay 1985; Scott and Scott 1988; Scott and Crossman 1998). Courtenay (1985) also reported that males may construct and tend two or three nests within the same vicinity. These nests may be placed one on top of the other, in a tiered effect (Reisman 1963; Rowland 1974a; Wootton 1976) or be scattered throughout a male's territory (Courtenay and Keenleyside 1983; Courtenay 1985).

Larvae (4.2 to 4.5 mm in length) hatch within a week at water temperatures of 16-18°C, within 8 to 9 days at 18.3°C, and remain on the bottom for several days before swimming (Breder and Rosen 1966; Wootton 1976; Blouw and Hagen 1981; Scott and Scott 1988). Parental care of larvae has not been observed (Wootton 1976). Three and eight day old young have been reported to attain lengths of 6.5 and 7 mm, respectively (Kuntz and Radcliffe 1917; Hardy 1978). In Newfoundland, Methven et al. (2001) found that young-of-the-year fourspine stickleback utilized shallow (<1.2 m) subtidal areas having substrates comprised mainly of small rocks and gravel as nursery grounds. Szedlmayer and Able (1996) reported that young-of-the-year were associated with eelgrass habitats within estuaries.

### 3.12.2.2 Juvenile/Adult

Within the literature reviewed there was no information on juvenile fourspine stickleback, and aside from spawning behaviour, there was little information regarding the life history characteristics of adults. In Placentia Bay, Newfoundland, fourspine sticklebacks were observed primarily in areas of dense, emergent vegetation over a predominantly rocky bottom covered in black mud (Fitzpatrick 1988). Within a Newfoundland subtidal area, fourspine stickleback were captured at depths <1.2 m over substrates comprised mainly of small rocks and gravel throughout most of the year except winter (Methven et al. 2001). Lazzari (2002) observed fourspine stickleback within eelgrass beds as well as over unvegetated sandy substrates in shallow subtidal (3-6 m) areas from August to November.

Scott and Scott (1988) reported that male fourspine sticklebacks have a one year lifespan, but females may live a second winter and spawn the following spring. In the Great Lakes areas, they have been reported to reach sexual maturity at age 2 (Minns et al. 1993). In Pt. Verde, Placentia Bay, Newfoundland, no individuals were found to live beyond 2 years of age (Fitzpatrick 1988), while Coad and Power (1973c) and McInerney (1969) reported 3-year-old females from the Matamek River, Quebec, and the Miramichi River, New Brunswick. Scott and Scott (1988) reported that the average size of mature fish is 52 mm in length.

## 3.12.3 Ninespine stickleback (*Pungitius pungitius*)

Ninespine sticklebacks are a circumpolar species inhabiting both fresh and salt water throughout the northern hemisphere, in North America, Europe, and Asia (Scott and Scott 1988). In the western North Atlantic, they are found along the entire Arctic and Atlantic coasts, south to New Jersey (Scott and Scott 1988; Scott and Crossman 1998). In coastal waters they are usually restricted to nearshore habitats (Scott and Scott 1988). In inland fresh waters, ninespine stickleback range from the Arctic to the Mississippi River drainage and from Newfoundland in the east to Alaska in the west (Scott and Crossman 1998). They have been reported from coastal and inland waters of both Newfoundland and Labrador, although to date no life history research has been conducted (Scott 1955; McPhail and Lindsey 1970; Black et al. 1986; Scott and Crossman 1998).

Ninespine sticklebacks inhabit shallow bays in lakes, tundra ponds and slow streams (McPhail and Lindsey 1970). According to Page and Burr (1991), they occur primarily along shallow shorelines, embayments, and backwaters of sluggish streams, although sometimes they may occur in open water over sand. In Europe, freshwater dwellers are tolerant of low dissolved oxygen levels and prefer cool, shallow, quiet, weedy streams and ditches (Bertin 1925; Leiner 1931; Sevenster 1949; Morris 1958; McKenzie and Keenleyside 1970). Although numerous authors refer to riverine use by ninespine stickleback (Hynes 1950; Jones and Hynes 1950; Münzing 1969; McPhail and Lindsey 1970; Coad and Power 1973a; Becker 1983; Scott and Crossman 1998), it is not well documented since there were no references within the literature reviewed that dealt specifically with riverine habitat requirements. For the purposes of this report, it was assumed that riverine habitat utilization is comparable to lacustrine habitat.

### 3.12.3.1 Spawning, Incubation, and Emergence/Young-of-the-Year/Nursery

During the summer, coastal (marine) ninespine stickleback move into freshwater streams or brackish estuaries to spawn (Scott and Scott 1988; Scott and Crossman 1998) where they have been shown to occupy shallow shorelines and sluggish pools (Wootton 1976; Morrow 1980; Becker 1983; Page and Burr 1991). Various spawning times have been reported: May to the end of June in the Rivière des Vases, Quebec (Worgan and FitzGerald 1981), June and July in the Matamek River, Quebec (Coad and Power 1973b), between April and June in the River Birket, England (Wootton 1976), late June and early July in Alaska (Cameron et al. 1973), and May to late July in the Arctic (McPhail and Lindsey 1970). Throughout its range, spawning occurs primarily in shallow areas of low water velocity, dense aquatic vegetation and substrates comprised of mud and silt (McPhail and Lindsey 1970; Wootton 1976; Morrow 1980; Scott and Scott 1988; Scott and Crossman 1998), but may also occur in sparsely vegetated areas over sand, gravel, or rocky substrates (McPhail and Lindsey 1970; Wootton 1976). Worgan and FitzGerald (1981) reported that spawning occurred in the Rivière des Vases, Quebec at an average water temperature of 15.5°C, water velocities <0.3 m/s, and depths <0.5 m.

Males construct a tunnel-shaped nest of aquatic vegetation, which is usually suspended within plants 10 to 15 cm above the bottom and at depths ranging from 25 to 80 cm (Morris 1958; McKenzie and Keenleyside 1970; McPhail and Lindsey 1970; Wootton 1976; Morrow 1980; Scott and Scott 1988; Scott and Crossman 1998). In Mississippi, nests were usually constructed on aquatic plants 0-4 cm above the substrate at depths between 0.9-1.4 m (Foster 1977). It has also been reported that in areas of sparse vegetation nests may be constructed directly upon the substrate (Becker 1983; Morris 1958) or amongst rock crevices (McKenzie and Keenleyside 1970, Lake Huron). Females deposit clutches of 20 to 30 eggs within the nest, which are fertilized, aerated (fanning with pectoral fins), and guarded by the male (McPhail and Lindsey 1970; Wootton 1976; Becker 1983; Scott and Scott 1988; Scott and Crossman 1998). Males will spawn with one or more females (Griswold and Smith 1973; Becker 1983) and have been reported spawning with up to seven females (Scott and Crossman 1998). While eggs are incubating in one nest, males may begin construction of a second nest, subsequently enticing another female to deposit her eggs, and beginning the spawning process again (Wootton 1976; Scott and Scott 1988; Scott and Crossman 1998). During incubation, males have been observed to remove damaged egg cases (Morris 1958) and provide parental care for the young while they are in the vicinity of the nest (about two weeks after hatching) (Wootton 1976; Scott and Scott 1988). Incubation times have been reported ranging from 4 to 5 days at a water temperature of 18-19°C to 6 to 7 days at a water temperature of 15-16°C (Wootton 1976).

Griswold and Smith (1972) reported an average length of 5.7 mm for newly hatched young. Morrow (1980) found that newly hatched larvae move to the top of the nest where they remain relatively inactive. Young may be transferred by the male to a 'nursery' area (a loose aggregation of nesting materials usually only constructed in areas with abundant vegetation) or simply remain within the vicinity of the nest (McPhail and Lindsey 1970; Wootton 1976; Keenlyside 1979). After a few days, young are completely free-swimming (Keenleyside 1979). According to Scott and Crossman (1998), when young are about two weeks old, the male can no longer control their wanderings and the small fish typically move into the open water. Becker

(1983) reported that young congregate in shallow sandy areas, leaving for deeper overwintering areas in the fall when they have attained a total length of at least 45 mm.

#### 3.12.3.2 Juvenile/Adult

Ninespine sticklebacks typically inhabit cool, quiet waters (McPhail and Lindsey 1970; Becker 1983). Under laboratory conditions, they were found to have a bimodal temperature preference between 9-10°C and 15-16°C (Lachance et al. 1987). Dense aggregations are often associated with heavy vegetation, while smaller numbers of individuals may be found over sand or gravel and other areas of sparse vegetation (McPhail and Lindsey 1970; Dadswell 1972b). According to Worgan and FitzGerald (1981), adults are typically found at depths of 0.5-2.5 m, velocities <0.3 m/s over mud or sand substrates. In the UK, they are commonly found at depths of 0.1-1.0 m, in nil to weak currents, over mud, clay, detritus and sand substrates and occasionally gravel in the vicinity of emergent or submergent vegetation (Copp et al. 1998).

Jones and Hynes (1950) reported that in two English rivers, growth was rapid in the first year but slowed considerably in following years. One, two, and three year olds attained lengths of 36-44 mm, 45-48 mm, and 48-55 mm, respectively. Scott and Scott (1988) stated that Atlantic coast specimens reach a length of 51 to 76 mm and have a life expectancy of 3 to 3.5 years. Griswold and Smith (1973) reported that in the Apostle Islands area of Lake Superior, females grow faster than males, reaching an average length of 80 mm at age 5, while males live to age 3 and attain an average length of 66 mm. Coad and Power (1973a) reported that in the Matamek River System, Quebec, riverine fish lived a maximum of 1 year and some months, while lacustrine fish lived over 2 years. They also reported that age at spawning was 1+ for riverine fish and 2+ for lacustrine fish. Jones and Hynes (1950) reported spawning occurred at 1, 2, and 3 years of age for riverine European populations. In Quebec, they mature at age one and may breed a second time at age two (Craig and FitzGerald 2982).

### 3.12.4 Threespine stickleback (*Gasterosteus aculeatus*)

Threespine stickleback are almost circumpolar in distribution (it is absent from the cold Arctic seas of Siberia and North America) and are widely distributed in the northern hemisphere (Scott and Scott 1988; Scott and Crossman 1998). It is a common species on Canada's east and west coasts as well as the Hudson Bay area, and due to its euryhaline characteristics can be found in coastal waters, inland ponds, lakes, rivers, and tributaries (Wootton 1976; Scott and Scott 1988; Scott and Crossman 1998). It is also one of the most intensively studied noncommercial fish species.

The threespine stickleback is common throughout the fresh, brackish, and salt waters of Newfoundland and Labrador (Scott and Scott 1988; Scott and Crossman 1998). Its presence has been documented in a number of Newfoundland lakes (van Vliet 1970; Pepper 1976; Rombough et al. 1978; Ryan 1984; Campbell and Knoechel 1988; 1990; 1991), rivers and coastal waters (Scott and Crossman 1964; 1973), and in a saltwater lagoon (Fitzpatrick 1988). It has also been reported within the Churchill River system and coastal waters of Labrador (Scott and Crossman 1998). Populations of threespine stickleback in Newfoundland and Labrador exist as both freshwater resident and anadromous marine-dwelling forms. Moyle (1976) compared freshwater resident and anadromous forms in British Columbia and indicated that while anadromous fish were larger and exhibited a higher fecundity, they essentially utilized the same riverine habitat as freshwater forms. Given the similarity of riverine habitat usage, both forms will be presented simultaneously within this report. For information on lacustrine habitat requirements, refer to Bradbury et al. (1999).

### 3.12.4.1 Spawning, Incubation, and Emergence/Young-of-the-Year/Nursery

Anadromous populations undergo a spring (May-June) spawning migration into fresh or brackish water, while freshwater populations undergo a spring migration from deep to shallow waters of lakes or from larger rivers into smaller, slower tributaries and backwaters (Scott and Scott 1988; Scott and Crossman 1998). Spawning generally occurs in June or July, but depending upon geographical location and local conditions can occur from April to September (Scott and Crossman 1998). Although spawning times for riverine populations in Newfoundland and Labrador are not documented, lake spawning has been reported to occur in mid-summer (June-July) (Pepper 1976; Ryan 1984; Campbell and Knoechel 1991). At the end of April or early May, anadromous populations have been reported to migrate from the St. Lawrence estuary and enter tidal rivers and creeks for two to three months to breed (Craig and FitzGerald 1982; Picard et al. 1990).

Hagen (1967) reported that in the Campbell River, British Columbia, spawning occurred at water temperatures ranging from 14-23°C, water velocities of 0.03-0.06 m/s, average depths of 24 to 50 cm, and usually over a sand/mud substrate in the vicinity of vegetation. In the Salmon River, British Columbia, Virgl and McPhail (1994) reported that spawning occurred in areas with slow flow, over sand or mud where *Elodea* was the dominant submergent vegetation. Snyder and Dingle (1989) report that in the Navarro River, California, spawning occurred at water temperatures ranging from 18-22°C, weak to moderate water velocities, water depths <1 m, upon a mud/sand substrate, near sparse or abundant vegetation. In Japenese rivers, nests were constructed over mud and sand substrates (gravel and boulder were used sparingly), at depths ranging from 10-86 cm, and water velocities <0.2 m/s (Mori 1994). On Cape Breton Island, Nova Scotia, males were observed nesting along the shoreline in gravel or rocky areas at depths of 10-60 cm (Jamieson et al. 1992).

Wootton (1976) reported that nests may be constructed within or on the downstream edge of a bed of pond weed. Unlike other sticklebacks which suspend their nests in plant material, male threespine stickleback construct their nests of glued plant material and/or sand grains directly upon the substrate (McPhail and Lindsey 1970; Wootton 1976; Scott and Scott 1988; Scott and Crossman 1998). Females deposit clutches of 50 to 200 adhesive eggs within the nest, which are fertilized, aerated (by fanning water), and guarded by the male (McPhail and Lindsey 1970; Wootton 1976; Scott and Scott 1988; Scott and Crossman 1998). Males provide parental care during incubation and while young are still in the vicinity of the nest (about two weeks after hatching) (Wootton 1976; Scott and Scott 1988; Scott and Crossman 1998). Once they are free-swimming, young school around the male for a few days and then disperse (Morrow 1980). Incubation has been reported to require 7 days at temperatures ranging from 18-19°C (Breder and Rosen 1966), 8 days at 17-18°C (Wheeler 1969), 20 days at 12°C, and 40 days at 8°C (Heuts 1956). Hagen (1967) reported large numbers of dead and moribund threespine stickleback following spawning in ponds within the Campbell River System, British Columbia providing evidence that at least some individuals die shortly after spawning.

Newly hatched larvae have been reported to measure 4.2 to 4.5 mm (Kuntz and Radcliffe 1917, Massachusetts), 4.7 to 4.9 mm (Vrat 1949, California), and 5 mm (Jones and Hynes 1950, England; Coad and Power 1973c, Quebec). When they are active and free-swimming, the young leave the vicinity of the nest and join schools of other young sticklebacks (Wootton 1976). Some young (anadromous) leave the streams and/or estuaries where they hatched and move into saltwater in the fall to overwinter, at first remaining close to the coast seeking shelter among seaweed, but later entering the open ocean (Coad and Power 1973c). Growth is reported to be rapid during the first year of life with individuals attaining lengths of 20 to 55 mm (Jones and Hynes 1950) and 12 to 21 mm (Coad and Power 1973c, Quebec).

### 3.12.4.2 Juvenile/Adult

Anadromous threespine sticklebacks are known to make long (100 km) migrations up and down the Fraser River, British Columbia (Taylor and McPhail 1986). Outside the breeding season, and after migration back to sea (anadromous) or into deeper waters or large rivers (freshwater resident) in the fall, adults live in loosely polarized schools (Keenleyside 1955; Wootton 1976; Scott and Scott 1988; Scott and Crossman 1998). Threespine stickleback typically inhabit vegetated areas, usually over mud or sand (Page and Burr 1991), but this association is not as strong as with other stickleback species (McPhail and Lindsey 1970). In the UK, they are commonly found at depths of 0.1-1.0 m, in nil to weak currents, over substrates of mud, clay, detritus, sand and gravel in the vicinity of emergent or submergent vegetation (Copp et al. 1998). Lazzari (2002) observed threespine stickleback within eelgrass beds in shallow subtidal (3-6 m) areas from August to November and noted that they were absent from nearby unvegetated sandy substrates.

Jordan and Garside (1972) reported that for fish acclimatized in seawater at 10°C, the minimum upper lethal temperature ranged from 20.0-21.6°C. Under laboratory conditions, threespine sticklebacks were found to prefer temperatures between 9-12°C (Lachance et al. 1987).

Growth rates are variable depending upon local conditions such as water temperature, food availability and day length (Wootton 1976). Maximum length and age have been reported as 51.4 mm at 3+ years in northwest England (Jones and Hynes 1950; Pennycuick 1971), 73 mm at 2 years in Alaska and the Matamek River system of Quebec (Greenback and Nelson 1959; Coad and Power 1974), and 45.0 mm at 1+ years in southern England (Mann 1971). Although Wootton (1976) and Scott and Scott (1988) stated that threespine stickleback reach maturity during their first year of life, Ryan (1984) and Fitzpatrick (1988) reported that in Newfoundland, the maximum lifespan is 2 to 2.5 years with maturity occurring in the second or third year. According to Craig and FitzGerald (1982), threespine stickleback in the Rivière des Vases only live 2 years.

# 3.13 Sturgeons (Acipenseridae)

## 3.13.1 Atlantic sturgeon (*Acipenser oxyrinchus*)

The Atlantic sturgeon occurs in Hamilton Inlet on the coast of Labrador (Backus 1951), possibly in the George River, Ungava Bay (Scott and Scott 1988), and is common in the Gulf of St. Lawrence, the St. John River, New Brunswick, and the Bay of Fundy (Murawski and Pacheco 1977). Reports from Newfoundland have been based upon rare saltwater records off the northwest coast and Hermitage Bay (Scott and Scott 1988). In the United States, it occurs along the entire Atlantic coast to the St. Johns River in eastern Florida (Vladykov and Greeley 1963). It is an anadromous, bottom living species, entering freshwater rivers and estuaries to spawn. Most of its life is spent in saltwater, where the majority of growth takes place (Scott and Scott 1988).

### 3.13.1.1 Spawning, Incubation, and Emergence

Atlantic sturgeons undertake upstream spawning migrations beginning in February/March in southern areas, April/May in the mid-Atlantic region, and May-July in Canadian waters (Smith 1985a). They spawn in running water at depths up to 3 m, usually over substrates of gravel, rocks, rubble and other hard objects, in pools below waterfalls (Dees 1961; Vladykov and Greeley 1963; Leland 1968; Huff 1975; Smith 1985a), but have been observed spawning over sand and silt (Van Den Avyle 1984). Water temperatures during spawning have been reported as 13.3-17.8°C in the Delaware River, New Jersey (Borodin 1925) and 13-19°C in South Carolina (Dees 1961; Vladykov and Greeley 1963; Leland 1968; Huff 1975; Smith et al. 1982). Extruded eggs are demersal and highly adhesive, attaching to rocks, gravel, plants, roots, etc. within 20 minutes of being broadcasted (Smith 1985a). Incubation periods range from 94 hours at 20°C (Dean 1894), 132-140 hours at 17.5-18°C (Smith et al. 1981), or 168 hours at 17.8°C (Vladykov and Greeley 1963). Under culture conditions, Atlantic sturgeon hatched at a mean length of 7.8 cm and grew to a length of 17.7 cm in 204 days (Smith et al. 1981). Newly hatched larvae are free-swimming until yolk sacs are absorbed (9 to 10 days after hatching), after which they adopt a benthic lifestyle (Smith et al. 1981).

### 3.13.1.2 Young-of-the-Year/Nursery

There is little available information on young-of-the-year. Since subadults $\geq$30 cm are regularly captured in tidally influenced lower river and estuarine areas (Dovel and Berggren 1983; Lazzari et al. 1986; Collins et al. 1996), it is assumed that young-of-the-year move slowly downstream from spawning sites (Smith and Clugston 1997). Smith et al. (1982) captured young-of-the-year from nursery areas in the Edisto and Waccamaw rivers, South Carolina which were characterized as broad reaches in downstream tidally influenced transition zones having hard sand or shale substrates. Young Atlantic sturgeons remain and develop in freshwater for up to 3-4 years before migrating to sea (Scott and Scott 1988).

#### 3.13.1.3 Juvenile

The following information was obtained from a number of tagging studies carried out at various geographical locations (Vladykov and Greeley 1963; Holland and Yelverton 1973; Huff 1975; Murawski and Pacheco 1977; Hoff 1980; Rulifson and Huish 1982; Smith 1985a). In general, juveniles remain within their natal stream, but move progressively seaward over time. As temperatures decrease during the fall and winter, they tend to congregate and move to deeper pools. There is also some movement into brackish areas with decreasing temperatures and some immature individuals enter coastal waters. Van Den Avyle (1984) reported that in rivers, juveniles usually occur at depths ranging from 2 to 3 m, while at sea they have been captured at depths up to 20 m over substrates of hard sand and shale. Juveniles remain within riverine systems for 1-6 years before emigrating along the coast and onto the continental shelf where they grow and mature (Smith 1985a).

#### 3.13.1.4 Adult

There is little known of movements at sea (Scott and Scott 1988). Males mature earlier than females, with individuals in northern latitudes reaching maturity at an older age than those in southern areas (Smith 1985a). In Florida, females mature at 8 to 12 years (Huff 1975); in South Carolina, males mature at 5 to 13 years and females at 7 to 19 years (Smith et al. 1982); in the Hudson River males mature at 11 to 20 years and females at 20 to 30 years (Dovel 1979); and in the St. Lawrence River males mature at 22 to 34 years and females at 27 to 28 years (Vladykov and Greeley 1963). Evidence from South Carolina (Smith et al. 1984) indicates that females may spawn at intervals ranging from 3 to 5 years, while males exhibit an average of 1 to 5 years between spawning.

## 3.14 Suckers (Catostomidae)

### 3.14.1 Longnose sucker (*Catostomus catostomus*)

Longnose suckers are primarily bottom-dwelling fish (McPhail and Lindsey 1970; Morrow 1980) and are the most successful and widespread cypriniforms in North America, occurring almost everywhere in clear, cold waters (McPhail and Lindsey 1970; Lee et al. 1980; Edwards 1983; Scott and Crossman 1998). They are common throughout Canada and Alaska, from Labrador, west through Pennsylvania, the upper Mississippi, northern Colorado, and north through Washington and Alaska (Edwards 1983; Scott and Crossman 1998). Although, it occurs in southern Labrador, it has never been reported from the island of Newfoundland (Bruce et al. 1979; Black et al. 1986; Scott and Crossman 1998). Longnose suckers in North America inhabit streams, lakes and reservoirs, with lacustrine inhabitants moving into rivers to spawn or overwinter (Harris 1962; Walton 1980). Because they are well adapted to high current velocities (Walton 1980), they are often found in swift rivers with stony bottoms (Nikolskii 1954; Edwards 1983). They have also been reported in brackish waters near the vicinity of river mouths (Walters 1955).

### 3.14.1.1 Spawning, Incubation, and Emergence

Spawning occurs in the spring, usually in riffle areas of rivers and inlet streams, but can also take place in outlet streams of lakes, or shallow lake margins (Geen et al. 1966; McPhail and Lindsey 1970; Smith 1979; Walton 1980; Becker 1983; Edwards 1983; Dion et al. 1994; Scott and Crossman 1998). Spawning migrations begin from mid-April to early July as ice breaks up, with peak spawning usually occurring in June (Hayes 1957; Bassett 1958; Harris 1962; Barton 1980; Ryan 1980). According to Scott and Crossman (1998), migration into streams begins when water temperatures reach 5°C, but ceases once temperatures reach 15°C (Harris 1962). Throughout its range, spawning occurs at temperatures of 10-15°C (Harris 1962; Walton 1980). In Labrador, spawning usually occurs in June when water temperatures reach 10°C (Ryan 1980).

During spawning, adhesive eggs are broadcast over a clean substrate comprised of gravel, cobble, or rubble in riffle areas where velocities range from 0.3 to 1.0 m/s and depths are between 15 and 60 cm (Harris 1962; Geen et al. 1966; McPhail and Lindsey 1970; Walton 1980; Becker 1983; Scott and Crossman 1998). In a Quebec stream, longnose suckers were observed spawning at velocities averaging 0.35-0.43 m/s, average depths of 60-65 cm and substrates comprised mainly of gravel, with some sand (Dion et al. 1994). During spawning, eggs settle to the bottom near the tail of the riffle where they receive an abundant supply of oxygen (Walton 1980). Following a spawning act, females return to still water or move along the stream bank, while males maintain positions on the stream bottom within spawning areas (Geen et al. 1966).

Experimental incubation required 8 days at 15°C and 11 days at 10°C (Geen et al. 1966), but probably takes up to two weeks within a stream (Scott and Crossman 1998). In Willow Creek, Alberta, Walton (1980) observed that incubation required 14 days at a mean temperature of 12.2°C.

### 3.14.1.2 Young-of-the-Year/Nursery

Young-of-the-year remain in the substrate for one to two weeks before emerging and drifting downstream (Geen et al. 1966; McPhail and Lindsey 1970; Balon 1975; Walton 1980). Geen et al. (1966) reported that peak migration occurred about a month after spawning. Walton (1980, Willow Creek, Alberta) reported that young-of-the-year were initially encountered in shallows and backwaters, with downstream movement commencing in early June. During downstream migration, young-of-the-year were found at or near the water surface (Walton 1980). In the Tanana River, Alaska, young-of-the-year were most abundant over silt and sand substrates in shallow (<0.2 m) backwaters having velocities <0.1 m/s (Mecum 1984). However, they were also captured at varying densities over silt, sand, gravel, cobble and rubble substrates at depths <0.6 m and velocities ranging from 0-0.6 m/s (Mecum 1984).

### 3.14.1.3 Juvenile

Juveniles (23 to 89 mm in length) live in lentic waters and frequent shallow, reedy areas (Edwards 1983). In Black Lake, northern Saskatchewan, Johnson (1971) observed that juveniles seek out areas with some current and may enter the lower reaches of streams. In the Tanana River, Alaska, although juveniles were captured over silt, sand, gravel, cobble and rubble substrates at depths <0.6 m and velocities ranging from 0-0.9 m/s, they tended to prefer sand/gravel substrates at depths <0.1 m and velocities between 0.6-0.9 m/s (Mecum 1984). Mecum (1984) suggested that their preference for swift, shallow gravel riffle areas, particularly at the head of side channels, might be related to the presence of an abundant food supply. According to Scott and Crossman (1998), aquatic insect larvae are the primary prey organism of these species, which tend to be more abundant in riffle areas of streams (Surber 1946).

#### 3.14.1.4 Adult

Adults have been collected from lakes at temperatures ranging from 3.0-18.5°C (Rawson 1942; Cooper and Fuller 1945; Black 1953; Johnson 1971), with preferred temperature ranges of 10-15°C (Brown and Graham 1953) and 8-17°C (Wismer and Christie 1987). Black (1953) calculated an upper lethal temperature range of 26.5-27°C for fish acclimated at 14°C and 11.5°C, respectively. Adults were captured in tributaries of Atikonak Lake, south western Labrador, at temperatures ranging from 13.9-19.6°C and depths between 17 and 75 cm over a gravel, cobble, or boulder substrate (LGL Limited 1999).

Age at maturity is variable, ranging from 3 to 4 years in Colorado (Hayes 1957), 5 to 7 years in Sixteen Mile Lake, British Columbia (Geen et al. 1966), 9 years or greater in Great Slave Lake, Alberta (Harris 1962), and 6 to 7 years in the Lower Churchill River, Labrador (Ryan 1980).

### 3.14.2 White sucker (*Catostomus commersoni*)

White suckers are restricted to North America, occurring from central Ungava, Labrador, south to western Georgia in the United States and west to Alberta, British Columbia and the Mackenzie River delta (Scott and Crossman 1998). In eastern Canada, they occur from Nova Scotia and New Brunswick in the south, through to northern Labrador and northern Quebec, but has not been reported on the island of Newfoundland (Scott and Crossman 1998). In the south, the white sucker is tolerant of a wide variety of habitats, however, towards its northern range limit it is restricted to warmer, shallower (2-6 m) littoral areas of lakes (McPhail and Lindsey 1970).

#### 3.14.2.1 Spawning, Incubation, and Emergence

White suckers begin upstream spawning migrations in spring to early summer (May-June), when daily maximum water temperatures reach 10°C (Olson 1963; Geen et al. 1966; Fuiman 1978; Curry 1979; Walton 1980; Twomey et al. 1984; Scott and Crossman 1998). In Labrador, spawning usually occurs in June (Ryan 1980). Spawning generally occurs in inlets, outlets, small creeks, and rivers with relatively swift, shallow waters running over a gravel or coarse sand bottom (Forbes and Richardson 1920; Dence 1948; Nelson 1968b; Carlander 1969; McPhail and Lindsey 1970; Schneberger 1977; Twomey et al. 1984), but has been reported over boulder substrates as well (Dion et al. 1994). If access to streams is limited, they are also known to spawn along shallow lake margins on sand or gravel shoals, or in quiet areas at the mouths of obstructed streams (Reighard 1913; Hayes 1956; Olson 1963; Krieger 1980; Scott and Crossman 1998). Adults that move into tributary streams to spawn, generally return to the lake within a week or two after spawning is complete (Geen et al. 1966; Scott and Crossman 1998).

Spawning depths have been reported as <30 cm (Nelson 1968b), 15-20 cm (Fuiman 1978), 20-25 cm (Curry 1979), averaging between 51-91 cm (Dion et al. 1994) and ≤1 m (Corbett and Powles 1983). Water velocities associated with spawning have been reported in the range of 0.14-0.9 m/s (Nelson 1968b), averaging 0.45-0.62 m/s (Dion et al. 1994), 0.5 to 0.59 m/s (Curry 1979), and 0.6-0.9 m/s (Minckley 1963). Symons (1976) reported that white suckers in an artificial stream were most often located at modal velocities of 0.3 to 0.49 m/s. Twomey et al. (1984) and Aadland (1993) reported that spawning adults tend to prefer slow riffles where depths are <0.6 m and water velocity ranges from 0.3-0.6 m/s.

Females have been observed spawning more than once with different males (Becker 1983; Scott and Crossman 1998). During spawning, demersal, adhesive eggs are scattered over and adhere to the substrate in the immediate spawning area or drift downstream and adhere to the substrate in quieter areas (Scott and Crossman 1998). Although white suckers can spawn every year, they have been known to skip spawning for up to three years (Geen et al. 1966; Quinn and Ross 1985; Dion et al. 1994). Hatching time is variable depending on geographical location and temperature: Geen et al. (1966, British Columbia) reported hatching within approximately 8 days at 11°C; Walton (1980, Alberta) 15 days at 10°C; Corbett and Powles (1983, Ontario) 16 days at 6-16.8°C; and Dobie et al. (1956) 5 to 7 days at 13.9-20.0°C. McCormick et al. (1977) reported maximum hatching success at 15°C, which significantly diminished at temperatures <9 or >17°C and ceased at an upper and lower lethal limit of 24 and 6°C, respectively.

### 3.14.2.2 Young-of-the-Year/Nursery

Young-of-the-year prefer water temperatures of 23 to 25°C, but have been reported at temperatures ranging between 13-25°C (Marcy 1976b). McCormick et al. (1977) found that the greatest growth was obtained experimentally at a water temperature of 27°C and an upper lethal limit of 30-32°C was reported. Young-of-the-year were usually found over a sand/gravel substrate in areas with moderate currents (Thompson and Hunt 1930, Illinois; Twomey et al. 1984). They were also commonly found in shallow-pool areas having velocities <0.3 m/s and depths <0.6 m, and along channel margins where boulders, vegetation, woody debris and undercut banks were the primary cover types (Aadland 1993). Young-of-the-year sometimes form schools during their first year of life (Becker 1983) and although some migrate to lakes approximately one month after spawning (Geen et al. 1966; Becker 1983; Scott and Crossman 1998; Bradbury et al. 1999), others remain within their natal stream (Aadland 1993).

### 3.14.2.3 Juvenile

Upper lethal temperature limits for juveniles were 26-31°C at acclimation temperatures of 5 to 25°C (Carlander 1969). At acclimation temperatures of 20 to 25°C, the reported lower lethal temperatures were 2 to 6°C (McCormick et al. 1977). Propst (1982, Platte River, Colorado) reported that juveniles (<150 mm length) were found in shallow backwaters and riffles with moderate water velocities (approximately 0.50 m/s) and a predominantly sand/rubble substrate. According to Aadland (1993), juveniles prefer slow riffles where depths are <0.6 m and water velocities range from 0.3-0.6 m/s. Juveniles overwinter beneath rubble and boulders in streams when water temperatures drop below 5°C and have also been found occupying slow, deep (>2 m) steadies (Cunjak and Power 1986). Schneberger (1972) found that juveniles may form schools of several hundred fish.

### 3.14.2.4 Adult

Adults (>150 mm length) primarily inhabit pools and are common in areas of slow to moderate velocity (approximately 0.4 m/s) (Scherer 1965; Pflieger 1975; Propst 1982; Twomey et al. 1984). Propst (1982) observed that adults in Colorado streams inhabited pools having a rubble/gravel/sand substrate with a silt overburden, at preferred depths of 61 to 90 cm (range 21 to 240 cm). Adults occurred mainly over gravel, sand, silt and rubble substrates (Becker 1983; Twomey et al. 1984) and tended to be closely associated with riparian (overhanging trees, grass, shrubs, etc.) and instream (submerged logs, roots, macrophytes, undercut banks, large boulders, etc.) cover (Thompson and Hunt 1930; Dence 1948; Minckley 1963; Propst 1982). Symons (1976) reported that cover-seeking behaviour increased significantly as stream velocity increased. For instance, when present in shallow water with an appreciable current, Twomey et al. (1984) reported that white suckers are usually found in the shelter of vegetation, either instream or overhanging.

A preferred water temperature of 22.4°C was reported for white suckers in Ontario (Spotila et al. 1979). Experimental evidence suggests an optimal summer water temperature for adults of 24°C (Reynolds and Casterlin 1978), although they have been reported at temperatures up to 32°C (Thompson and Hunt 1930, Illinois). Reutter and Herdendorf (1976) reported a critical thermal maximum of 31.6°C in Lake Erie, Ohio. Brett (1944, Algonquin Park, Ontario) reported an upper lethal temperature of 31.2°C for suckers acclimated at 26°C. The wide North American distribution of white suckers indicates that they can survive temperatures as low as 1-2°C (Twomey et al. 1984).

Depending upon geographic location, males typically reach maturity between 2 and 8 years of age (Campbell 1935; Hayes 1956; Geen et al. 1966; Scott and Crossman 1998) with females usually maturing 1 to 2 years later (Spoor 1938). In Labrador, white suckers generally mature at 4 to 5 years of age (Ryan 1980) and a maximum age of 17 years has been reported for this species (Scott and Crossman 1998).

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# Appendix 1 – Tabular Summaries

Table 3. Habitat requirements data for **Atlantic tomcod (*Microgadus tomcod*)**.

| **Habitat Features:** | **Ratings**[1] | | | |
|---|---|---|---|---|
| **Categories**[2] | S | Y | J | A |
| **Velocity (m/s):** | *<0.3* | | | |
| **Depths:** | | | | |
| 0-1 meters | | | | *H* |
| 1-2 meters | | | | *H* |
| 2-5 meters | | | | *H* |
| 5-10 meters | | | | *L* |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | *H* | | | |
| Rubble | | | | |
| Cobble | | | | |
| Gravel | *H* | | | |
| Sand | *H* | | | |
| Silt | | | | |
| Muck(detritus) | | | | |
| Clay(mud) | | | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | | | | *H* |
| Emergents | | | | |
| Overhead | | | | |
| *In situ* | | | | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General:*

Atlantic tomcod occur mainly in shallow, inshore marine areas (Scott and Scott 1998).
Landlocked populations have been reported in Deer Lake, NL (Scott and Crossman 1964).

*Spawning* :

They prefer to spawn in brackish waters or in streams beyond tidal influence (Scott and Scott 1988).
Spawning has been reported over a sand, gravel or boulder substrate at a maximum velocity of 0.3 m/s (*Bergeron et al. 1998* ).

| |
|---|
| *Young-of-the-year:* |
| In the spring, larvae (up to 12 mm TL) (*Booth 1967*) drift downstream to estuaries (*Pearcy and Richards 1962*; *Howe 1971*; Scott and Crossman 1973), where they remain throughout the summer (*Bigelow and Schroeder 1953*). |
| |
| *Juveniles:* |
| No available information on riverine habitat use by juveniles. |
| |
| *Adults*: |
| Adults are commonly found at the high tide mark of saltmarshes and mudflats (*Dutil et al. 1982*), in eelgrass beds (*Howe 1971*), to a maximum depth of 6 m in bays, estuaries and coastal waters within 1.6 km of shore (*Bigelow and Schroeder 1953*). |

Table 4. Habitat requirements data for **burbot (*Lota lota*)**.

| Habitat Features: | Ratings[1] | | | |
|---|---|---|---|---|
| **Categories[2]** | S | Y | J | A |
| **Velocity (m/s):** | *low* | | | *low-fast* |
| **Depths:** | | | | |
| 0-1 meters | *H* | | | |
| 1-2 meters | *H* | | | *M* |
| 2-5 meters | *M* | | | *H* |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | | | | |
| Rubble | *M* | | | *H* |
| Cobble | *M* | *H* | *H* | *H* |
| Gravel | *H* | *H* | *H* | *H* |
| Sand | *H* | *H* | | |
| Silt | *L* | | | |
| Muck(detritus) | | | | |
| Clay(mud) | | | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | | *H* | *H* | *H* |
| Emergents | | *H* | *H* | *H* |
| Overhead | | *H* | *H* | *H* |
| *In situ* | | *H* | *H* | *H* |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General*:

Burbot occur in cool waters of large rivers, lower reaches of tributaries and large lakes (*Becker 1983*).

*Spawning*:

Burbot spawn in lakes (*Boag 1989*; *Ghan and Sprules 1991*; Scott and Crossman 1998) and rivers (*Johnson 1981*; *Sandlund et al. 1985*; *Breeser et al. 1988*).

Burbot spawn in low velocity areas in the main stem of rivers (*Breeser et al 1988*) and behind deposition bars in side channels (*Sorokin 1971*; *McPhail 1997*) or in areas having good aeration such as mouths of small streams, which are open in the winter or in which an air space forms between the ice and water (*Sorokin 1971*).

Non-adhesive eggs are broadcast into the water column (*Fabricius 1954*) and depending on the current may initially drift, but eventually settle into interstices in the substrate (*Sorokin 1971*).

Preferred spawning substrate is sand and fine gravel (*Becker 1983*; *Breeser et al. 1988*; *Ford et al. 1995*; *McPhail 1997*), however, spawning may occur over cobble/rubble substrates with a small amount of silt, sand or detritus (*Sorokin 1971*).

Spawning has been reported at depths ranging from 0.3-3.0 m (*McPhail and Lindsey 1970*; *Ford et al. 1995*) and weak currents of approximately 0.03 m/s (*Sorokin 1971*).

*Young-of-the-year:*

According to *McPhail* (*1997*), quiet water downstream of spawning sites may provide nursery areas for developing larvae.

YOY occupy essentially the same habitat as juveniles (*McPhail 1997*).

YOY have been reported over a mainly sandy substrate and are often found among aquatic plants (*Hanson and Quadri 1980*; *Becker 1983*).

YOY often seek cover from undercut banks, submergent and floating vegetation, rocky substrate, woody debris and roots of tree stumps, especially during the day (*Hanson and Quadri 1980*; *McPhail 1997*).

*Juveniles*:

Juveniles usually occupy shallow regions of streams with rocky or gravel/cobble substrates (*Robins and Deubler 1955*; *Lawler 1963*; *Hartmann 1977*; *Becker 1983*; *Ford et al. 1995*).

Juveniles require cover during the day, sheltering in weed beds, under rocks, debris and undercut banks (*Robins and Deubler 1955*; *Hanson and Quadri 1980*; Scott and Crossman 1998; *Ford et al. 1995*).

Juveniles typically move from shallow to deeper areas during the summer as temperatures increase (*Hartmann 1977*; *Thornburgh 1986*).

*Adults*:

Adults are relatively sedentary (*McPhail 1997*).

In northern rivers, adults appear to prefer turbid water (*Chen 1969*; *Hatfield et al. 1972*; *Breeser et al. 1988*).

Adults tend to congregate in areas with gravel, rock or cobble substrates (*Ford et al. 1995*).

Preferred holding and feeding areas are deep, fast riffles and back eddies or lower velocity backwater areas with velocities <0.3 m/s (*Ford et al. 1995*).

They have been found to occupy deep sections of rivers (*Rawson 1951*; *McPhail and Lindsey 1970*) and deep eddies (*Thornburgh 1986*), mostly at depths >1.5 m (*Becker 1983*).

They often utilize undercut banks as cover as well as roots of trees and dense vegetation (*Becker 1983*).

Table 5. Habitat requirements data for **American eel (*Anguilla rostrata*)**.

| **Habitat Features:** | **Ratings**[1] | | | |
|---|---|---|---|---|
| **Categories**[2] | S | Y | J | A |
| **Velocity (m/s):** | | | | |
| **Depths:** | | | | |
| 0-1 meters | | | *H* | |
| 1-2 meters | | | | |
| 2-5 meters | | | | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | | | *H* | |
| Rubble | | | *H* | |
| Cobble | | | | |
| Gravel | | | *M* | |
| Sand | | | *M* | |
| Silt | | | *H* | |
| Muck(detritus) | | | *H* | |
| Clay(mud) | | | *H* | |
| **Cover:** | | | | |
| Pelagic None | | | | |
| Submergents | | | *H* | |
| Emergents | | | *H* | |
| Overhead | | | | |
| *In situ* | | | *H* | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

| **Comments and observations:** |
|---|
| *General:* |
| American eels are catadromous, which means that on attaining sexual maturity, adults migrate downstream to the sea where they ultimately spawn (*Facey and Van Den Avyle 1987*; Scott and Crossman 1998). |
| |
| *Spawning*: |
| Spawning occurs at sea (*Helfman et al. 1987*; *McCleave et al. 1987*; *Jessop 1996*). |
| Peak spawning migration usually occurs during the last quarter of the moon, which is further enhanced by dark, stormy nights and rising water levels (Communications Directorate 2000). |
| It is presumed that adults die after spawning (*Facey and Van Den Avyle 1987*). |

| |
|---|
| *Young-of-the-year:* |
| It generally takes 8-12 months for young eels, referred to as glass eels, to reach Canadian waters (*Kleckner and McCleave 1985*; Communications Directorate 2000). |
| By the time glass eels reach the estuaries of coastal streams they have become more or less pigmented and are referred to as elvers. Elvers typically migrate into rivers during the summer in NL (Scruton et al. 1997) and always do so at night and on a rising tide (Hudson 1974). |
| Upstream migrating elvers tend to be bottom dwellers, hiding in burrows, snags, plant masses, under rocks or any type of shelter, including burrowing directly into the substrate (*Fahay 1978*; *Facey and Van Den Avyle 1987*). |
| The presence of soft bottom substrates is critical as shelter for migrating elvers (*Fahay 1978*; *Facey and Van Den Avyle 1987*). |
| |
| *Juveniles:* |
| Yellow eels are the feeding and growth phase of American eels (Scott and Crossman 1998). |
| Yellow eels are primarily nocturnal and during the day they are usually partially or completely buried in mainly soft substrates (*Becker 1983*), including sand and gravel (*Trautman 1981*). |
| Their snakelike movements allow them to enter extremely shallow water, sometimes completely leaving the water and clinging to wet grass or rocks to facilitate passage in areas of high flow (*Dintaman 1975*; *Becker 1983*; Scott and Scott 1988). |
| During winter, eels hibernate in the bottom mud (*Vladykov 1955*; *Tesch 1977*; Scott and Scott 1988; Scott and Crossman 1998; Communications Directorate 2000). |
| |
| *Adults*: |
| During downstream migration in the fall, yellow eels transform into silver eels, which prepares them for life in the ocean (Communications Directorate 2000). |
| |

Table 6. Habitat requirements data for **alewife (*Alosa pseudoharengus*)**.

| **Habitat Features:** | **Ratings**[1] | | | |
|---|---|---|---|---|
| **Categories**[2] | S | Y | J | A |
| **Velocity (m/s):** | *slow/rapids* | | | |
| **Depths:** | | | | |
| 0-1 meters | *H* | *H* | *H* | |
| 1-2 meters | *H* | *H* | *H* | |
| 2-5 meters | *H* | | *H* | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | | | | |
| Rubble | | | | |
| Cobble | | | | |
| Gravel | *H* | | | |
| Sand | *H* | *H* | | |
| Silt | | | | |
| Muck(detritus) | *H* | | | |
| Clay(mud) | | | | |
| Pelagic | | *M* | *M* | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | *M* | | | |
| Emergents | | | | |
| Overhead | | | | |
| *In situ* | *M* | | | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

| **Comments and observations:** |
|---|
| *General:* |
| In NL, alewives occur in anadromous (Winters et al. 1973; Hare and Murphy 1974; Anderson 1985) and landlocked forms (Scott and Crossman 1998). |
| Anadromous alewives utilize freshwater streams for spawning, but spend most of their life at sea (Scott and Scott 1988; Scott and Crossman 1998), while landlocked forms spend their entire lives in freshwater (*Communications Directorate 1990*). |
| |
| *Spawning*: |
| Alewives spawn in rivers and streams above tidal influence (*Pardue 1983*; Scott and Scott 1988; Scott and Crossman 1998). |

| |
|---|
| Adults return to the sea shortly after spawning (*Communications Directorate 1990*). |
| Spawning typically occurs in sluggish stretches of streams (*Jones et al. 1978*; *Communications Directorate 1990*), but has been reported in rapids (*McKenzie 1959*). |
| Eggs are broadcast and are initially adhesive in still water, but are mainly pelagic in running water (*Loesch and Lund 1977*; *Jones et al. 1978*; *Communications Directorate 1990*). |
| Alewives spawn at depths of 15 cm to 3 m over substrates of gravel, sand and detritus with attached vegetation or sticks (*Edsall 1964*; *Mansuetti and Hardy 1967*; *Pardue 1983*; *Loesch 1987*; *Bozeman et al. 1989*). |
| |
| *Young-of-the-year:* |
| Larvae normally hatch in the spring (*Communications Directorate 1990*) and typically remain within the vicinity of spawning grounds for 1-2 weeks after hatching (*Jones et al. 1978*). |
| Larvae were found to occupy shallow (<2 m), sandy areas near spawning sites (*O'Neill 1980*). |
| In late fall and early winter, most young begin migrating downstream and some utilize estuarine waters as nurseries before migrating to sea (*Hildebrand and Schroeder 1929*; *Holland and Yelverton 1973*). |
| Once at sea, young typically remain there for 4-5 years before returning to freshwater to spawn (*Communications Directorate 1990*). |
| |
| *Juveniles:* |
| Juveniles are often concentrated near the bottom during the day and move up into the water column at night (*Loesch 1987*). |
| Juveniles have been found at depths up to 4.6 m (*Warinner et al. 1969*). |
| |
| *Adults*: |
| Adults spend most of their lives at sea, entering freshwater only to spawn (*Jones et al. 1978*; Scott and Crossman 1998). |
| |

Table 7. Habitat requirements data for **American shad (*Alosa sapidissima*)**.

| **Habitat Features:** | **Ratings**[1] | | | |
|---|---|---|---|---|
| **Categories**[2] | S | Y | J | A |
| **Velocity (m/s):** | *0.09-1.3* | *variable* | | |
| **Depths:** | | | | |
| 0-1 meters | *H* | *H* | *L* | |
| 1-2 meters | *H* | *H* | *H* | |
| 2-5 meters | *H* | | *H* | |
| 5-10 meters | *H* | | | |
| 10+ meters | *H* | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | *H* | | | |
| Rubble | *H* | | | |
| Cobble | *H* | | | |
| Gravel | *H* | | | |
| Sand | *H* | | | |
| Silt | *H* | | | |
| Muck(detritus) | *H* | | | |
| Clay(mud) | | | | |
| Pelagic | *H* | *H* | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | | | | |
| Emergents | | | | |
| Overhead | | | | |
| *In situ* | | | | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General:*

American shad are anadromous (Dempson et al. 1983).

*Spawning* :

Although shad spawn practically anywhere in rivers and streams (*Walburg and Nichols 1967* ; *Leggett and Whitney 1972* ; *Weiss-Glanz et al. 1986* ; Scott and Crossman 1998), they prefer broad flats or shallow water (*Smith 1907* ; *Bigelow and Welsh 1925* ; *Hildebrand and Schroeder 1928* ; *Massman 1952* ; *Marcy 1972* ).

Spawning has been reported over a range of velocities from 0.09-1.3 m/s (*Kuzmeskus 1977* ), but usually occurs at velocities between 0.3 and 0.9 m/s (*Walburg 1960* ; *Walburg and Nichols 1967* ).

| |
|---|
| Spawning occurs at depths ranging from 0.45-12.2 m (*Mansueti and Kolb 1953* ; *Walburg 1960* ; *Walburg and Nichols 1967* ; *Kuzmeskus 1977* ). |
| Since eggs are released in open water (Scott and Crossman 1998), shad do not exhibit strong substrate preferences. Spawning has been observed over sand, silt, muck, gravel and boulder substrates, providing there is sufficient flow to remain silt-free (*Mansueti and Kolb 1953* ; *Walburg 1960* ; *Leggett 1976* ). |
| *Jones et al.* (*1978* ) reported eggs lodged in rubble. |
| Shad spawn far enough upstream to allow the eggs sufficient time to drift and hatch before reaching saltwater (*Weiss-Glanz et al. 1986* ). |
| |
| *Young-of-the-year:* |
| Newly hatched larvae are initially planktonic (*Marcy 1976* ). |
| Larvae have been shown to have an affinity for riffle pools characterized by moderate depth (assumed to be <2 m) and currents of varying velocity (*Ross et al. 1993b* ). |
| Young form schools and gradually migrate downstream in the fall (*Leggett and Whitney 1972* ; *O'Leary and Kynard 1986* ) and although some may remain in the estuary during their first year (*Hildebrand 1963* ), others move directly to the open ocean (*Chittenden 1969* ; *Jones et al. 1978* ). |
| |
| *Juveniles:* |
| While in rivers, juveniles occupy depths of 0.9-4.9 m, where they are found near the bottom during the day and occupy surface waters at night (*Marcy 1976* ). |
| Juveniles do not appear to have any substrate preferences (*Ross et al. 1997* ). |
| They usually spend 4-5 years at sea until they mature (*Communications Directorate 1990* ). |
| |
| *Adults* : |
| Adults are generally found at sea (*Morrow 1980* ; *Communications Directorate 1990* ) where they remain for 2-6 years (*Talbot and Sykes 1958* ; *Walburg and Nichols 1967* ; *Leggett 1976* ; *Leggett and Carscadden 1978* ; *Morrow 1980* ; *Melvin et al. 1986* ) before returning to rivers to spawn (*Weiss-Glanz et al. 1986* ; Scott and Crossman 1998). |
| |

Table 8. Habitat requirements data for **banded killifish (*Fundulus diaphanous*)**.

| **Habitat Features:** | | **Ratings**[1] | |
|---|---|---|---|
| **Categories**[2] | S | Y + J | A |
| **Velocity (m/s):** | | | |
| **Depths:** | | | |
| 0-1 meters | *H* | *H* | *H* |
| 1-2 meters | | | |
| 2-5 meters | | | |
| 5-10 meters | | | |
| 10+ meters | | | |
| **Substrate:** | | | |
| Bedrock | | | |
| Boulder | | | |
| Rubble | | | |
| Cobble | | *H* | H |
| Gravel | | *H* | *H* |
| Sand | | *H* | H |
| Silt | | | |
| Muck(detritus) | | *H* | *H* |
| Clay(mud) | | *H* | *H* |
| Pelagic | | | |
| **Cover:** | | | |
| None | | | |
| Submergents | *H* | | *M* |
| Emergents | *H* | | |
| Overhead | | | |
| *In situ* | | | |
| Other | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

| **Comments and observations:** |
|---|
| *General:* |
| Although euryhaline and salinity tolerant to a degree, it is considered a freshwater resident (Scott and Scott 1988; Houston 1990). |
| |
| *Spawning* : |
| Spawning typically occurs in quiet shallows of weedy pools (Scott and Crossman 1998). |
| After fertilization, eggs attach to vegetation (Scott and Crossman 1998). |
| |
| *Young-of-the-year/Juveniles:* |
| Since banded killifish generally reach sexual maturity at one year of age (*Carlander 1969*), it is not |

| |
|---|
| necessary to have a separate column for young-of-the-year and juveniles. They are assumed to have |
| habitat utilization patterns similar to adults. |
| |
| *Adults* : |
| Adults usually form schools and are found in shallow water areas having a sand, gravel or detritus- |
| covered substrate near patches of submerged aquatic plants (Keast et al. 1978; *Rozas and* |
| *Odum 1987* ; *Killgore et al. 1989* ; Houston 1990; *Page and Burr 1991* ; Scott and Crossman 1998). |
| In NL, Gibson (1984) captured killifish over a sand/cobble substrate. |
| |

Table 9. Habitat requirements data for **mummichog (*Fundulus heteroclitus*)**.

| **Habitat Features:** | | **Ratings**[1] | |
|---|---|---|---|
| **Categories**[2] | S | Y | J + A |
| **Velocity (m/s):** | | | |
| **Depths:** | | | |
| 0-1 meters | *H* | | *H* |
| 1-2 meters | | | *H* |
| 2-5 meters | | | *H* |
| 5-10 meters | | | |
| 10+ meters | | | |
| **Substrate:** | | | |
| Bedrock | | | |
| Boulder | | | |
| Rubble | | | |
| Cobble | | | |
| Gravel | | | |
| Sand | *H* | | |
| Silt | | | |
| Muck(detritus) | | | |
| Clay(mud) | *H* | | *H* |
| Pelagic | | *M* | |
| **Cover:** | | | |
| None | | | |
| Submergents | *H* | *H* | *H* |
| Emergents | *H* | *H* | *H* |
| Overhead | | | |
| *In situ* | | | |
| Other | *H* | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General:*

Mummichog are most commonly found in salt marshes, estuaries, brackish ponds and tidal areas, particularly where there is submergent or emergent vegetation (*Abraham 1985*; Scott and Scott 1988; Scott and Crossman 1998).

Mummichog are euryhaline (*de Silva 1969*; *Fritz and Garside 1974*; *Abraham 1985*) and especially tolerant of abrupt salinity changes (*Garside and Chin-Yuen-Kee 1972*).

*Spawning*:

Spawning occurs in shallow fresh, salt or brackish water (*Hardy 1978*).

Peak spawning occurs during high spring tides at night (*Taylor et al. 1979*).

Eggs may be deposited in empty mussel shells within the intertidal zone (*Able and Castagna 1975* ; *Taylor et al. 1977* ; *Kneib and Stiven 1978* ; *Taylor et al. 1982* ; *Taylor and DiMichele 1983* ), over sand and mud, algal mats or aquatic plants (*Pearcy and Richards 1962* ; *Able and Castagna 1975* ; *Taylor et al. 1979* ; *Day and Taylor 1981* ; *Taylor 1986* ).

*Young-of-the-year:*

Larvae have been observed in shallow tidal waters of salt marshes (*Kneib 1984* ) and surface waters of an intertidal marsh (*Taylor et al. 1979* ).

*Juveniles:*

There was no distinction in the literature reviewed with respect to habitat requirements of juveniles and adults, therefore their habitat requirements were combined.

*Adults* :

Mummichog have been shown to prefer areas of submerged grass and mud substrates (*Hildebrand and Schroeder 1928* ; *Abraham 1985* ).

They seldom occur at depths >4 m (*Bigelow and Schroeder 1958a* ).

In NL, they were found in a stagnant backwater area of an estuary at a depth of 1 m over a mud substrate devoid of vegetation and a small lagoon in dense eelgrass over a soft mud substrate (Dickinson 1974).

During winter, some mummichog reside in pools where they have been shown to burrow 15-25 cm into the mud (*Chidester 1920* ; *Hardy 1978* ), while others migrate to the mouths of their tidal channels (*Butner and Brattstrom 1960* ).

Table 10. Habitat requirements data for sea lamprey (*Petromyzon marinus*).

| Habitat Features: | Ratings[1] | | | |
|---|---|---|---|---|
| **Categories[2]** | S | Y | J | A |
| **Velocity (m/s):** | *0.5-1.5* | *low* | | |
| **Depths:** | | | | |
| 0-1 meters | H | | | |
| 1-2 meters | *H* | | | |
| 2-5 meters | | | | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | *M* | *L* | | |
| Rubble | | *L* | | |
| Cobble | H | *L* | | |
| Gravel | H | | | |
| Sand | *H* | *H* | | |
| Silt | | *H* | | |
| Muck(detritus) | | *H* | | |
| Clay(mud) | | *H* | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | | *H* | | |
| Emergents | | *H* | | |
| Overhead | *H* | *H* | | |
| *In situ* | *H* | *H* | | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General:*

Although sea lamprey are typically anadromous, ascending streams in spring to spawn, and otherwise spend their entire adult life at sea where it leads a parasitic existence, feeding upon other fish (*Downs 1982*; Scott and Scott 1988), landlocked forms have been reported within the watersheds of all the Great Lakes (Scott and Crossman 1998).

*Spawning*:

Lampreys may spawn communally (*Huggins and Thompson 1970*), be monogamous (*Manion and Hanson 1980*), or exhibit little fidelity to a mate (*Noltie and Robilliard 1987*; *Kelso et al. 2001*). Although sea lampreys were observed in a variety of habitats, they were almost always in areas with reduced light, seeking cover in refugia, such as brush or log piles, overhanging or undercut banks and boulders (*Kelso and Gardner 2000*).

Spawning occurs over a sand, gravel or cobble substrate at depths ranging from 0.1-1.7 m and velocities between 0.5-1.5 m/s (*Beamish 1980*; *Manion and Hanson 1980*; *Mormon et al. 1980*; Scott and Scott 1988; Scott and Crossman 1998; *Johns 2002*).

In tributaries of the Great Lakes, lamprey utilized clam shells and lumps of clay for nest construction in the absence of suitable substrate (*Morman et al. 1980*).

In the Carp River, Lake Superior, lamprey were observed spawning in riffle areas containing mixed gravel, pebbles, and small boulders (*Kelso et al. 2001*).

In NL, lamprey nests were found at water depths ranging from 0.25-1 m over a gravel/cobble substrate (Dempson and Porter 1993).

Males excavate a depression in the substrate by thrashing their tail and moving large particles with their suctorial mouth (Scott and Crossman 1998; *Johns 2002*).

Spawning occurs in the nest with females depositing adhesive, non-buoyant eggs (Scott and Scott 1988).

All lamprey die after spawning (*Beamish 1980*; Dees 1980; *Manion and Hanson 1980*; Scott and Scott 1988; Scott and Crossman 1998).

*Young-of-the-year:*

Upon hatching, larvae are referred to as ammocoetes and remain buried in the substrate for up to 8 days before emerging from the nest (*Becker 1983*; Scott and Scott 1988; Scott and Crossman 1998).

After emergence, larvae drift downstream into eddies and pools having sand, silt and mud bottoms (*Beamish 1980*; *Trautman 1981*; Scott and Crossman 1998).

Larvae burrow into the soft substrate where they remain as filter feeders for 3-17 years until they transform into juveniles (*Wigley 1959*; *Wadden 1968*; *Beamish 1980*; *Dees 1980*; *Downs 1982*; Scott and Scott 1988).

Suitable nursery habitats are typically characterized by marginal deposits of fine sediments, a degree of shading, and the presence of aquatic plants and organic detritus (*Johns 2002*), however, they have also been found in other locations, including silted cobble deposits and among submerged blockstones used to reinforce stream banks (*Johns 2002*).

*Juveniles:*

Following metamorphosis, they migrate downstream to estuaries (*Beamish 1980*), where they remain largely within the confines of the estuary or at least close to shore (*Bigelow and Schroder 1948*; *1953*).

*Adults*:

Adults spend their entire life at sea (anadromous) or in lakes (landlocked) (*Downs 1982*; Scott and Scott 1988).

Table 11. Habitat requirements data for **lake chub (*Couesius plumbeus*)**.

| **Habitat Features:** | **Ratings[1]** | | | |
|---|---|---|---|---|
| **Categories[2]** | S | Y | J | A |
| **Velocity (m/s):** | *slow* | *<0.5* | *0-0.9* | *0-0.9* |
| **Depths:** | | | | |
| 0-1 meters | *H* | *H* | *H* | *H* |
| 1-2 meters | | | | |
| 2-5 meters | | | | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | *M* | | | *H* |
| Rubble | *M* | | *H* | *H* |
| Cobble | *H* | | *H* | *H* |
| Gravel | *H* | | *H* | *H* |
| Sand | | | *H* | *H* |
| Silt | | | *H* | |
| Muck(detritus) | | | | |
| Clay(mud) | | | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | | *H* | | |
| Emergents | | | | |
| Overhead | | | | |
| *In situ* | | | | *H* |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General*:

Although lake chub have been found in both clear and turbid waters of lakes and streams (*McPhail and Lindsey 1977*; *Becker 1983*; Bradbury et al. 1999), in Labrador, they occur mostly in streams and lake-like expansions of rivers (Scott and Crossman 1998).

In central Canada, lake chub appear to be common in tributary streams only during spring spawning migrations, returning to lakes once water temperatures exceed 16$^0$C (*Brown et al. 1970*). Thus, lake chub appear to resort to lakes whenever they are available (Scott and Crossman 1998).

*Spawning:*

Shortly after ice-out in the spring, lake chub usually undergo spawning migrations from lakes to

| |
|---|
| tributary streams, or within streams to desired spawning locations (*Becker 1983* ; Scott and Crossman 1998). |
| Spawning has been observed in shallow water (<1 m) over gravel and rocks (which were assumed to be cobble, rubble and boulders) (*Brown et al. 1970* ; *McPhail and Lindsey 1977* ; *Morrow 1980* ; *Becker 1983* ; Scott and Crossman 1998). |
| Spawning has been reported along stream margins at depths of 5 cm (*Becker 1983* ) and at depths <1 m in a western Labrador stream (Bruce and Parsons 1976). |
| |
| *Young-of-the-Year:* |
| Fry were captured at depths <5 cm amongst submerged vegetation away from the main current and were also reported at depths of approximately 50 cm near river mouths (*Brown et al. 1970* ). |
| YOY were captured most frequently in shallow (<0.9 m) backwaters over sand and silt, where velocities were <0.5 m/s (*Mecum 1984* ). |
| |
| *Juveniles* : |
| Juveniles were captured over a variety of substrates, including silt, sand, gravel, cobble and rubble at depths <0.6 m and velocities ranging from 0-0.9 m/s (*Mecum 1984* ). |
| |
| *Adults:* |
| Lake chub were reported to remain hidden among rocks (assumed to be cobble, rubble and boulders) until water temperatures reached $8^0$C (*Brown et al. 1970* ). |
| Lake chub are commonly found near the mouths of streams at depths <1 m over a sand bottom interspersed with large-sized boulders (*Becker 1983* ). |
| Adults are common in gravel-bottomed pools and runs of streams (*Page and Burr 1991* ). |
| In Alaska, adults preferred shallow (<0.6 m) riffle areas over gravel, cobble and rubble substrates and although they were observed at velocities ranging from 0-0.9 m/s, they were most commonly captured at velocities >0.4 m/s (*Mecum 1984* ). |
| |

Table 12. Habitat requirements data for **longnose dace (*Rhinichthys cataractae*)**.

| **Habitat Features:** | **Ratings**[1] | | | |
|---|---|---|---|---|
| **Categories**[2] | S | Y | J | A |
| **Velocity (m/s):** | *0.3-1.0* | *0-1.2* | *0.2-1.2* | *0.2-1.9* |
| **Depths:** | | | | |
| 0-1 meters | *H* | *H* | *H* | *H* |
| 1-2 meters | | | | |
| 2-5 meters | | | | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | *L* |
| Boulder | | *H* | *H* | *H* |
| Rubble | *H* | *H* | *H* | *H* |
| Cobble | *H* | *H* | *H* | *H* |
| Gravel | *H* | *H* | | *H* |
| Sand | | *M* | | *H* |
| Silt | | *M* | | *M* |
| Muck(detritus) | | | | *L* |
| Clay(mud) | | | | *L* |
| Pelagic | | *M* | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | | | | *H* |
| Emergents | | | | *H* |
| Overhead | *H* | *H* | *H* | *H* |
| *In situ* | *H* | *H* | *H* | *H* |
| Other | | | | |

[1]Ratings are Nil (default); L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General* :

Longnose dace are bottom dwellers (Scott and Crossman 1998), usually found in running water, either clear or muddy (*McPhail and Lindsey 1970*), however, at higher altitudes (where biological competition is not very intense), they are commonly found in areas of moderate current and even lakes (*Becker 1983*).

All age groups of longnose dace occur in very shallow water, usually <0.3 m deep and rarely >1.0 m deep (*Edwards et al. 1983*).

*Spawning* :

Spawning usually occurs in riffles at depths <0.6 m, water velocities between 0.3-0.6 m/s, and mainly gravel, cobble or rubble substrates (*Bartnik 1970* ; *Edwards et al. 1983* ; *Aadland 1993* ; Scott and Crossman 1998).

Spawning has also been reported over fine gravel in a strong current (*Greeley and Bishop 1933* ) and spawning redds have been found in riffle areas having surface velocities ranging from 0.5-1.0 m/s, over a mainly cobble substrate and depths of 0.1-0.4 m (*Gibbons and Gee 1972* ).

*Bartnik (1970)* noted that overhead cover and shelter from the current is always present at spawning sites.

*Young-of-the-year* :

YOY are pelagic within 2 weeks after spawning (*McPhail and Lindsey 1970* ; *Becker 1983* ; *Edwards et al. 1983* ) and inhabit shallow, relatively quiet waters along river margins (*McPhail and Lindsey 1970* ; *Edwards et al. 1983* ; Scott and Crossman 1998).

This pelagic stage usually lasts from 2 weeks (*Gee and Northcote 1963* ) to about 4 months (*Becker 1983* ; Scott and Crossman 1998) before the typical bottom-dwelling existence of adults commences at which time they begin choosing faster currents and gradually move into deeper water (*McPhail and Lindsey 1970* ; *Gibbons and Gee 1972* ; *Becker 1983* ; Scott and Crossman 1998).

*Aadland (1983)* reported that YOY were found most often in shallow pools having velocities <0.3 m/s and depths <60 cm, while *Gibbons and Gee (1972)* found they typically inhabited stream margins (i.e., mean velocities of 0-0.15 m/s, depths ranging between 7-25 cm and substrates comprised mainly of silt and sand).

As YOY increase in size they tend to occupy gravel and small rock riffle habitats (i.e., water velocities between 0.45-1.0 m/s, depths between 7-35 cm, and mainly gravel/cobble substrates) as well as large rock riffles (i.e., mean velocities of 0.45-1.2 m/s, depths between 0.1-0.35 m, and mainly rubble/ boulder substrates) (*Gibbons and Gee 1972* ).

YOY show a preference for areas with overhead cover (*Edwards et al. 1983* ) and have been shown to seek cover under flat stones within riffle areas during the fall (*Gibbons and Gee 1972* ).

*Juveniles:*

In general, juvenile habitat requirements are similar to those of adults; they are found in riffle areas with velocities >0.45 m/s, but will also seek out quieter areas (*Edwards et al. 1983* ).

Juveniles tend to complete their life cycle in large rock riffles (i.e., mean velocities of 0.45-1.2 m/s, depths between 0.1-0.35 m, and mainly rubble/boulder substrates) (*Gibbons and Gee 1972* ).

Juveniles were reported at depths between 10-19 cm, velocities between 0.25-0.5 m/s (avoided velocities <0.1 m/s), and boulder substrates (*Mullen and Barton 1995* ; *1998* ).

Juveniles often seek cover under stones within riffle areas (*McPhail and Lindsey 1970* ; *Gibbons and Gee 1972* ).

*Adults* :

Longnose dace are characteristic of clean, swift-flowing, gravel, rubble or boulder streams, at times inhabiting very turbulent waters (*Becker 1983* ; *Hubert and Rahel 1989* ; *Johnson et al. 1992* ; Scott and Crossman 1998) and generally avoid pools and quiet runs, except during the winter (*Becker 1983* ).

High water velocity seems to be a key habitat variable for longnose dace (*Johnson et al. 1992* ); they are typically found in areas with velocities >0.45 m/s (*Edwards et al. 1983* ).

In summer, longnose dace were found primarily in areas with high water velocities (0.25-0.45 m/s) and

| |
|---|
| depths of 5-15 cm (*Johnson et al. 1992*), while during winter they became sedentary and inactive in |
| relatively quiet, shallow (15-30 cm) pools or in shallow (15-30 cm), flat, sand- and gravel-bottomed |
| slicks adjacent to summer habitat (*Becker 1983*). |
| Adults inhabit areas with faster currents (0.25-0.5 m/s), water depths between 10-30 cm and boulder |
| substrates (*Mullen and Barton 1995*; *1998*; LGL Limited 1999). |
| In Wisconsin streams, longnose dace were found over the following substrates in order of decreasing |
| frequency: gravel, rubble, sand, boulders, silt, mud, clay, bedrock and detritus (*Becker 1983*). |
| Adults seek shelter under cobble, rubble or boulder substrates or submergent vegetation (*Aadland* |
| *1993*; *Cunjak 1996*), especially in the fall and winter when water temperatures drop below $5^0$C |
| (*Gibbons and Gee 1972*; *Cunjak and Power 1986*). |
| Most adults seem to prefer areas with aquatic vegetation and overhead cover (*Hubert and Rahel 1989*; |
| *Aadland 1993*). |
| They live in crevices between stones in very fast water (as high as 1.9 m/s surface velocity) (*McPhail* |
| *and Lindsey 1970*; *Edwards et al. 1983*). |
| |

Table 13. Habitat requirements data for **pearl dace (*Semotilus margarita*)**.

| **Habitat Features:** | **Ratings**[1] | | | |
|---|---|---|---|---|
| **Categories**[2] | S | Y | J | A |
| **Velocity (m/s):** | *low-mod.* | *<0.05-0.45* | *<0.05-0.45* | <0.05-0.45 |
| **Depths:** | | | | |
| 0-1 meters | *H* | *H* | *H* | *H* |
| 1-2 meters | | | | |
| 2-5 meters | | | | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | | | | |
| Rubble | | | | |
| Cobble | | | | |
| Gravel | *H* | | | |
| Sand | *H* | | | |
| Silt | | | | |
| Muck(detritus) | | | | |
| Clay(mud) | | | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | | | | |
| Emergents | | | | |
| Overhead | | | | |
| *In situ* | | | | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General*:

Pearl dace occur in cool, clear headwater streams and small lakes throughout most of its Canadian range (Scott and Crossman 1998).

*Spawning*:

Spawning typically occurs at depths of 0.4-0.6 m, over a sand/gravel substrate, in areas with a weak or moderate current (*Langlois 1929*; *McPhail and Lindsey 1970*).

*Young-of-the-year*:

In May, YOY were most common in shallow pools (depths <0.5 m and velocities <0.05 m/s) (*Tallman*

| |
|---|
| *and Gee 1982* ). |
| From June to August, YOY were found mostly in shallow (<0.5 m), slow moving water (pools, <0.05 m/s or channels, 0.05-0.45 m/s) (*Tallman and Gee 1982* ). |
| In September, they began to appear in deeper (>0.5 m) sections of the streams (*Tallman and Gee 1982* ). |
| |
| *Juveniles/Adults:* |
| From May to August, age 1 individuals fed up in the water column, while those age 2+ chose feeding sites close to the bottom (*Tallman and Gee 1982* ). |
| In May, age 1 and 2+ dace were abundant in pools (velocities <0.05 m/s) and channels (velocities 0.05-0.45 m/s), but not riffles (*Tallman and Gee 1982* ). |
| During summer, age 1 fish occupied shallow pools (depths <0.5 m, velocities <0.05 m/s) and deep channels (depths >0.5 m, velocities 0.05-0.45 m/s), while age 2+ occurred in deep pools (depths >0.5 m, velocities <0.05 m/s) and deep channels (>0.5 m and velocities 0.05-0.45 m/s) (*Tallman and Gee 1982* ). |
| By November, age 1 and 2+ were found almost exclusively in deep pools (*Tallman and Gee 1982* ). |
| |

Table 14. Habitat requirements data for **logperch (*Percina caprodes*)**.

| **Habitat Features:** | **Ratings**[1] | | | |
|---|---|---|---|---|
| **Categories**[2] | S | Y | J | A |
| **Velocity (m/s):** | *riffle* | *pools* | | *fast* |
| **Depths:** | | | | |
| 0-1 meters | | *H* | | H |
| 1-2 meters | | | | |
| 2-5 meters | | | | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | | | | |
| Rubble | | *H* | | |
| Cobble | | *H* | | H |
| Gravel | *H* | *H* | | *H* |
| Sand | *H* | | | *H* |
| Silt | | | | |
| Muck(detritus) | | | | |
| Clay(mud) | | | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | | *H* | | |
| Emergents | | *H* | | |
| Overhead | | | | |
| *In situ* | | *H* | | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General*:

Logperch tend to inhabit sand, gravel or rocky substrates in rivers, sometimes in rather swift water (*Dymond 1926*).

Most common over gravel and sand in medium-sized rivers, but can be found almost anywhere from small, fast-flowing rock-bottomed streams to vegetated lakes (*Page and Burr 1991*).

*Spawning*:

Spawning typically occurs in sand and gravel riffle areas (*Becker 1983*).

| |
|---|
| *Young-of-the-Year:* |
| Larvae were most commonly associated with vegetated shorelines, pools and gravel substrates (*Floyd et al. 1984*). |
| YOY seek cover among roots and algae (*Floyd et al. 1984*) and were often associated with dense beds of vegetation in shallow water (*Becker 1983*). |
| |
| *Juveniles:* |
| There was no information on riverine habitat requirements of juveniles in the literature reviewed. |
| |
| *Adults:* |
| After spawning, adults migrate to deeper areas of lakes and streams (*Becker 1983*). |
| In Labrador, adults were captured in relatively fast-flowing riffle areas over a mainly cobble substrate at depths of 0.5-0.8 m (Grant et al. 2000). |
| |

Table 15. Habitat requirements data for **northern pike (*Esox lucius*)**.

| **Habitat Features:** | **Ratings[1]** | | | |
|---|---|---|---|---|
| **Categories[2]** | S | Y | J | A |
| **Velocity (m/s):** | *slow* | *slow* | *slow* | *<0.3* |
| **Depths:** | | | | |
| 0-1 meters | *H* | *H* | *H* | *H* |
| 1-2 meters | *M* | | *H* | *H* |
| 2-5 meters | *L* | | | *H* |
| 5-10 meters | | | | *M* |
| 10+ meters | | | | *L* |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | | | | |
| Rubble | *M* | *M* | | |
| Cobble | | | | |
| Gravel | | | | |
| Sand | *L* | | | |
| Silt | *H* | *H* | *H* | *H* |
| Muck(detritus) | *L* | | *H* | *H* |
| Clay(mud) | *L* | | *H* | *H* |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | *H* | *H* | *H* | *H* |
| Emergents | *H* | *H* | | *H* |
| Overhead | | | | *H* |
| *In situ* | | *H* | | *H* |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General*:

In Canada, pike generally inhabit clear, cool to moderately warm, slow, meandering, heavily vegetated rivers or warm, weedy bays of lakes (*Becker 1983*; Scott and Crossman 1998) and typically occur more frequently in lakes than in rivers (*Inskip 1982*).

Pike inhabit areas containing aquatic vegetation throughout all stages of their life cycle (*Ford et al. 1995*; *Inskip 1982*) and have been found over a wide range of turbidity, although they are much more common in clear and only slightly turbid water (*Becker 1983*).

*Spawning*:

Strong currents (>1.5 m/s) have been shown to prevent spawning migrations (*Dryden and Jessop 1974*). Although, preferred spawning depths have been reported ranging between 0.1-0.7 m (*Johnson 1957*; *Machniak 1975b*; *Inskip 1982*; *Becker 1983*; *Ford et al. 1995*; *Casselman and Lewis 1996*), *Farrell et* *al.* (*1996*) observed spawning over depths of 0.5-2.6 m.

Pike generally spawn in shallow, heavily vegetated floodplains of rivers, marshes, and lakes (*Klemetsen et al. 1989*; Scott and Crossman 1998; Bradbury et al. 1999).

Spawning has been reported over flooded emergent vegetation (*Machniak 1975b*; *Becker 1983*; *Holland and Huston 1984*) as well as submerged vegetation (*McPhail and Lindsey 1970*; *Ford et al. 1995*).

Shallow vegetated areas, such as flooded marshes, flooded terrestrial vegetation or weedy bays provide suitable spawning habitat provided high water levels are maintained throughout the embryo and fry stage (*McPhail and Lindsey 1970*; *Inskip 1982*; *Ford et al. 1995*; Scott and Crossman 1998).

Grasses, sedges or rushes with fine leaves appear to make the best substrate for egg deposition (*Machniak 1975b*; *Inskip 1982*; *Becker 1983*; *Ford et al. 1995*).

The type of bottom over which spawning occurs varies widely, but a soft, silt-filled rubble with decaying vegetation is common (*Ford et al. 1995*). According to *Casselman and Lewis* (*1996*), preferred spawing substrate is well-oxygenated detritus and elaborate root systems of emergent vegetation, but has been reported over sand to mud substrates (*Holland and Huston 1984*; Scott and Crossman 1998).

Flowing water is not required for spawning (*Ford et al. 1995*).

*Young-of-the-year*:

Larvae remain attached to the vegetation for 4-15 days after hatching (*Howard and Thomas 1970*; *Inskip 1982*; *Ford et al. 1995*) and may remain within the spawning area for several weeks (*Machniak 1975b*; *Inskip 1982*; *Becker 1983*; *Ford et al. 1995*; Scott and Crossman 1998).

Although YOY prefer submerged vegetation with some emergent and floating vegetation interspersed, woody debris and other structures can sometimes provide cover (*Inskip 1982*; *Anderson 1993*; *Casselman and Lewis 1996*).

*Juveniles*:

Although there are some reports of extensive migrations of juveniles, they generally remain sedentary for most of their early life where there is adequate food and cover available (*Ford et al. 1995*; Scott and Crossman 1998).

Juveniles are typically found over a mud or silt bottom at depths <2.0 m (*Ford et al. 1995*).

Submerged vegetation is important for juveniles as it provides refuge (*Ford et al. 1995*).

*Adults*:

Northern pike are visual predators and their ambush style of feeding requires cover, usually in the form of aquatic vegetation, tree stumps or fallen logs (*Inskip 1982*; *Becker 1983*; *Ford et al. 1995*).

Adults have been shown to prefer areas containing open water interspersed with moderately abundant vegetation comprising approximately 30-70% cover (*Inskip 1982*; *Grimm and Backx 1990*; *Casselman and Lewis 1996*; *Randall et al. 1996*).

Adults were found most often in medium pool habitats (i.e., velocities <0.3 m/s and depths of 0.6-1.5 m) (*Aadland 1993*) containing a mud, silt or organic bottom (*Inskip 1982*; *Ford et al. 1995*; *Casselman and Lewis 1996*).

Although adults generally occupy relatively shallow water during summer (<4 m), they sometimes move into areas as deep as 12 m, providing it is relatively clear, cool and well-oxygenated with some vegetative cover (*Inskip 1982*; *Casselman and Lewis 1996*).

Table 16. Habitat requirements data for **Arctic charr (*Salvelinus alpinus*)**.

| **Habitat Features:** | **Ratings**[1] | | | |
|---|---|---|---|---|
| **Categories**[2] | S | Y | J | A |
| **Velocity (m/s):** | 0.1-0.7 | *0.1-0.5* | *<0.1* | *<0.1* -1.0 |
| **Depths:** | | | | |
| 0-1 meters | H | *H* | *H* | M |
| 1-2 meters | H | | *M* | *H* |
| 2-5 meters | *M* | | | |
| 5-10 meters | *L* | | | |
| 10+ meters | *L* | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | | | | H |
| Rubble | *M* | *H* | *H* | H |
| Cobble | *H* | *H* | *H* | *M* |
| Gravel | H | *H* | *H* | L |
| Sand | M | | *M* | L |
| Silt | | | | |
| Muck(detritus) | | | | |
| Clay(mud) | | | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | | | | |
| Emergents | | | | |
| Overhead | | | | |
| *In situ* | | H | H | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

| **Comments and observations:** |
|---|
| *General:* |
| In the northern part of its range, Arctic charr are mostly anadromous, but may also be landlocked (Scott and Crossman 1998). |
| Although they are found in streams, lakes or at sea, lacustrine populations are most common (*Klemetsen et al. 2003*). |
| |
| *Spawning* : |
| In northern Labrador, anadromous Arctic charr have been observed spawning adjacent to inlet streams of lakes and ponds (Dempson and Green 1985). |
| Spawning typically occurs over substrates ranging from sand to small rubble (Dempson and Green |

1985; *Cunjak et al. 1986*) and has been reported over substrates ranging from coarse sand to boulder-strewn gravel (*Moore 1975a*).

Spawning generally occurs at depths of 0.5-1.5 m (Dempson and Green 1985; *Cunjak et al. 1986*) sufficient to keep the eggs safe from winter ice or in quiet pools (depths of 1.0-4.5 m) below rapids where no ice forms (Communications Directorate 1991; Scott and Crossman 1998).

In Baffin Island streams, *Moore (1975a)* observed charr spawning at depths ranging from 1-11 m.

Spawning has been reported at velocities ranging from 0.1-0.7 m/s (*Moore 1975a*; *Heggberget 1984*; *Cunjak et al. 1986*).

Beddow et al. (1998) found that charr from Reid Brook, Labrador immediately moved downstream after spawning, presumably to find suitable overwintering habitat.

*Young-of-the-year:*

YOY appear to have a preference for depths <0.2 m and velocities between 0.1-0.5 m/s (*Moore 1975b*; *Heggberet 1984*).

They were reported hiding among stones (*Moore 1975b*), which were assumed to be gravel, cobble and rubble.

*Juveniles:*

Juveniles generally occupy slow-flowing areas (<0.1 m/s) (*Heggberet 1984*) and although they typically occur at depths <0.2 m (*Heggberet 1984*; *Adams et al. 1988*), they have also been reported in pools, which were assumed to be >1 m deep (*Heggberet 1984*).

In summer, juveniles spend most of their time over gravel/rubble substrates during the day, often seeking refuge underneath rubble (*Adams et al. 1988*).

At night, *Adams et al. (1988)* found that juveniles occupy positions in quiet near shore areas over sand.

*Adults*:

Adults occur in deep runs and pools (depths of 1-2 m) of medium to large size rivers (*Page and Burr 1991*; Beddow et al. 1998).

Although adults have been found to occupy pools having velocities <0.1 m/s (*Heggberet 1984*), they also occur at velocities ranging from 0.5-1.0 m/s in northern Labrador (Beddow et al. 1998).

In northern Labrador, Beddow et al. (1998) found adults associated with substrates comprised of rubble (50%), boulders (40%) and sand/gravel (10%).

Table 17. Habitat requirements data for **Atlantic salmon - anadromous (*Salmo salar*)**.

| Habitat Features: | Ratings[1] | | | |
|---|---|---|---|---|
| **Categories[2]** | S | Y | J | A |
| **Velocity (m/s):** | 0.1-0.8 | 0.05-0.7 | 0.05-1.0 | 0.05-0.6 |
| **Depths:** | | | | |
| 0-1 meters | H | H | H | H |
| 1-2 meters | | | *H* | |
| 2-5 meters | | | *H* | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | | *H* | H | *H* |
| Rubble | | *H* | H | |
| Cobble | *H* | H | H | |
| Gravel | H | H | H | |
| Sand | nil | *nil* | *nil* | |
| Silt | nil | *nil* | *nil* | |
| Muck(detritus) | | *nil* | *nil* | |
| Clay(mud) | nil | | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | | | | |
| Emergents | | | | |
| Overhead | | | H | |
| *In situ* | | *H* | H | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

| **Comments and observations:** |
|---|
| *Spawning:* |
| Atlantic salmon typically remain at sea for 1-3 years before returning to their natal river to spawn (Porter 1975; Scott and Scott 1988). |
| Spawning sites are generally found in clean, well-aerated, gravel-bottom riffle sections of streams (Porter 1975; *Danie et al. 1984*; Scott and Scott 1988; *Smith 1988*; Gibson 1993; *Stanley and Trial 1995*; Scott and Crossman 1998), while still water and stream bottoms of mud, silt or sand are typically avoided (Porter 1975; *Smith 1988*). Spawning has also been reported at the tail of pools on the upstream edge of riffles (*Danie et al. 1984*; *Smith 1988*; Gibson 1990; *Stanley and Trial 1995*; Scott and Crossman 1998; Scruton et al. 2000). |
| Spawning substrates consist mainly of gravel and cobble (*Warner 1963*; *Peterson 1978*; *Heggberget et al. 1988*; Gibson 1990; *Bardonnet and Baglinière 2000*; Scruton et al. 2000). |
| Spawning typically occurs at depths ranging from 0.1-0.7 m: *Danie et al.* (*1984*) 0.2-0.4 m; *Sorokin* (*1971*) 0.1-0.4 m; Pratt (1968); *Peterson* (*1978*); *Beland et al.* (*1982*); deGraaf and Chaput (1984); *Heggberget et al.* (*1988*); Scruton et al. (2000) 0.2-0.7 m. |

Spawning has been reported at velocities ranging from 0.15-0.8 m/s: *Jones (1969)* 0.31-0.46 m/s; *Stanley and Trial (1995)* 0.15-0.5 m/s (mean 0.5 m/s); Gibson (1990) 0.3-0.45 m/s; Scruton et al. (2000) 0.1-0.8 m/s; *Heggberget et al. (1988)* 0.4-0.8 m/s (mean 0.56 m/s); *Danie et al. (1984)* 0.49-0.52 m/s.

A preferred mid-water velocity of 0.3-0.6 m/s has also been suggested (Pratt 1968; *Beland et al. 1982*) and Jones (*1959*) reported that spawning ceased if velocities were reduced to 0.05–0.08 m/s.

*Young-of-the-year*:

After emergence, most fry disperse downstream and establish territories, usually occupying areas of slow flowing water initially and move into faster flowing water, such as riffles or rapids, as they increase in size (Porter 1975; *Danie et al. 1984*; *Smith 1988*; Gibson 1990; *Stanley and Trial 1995*).

YOY have been reported at velocities ranging from 0.1-0.7 m/s (*Elson 1967*; *Knight et al. 1981*; *Danie et al. 1984*; *Rimmer et al. 1984*; *Trial and Stanley 1984*; deGraff and Bain 1986; *Morantz et al. 1987*; Gibson 1993; Scruton and Gibson 1993).

During the day and early evening, young are more commonly found in fast flowing water, while at night they rest on the bottom in quieter water (*Danie et al. 1984*).

Although YOY (<6.5 cm in length) appear to prefer depths <0.3 m (*Symons and Héland 1978*; *Egglishaw and Shackley 1982*; *Danie et al. 1984*; Gibson 1990; Scruton and Gibson 1993; Scruton et al. 2000), they have been observed at depths up to 1 m (*Keenleyside 1962*; *Francis 1980*; *Knight et al. 1981*; *Baglinère and Champigneulle 1986*; *Rimmer et al. 1984*; *Trial and Stanley 1984*; *deGraff and Bain 1986*; *Morantz et al. 1987*; Scruton et al. 2000).

YOY tend to occupy shallow areas, often near stream margins (*MacCrimmon 1954*; *Elson 1967*; *Symons and Héland 1978*; *Kennedy and Strange 1982*; *1986*; *Gardiner 1984*; *Morantz et al. 1987*; Scruton et al. 2000).

They are most common over gravel or cobble substrates (*Keenleyside 1962*; *Symons and Héland 1978*; *deGraff and Bain 1986*; *Gibson 1990*; Scruton and Gibson 1993).

YOY seek shelter in the substrate, especially when water temperatures drop below 10$^0$C (*Rimmer et al. 1983; Danie et al. 1984*). They move beneath coarse substrates, such as rubble, in riffle-run habitats to overwinter in areas where mean water depths are 0.4-0.5 m and mean water velocities are between 0.4-0.5 m/s (*Cunjak 1990*).

Many YOY overwinter within redd excavations made that spawning season (Porter 1975; *Cunjak 1990*).

*Juveniles*:

In Newfoundland, parr remain in freshwater for 2-4 years, while they may remain in freshwater for 3-6 years in Labrador (Porter 1975).

Juveniles have been found to occupy velocities ranging from 0.05-1.0 m/s (*Rimmer et al. 1983*; *Cunjak 1990*; Gibson 1990; Scruton and Gibson 1993; *Morantz et al. 1987*; *Heggenes 1990*).

Although juveniles typically occur at depths <0.5 m (*Danie et al. 1984*; deGraaf and Bain 1986; *Morantz et al. 1987*), some occupy greater depths (*Lindroth 1955*; *Gibson 1966*; *Elson 1967*; *Symons and Héland 1978*; *Heggberget 1984*; Scruton et al. 2000).

Shelter is provided by undercut banks, deep pools, surface water turbulence, rocky substrates and overhanging vegetation (Gibson and Power 1975; Gibson 1978; 1990; *Rimmer et al. 1983*; *Heggenes 1990).*

With respect to cover, optimum habitat suitability for juveniles in NL was determined to be in the range of 0-10% with a marked decline in suitability above 80% cover (Scruton et al. 2000).

Older juveniles prefer deeper pools, steadies and ponds (Gibson 1973; Porter 1975; *Danie et al. 1984*; Gibson 1990; Gibson et al. 1993; *Bremset and Berg 1997*) especially during floods, low water levels, high water temperatures and winter freezing (Porter 1975) or when interspecific competition and fish predation is low (Gibson 1990).

| |
|---|
| Older and larger parr are usually found in riffles that are deeper than 20 cm, with surface velocities between 0.5-0.7 m/s (i.e., faster waters associated with cobble, rubble and boulders), but occupy pools and lentic waters where interspecific competition and fish predation is low (Gibson 1990). |
| During summer and autumn, all age classes of juveniles are markedly more frequent in runs (i.e., water depths of 25-45 cm, velocities of 0.2-0.4 m/s, and substrates comprised of boulder, rubble, cobble, and gravel with no sand, silt or detritus) than in either riffles or pools (*Rimmer et al. 1983*). |
| In NL, older juveniles exhibited a preference for boulder dominated substrates (Scruton and Gibson 1993). |
| As water temperatures drop below 10$^0$C, young seek shelter under coarse substrate (*Rimmer et al. 1983*; Gibson 1990; Scruton et al. 2000) or move to pools (Gibson 1990). |
| Young salmon (5-15 cm FL) move beneath coarse substrates, such as rubble, in riffle-run habitats to overwinter (*Rimmer et al. 1983*; Cunjak 1990; Scruton et al. 2000), primarily in areas where mean water depths are 0.4-0.5 m and mean water velocities are between 0.4-0.5 m/s (*Cunjak 1990*). |
| |
| *Adults:* |
| Returning adults are called grilse after spending only one winter at sea and salmon if they have spent two or more years at sea (Porter 1975). |
| Upstream migrations are primarily nocturnal and tend to occur during ebb tides (*Smith and Smith 1997*). |
| Adults require a minimum velocity of 0.3-0.6 m/s to continue upstream movement (*Weaver 1963*). |
| Large boulders and other stream obstructions provide eddies and slack water where adults may rest during upstream migrations (*Danie et al. 1984*). |
| The quantity and quality of pool habitat appears to be an important habitat feature for adults (*Hawkins 1988*; *Bardonnet and Bagliniere 2000*). *Moreau and Moring* (*1993*) suggest that a minimum depth of 0.9 m is required in pools. |
| |

Table 18. Habitat requirements data for **ouananiche (*Salmo salar*)**.

| **Habitat Features:** | **Ratings[1]** | | | |
|---|---|---|---|---|
| **Categories[2]** | S | Y | J | A |
| **Velocity (m/s):** | 0.1-0.3 | 0.1-1.0 | 0.1-1.0 | variable |
| **Depths:** | | | | |
| 0-1 meters | H | H | H | |
| 1-2 meters | | H | H | H |
| 2-5 meters | | | | H |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | | | H | |
| Rubble | | | H | |
| Cobble | H | | H | |
| Gravel | | | M | |
| Sand | M | | | |
| Silt | M | | | |
| Muck(detritus) | | | | |
| Clay(mud) | M | | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | | | | |
| Emergents | | | | |
| Overhead | | | | |
| *In situ* | | | | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General:*

Landlocked salmon may exist in normal (Andrews 1966; Ryan 1980; Chaput and Astle 1985) or dwarf forms (Bruce 1976; Barbour et al. 1979; Gibson et al. 1996).

*Spawning:*

The life history of ouananiche is similar to anadromous Atlantic salmon except adults typically remain in lakes where they spawn along rocky shorelines (Scott and Crossman 1964; Cowan and Baggs 1988; Scruton et al. 1997) or migrate into tributary streams to spawn (Scott and Crossman 1964; 1998; Hutchings 1986; *Einarsson et al. 1990*).

In NL, spawning has been reported in moving water, usually above outlet streams and near the mouths of inlet streams (Leggett 1965; Leggett and Power 1969; Havey and Warner 1970; Beak Consultants Ltd. 1980; *Einarsson et al. 1990*; Scruton et al. 1996a).

According to Gibson et al. (1996), landlocked salmon apparently spawn over cobble in shallow (mean depth 10-18 cm) riffles having velocities ranging from 0.1-0.3 m/s.

Ouananiche have been observed spawning in substrates containing up to 18% fines (sand, silt and clay) with little apparent effect on survival (Scruton et al. 2000).

*Young-of-the-year/Juveniles*:

In NL, YOY and juveniles generally occupy riffle areas (depths of 0.3-1.5 m and velocities ranging from 0.1-1.0 m/s) (Gibson et al. 1996) in tributary streams *(Leggett and Power 1969*), where they remain for 2-3 years before migrating into lakes (*Leggett 1965*; *Leggett and Power 1969*; *Havey and Warner 1970*; Wiseman 1971).

*Stanley and Trial* (*1995*) found that the most suitable habitats for fry were depths between 10-40 cm and velocities of 0.1-0.3 m/s, while depths of 20-50 cm and velocities between 0.1-0.4 m/s were most suitable for parr.

*Adults:*

Most stream spawning ouananiche return to their lake of origin after spawning (*Havey and Warner 1970*; Scruton et al. 1996; Scott and Crossman 1998), although some may overwinter in tributary pools before returning to lakes the following spring (Scott and Crossman 1964; *Havey and Warner 1970*).

In NL, ouananiche have been found to overwinter in fast-flowing, ice-free waters of inlets, outlets and canals (Scruton et al. 1997).

Table 19. Habitat requirements data for **brook trout (*Salvelinus fontinalis*)**.

| **Habitat Features:** | Ratings[1] | | | |
|---|---|---|---|---|
| **Categories**[2] | S | Y | J | A |
| **Velocity (m/s):** | *0.01-0.9* | 0.01-0.4 | 0.01-1.5 | 0.01-0.5 |
| **Depths:** | | | | |
| 0-1 meters | H | H | *H* | *H* |
| 1-2 meters | | | *H* | *M* |
| 2-5 meters | | | *M* | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | *M* |
| Boulder | | *H* | *H* | *H* |
| Rubble | | *H* | *H* | *H* |
| Cobble | *H* | *H* | *H* | *H* |
| Gravel | H | *H* | *H* | *H* |
| Sand | H | *L* | *H* | *M* |
| Silt | L | | *H* | *L* |
| Muck(detritus) | *L* | | | *L* |
| Clay(mud) | | | | *L* |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | | *H* | *H* | *H* |
| Emergents | | | | |
| Overhead | *M* | *M* | *H* | *H* |
| *In situ* | *M* | *H* | *H* | *H* |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

| **Comments and observations:** |
|---|
| *General*: |
| Some populations may spend their entire life cycle in freshwater, while others are anadromous, spending one or two months feeding at sea in relatively shallow coastal waters within the vicinity of their natal stream (Scott and Crossman 1964; *Morrow 1980*; *Power 1980*; Ryan 1988; Scott and Scott 1988). |
| Apart from migration to and from the sea, life histories of both anadromous and resident forms are similar (Scott and Crossman 1964). |
| *Raleigh (1982)* characterized optimal brook trout riverine habitat as clear, cold spring-fed water; a silt-free rocky substrate in riffle-run areas; an approximate 1:1 pool-riffle ratio with areas of slow, deep water; well vegetated stream banks; abundant instream cover; and relatively stable water flow, temperature regimes and stream banks. |

| |
|---|
| *Spawning* : |
| Brook trout usually spawn in shallow headwater streams, over a gravel substrate (Scott and Crossman 1964; 1998; Wiseman 1970; 1971; *Raleigh 1982* ; Ryan 1988; *Ford et al. 1995* ) |
| Although they have been shown to spawn in areas of groundwater upwelling (*Webster and Eiridsdottier 1976* ), the importance of such areas for brook trout spawning has not been documented in NL. |
| They have been reported spawning at depths between 0.1-0.3 m and velocities ranging from 0.01-0.9 m/s (*Smith 1973* ; *Reiser and Wesche 1977* ; *Witzel and MacCrimmon 1983* ). |
| In NL, O'Connell (1982) reported brook trout spawning over a sand, silt, gravel substrate, while in other areas they have been reported spawning over sand, gravel and cobble (*Reiser and Wesche 1977* ; *Raleigh 1982* ; *Witzel and MacCrimmon 1983* ) with <5% fines (*Raleigh 1982* ). |
| In general, as the amount of sand in spawning gravel increases, especially above 15-20%, there is an overall reduction in the percentage of alevins that emerge (*Becker 1983* ; *Ford et al. 1995* ). |
| They have also been found spawning over silt and detritus providing there is ground water seepage (*Witzell and MacCrimmon 1983* ). |
| Brook trout redds appear to be in close proximity to cover, mainly submerged logs and tree branches (*Witzel and MacCrimmon 1983* ). |
| |
| *Young-of-the-year* : |
| Upon emergence, YOY disperse into shallows along the edges of streams, in suitable eddies or even mid-stream in slower currents, over gravel/cobble/rubble substrates (*Johnson et al. 1993* ; *Ford et al. 1995* ) and have also been found in areas containing sand and organic fines (*Johnson et al. 1992* ). |
| YOY occur in relatively silt-free areas over mainly cobble, rubble, boulder substrates (*Bustard and Narver 1975* ; *Raleigh 1982* ; *Cunjak and Power 1986* ). |
| In NL, they were reported at velocities ranging from 0.02-0.4 m/s (Cunjak and Green 1983), while in other areas they were reported at velocities ranging from 0.02-0.23 m/s (*Griffith 1972* ; *Scherer et al. 1984* ; *Cunjak and Power 1986* ). |
| According to *Johnson et al.* (*1992* ) and *Ford et al.* (*1995* ), YOY appear to prefer water velocities <0.1 m/s. |
| Alevins are usually found at depths of 0.2-0.5 m (*Griffith 1972* ; *Williams 1981* ). |
| In NL and other Canadian streams, YOY have been reported at depths of 0.1-0.7 m (Cunjak and Green 1983; *Scherer et al. 1984* ; *Cunjak and Power 1986* ; *Johnson et al. 1992* ). |
| *Boussu* (*1954* ) reported that aquatic vegetation is an important form of cover for juveniles. |
| YOY and small juveniles (<15 cm) are associated more with instream cover (mainly rubble) than overhead streambank cover (*Wesche 1980* ). *Everest* (*1972* ), *Bustard and Narver* (*1975* ) *and Cunjak and Power* (*1986* ), also found that YOY seek shelter under rubble. |
| During winter, YOY have been observed seeking shelter under coarse substrates, vegetation and debris (*Cunjak and Power 1986* ). |
| |
| *Juveniles* : |
| Although velocities ranging from 0.01-0.5 m/s have been reported as being suitable for juveniles (*Raleigh 1982* ; *Cunjak and Power 1986* ; *Johnson et al. 1992* ; *Ford et al. 1995* ; *Jirka and Homa 1990* ; Scruton et al. 2000), they have also been reported holding in velocities up to 1.5 m/s (*Jirka and Homa 1990* ). |
| Although, *Jirka and Homa* (*1990* ) reported an optimal depth range of 20 to 40 cm, juveniles have been reported at depths at least up to 1.0 m (*Cunjak and Power 1986* ; *Jirka and Homa 1990* ; *Johnson et al. 1992* ). |

*Jirka and Homa (1990)* reported that juveniles will seek depths up to 1.3 m as a means of escape or forage in the absence of predators or large competitors and during the winter, they have been shown to occupy slow, deep (>2 m) steadies (*Cunjak and Power 1986*).

Juveniles have been reported over a range of substrates, including silt, sand, gravel, cobble, rubble and small boulders (*Kendall and Dence 1927*; *Dence 1928*; *Keenleyside 1962*; *Scherer et al. 1984*; *Hanson et al. 1987*; *Johnson et al. 1992*; Scruton et al. 2000).

Small juveniles (<15 cm) are associated with cover in the form of undercut banks, surface water turbulence, rocky substrate, logs, large woody debris, brush cover, pools and overhanging vegetation (*McPhail and Lindsey 1970*; *Wesche 1980*; *Raleigh 1982*; *Jirka and Homa 1990*; *Ford et al. 1995*; Scruton et al. 2000).

According to *Raleigh (1982)*, an area of cover >15% of the total stream area is adequate for juveniles.

*Adults*:

In NL, Cunjak and Green (1983) reported nose velocities ranging from 0.01-0.5 m/s, while in other areas velocities ranging from 0.07-0.3 m/s have been reported (*Griffith 1972*; *Wesche 1974*; *Raleigh 1982*; *Chisholm et al. 1987*; *Ford et al. 1995*).

Although, *Jirka and Homa (1990)* reported an optimal depth range of 20 to 40 cm, adults have been found at depths ranging from 0.1-1.1 m (*Jirka and Homa 1990*; *Scherer et al. 1984*; *Chisholm et al. 1987*; *Smith and Aceituno 1987*).

Adults have been encountered over a wide range of substrates from mud to bedrock, but are generally associated with clean substrates ranging from gravel to boulders (*Keenleyside 1962*; *Chisholm et al. 1987*; *Jirka and Homa 1990*; Scruton et al. 2000).

In a Pennsylvanian stream, they were most frequently found over gravel substrates (*Magoulick and Wilzbach 1997*).

They are often associated with cover provided by overhanging vegetation, submerged vegetation, undercut banks, instream objects such as stumps, logs, roots and rocky substrates, and water surface turbidity (*McPhail and Lindsey 1970*; *Giger 1973*; *Becker 1983*; *Raleigh 1982*; *Kozel and Hubert 1989*; *Ford et al. 1995*).

During winter, they appear to select areas with maximum velocities <0.15 m/s and depths <0.5 m (*Chisholm et al. 1987*; Scruton et al. 2000) and were found predominantly in areas containing sand or silt substrate, however, some were found over rocky substrates (gravel, cobble, rubble or boulders) (*Chisholm et al. 1987*).

Pools with low current velocity are considered important for brook trout during winter (*Chisholm et al. 1987*).

Table 20. Habitat requirements data for **brown trout (*Salmo trutta*)**.

| Habitat Features: | Ratings[1] | | | |
|---|---|---|---|---|
| **Categories[2]** | S | Y | J | A |
| **Velocity (m/s):** | *0.1-0.8* | *0-0.2* | *0.05-0.8* | *slow-fast* |
| **Depths:** | | | | |
| 0-1 meters | *H* | *H* | *H* | *H* |
| 1-2 meters | | | *H* | *H* |
| 2-5 meters | | | *H* | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | *L* | *H* | *H* | *H* |
| Rubble | *M* | *H* | *H* | *H* |
| Cobble | *H* | *H* | *H* | |
| Gravel | *H* | *H* | *H* | |
| Sand | | *nil* | *nil* | *nil* |
| Silt | | *nil* | *nil* | *M* |
| Muck(detritus) | | | | |
| Clay(mud) | | | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | | *H* | *H* | *H* |
| Emergents | | | | |
| Overhead | *H* | *H* | *H* | *H* |
| *In situ* | *M* | *H* | *H* | *H* |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General*:

Brown trout occur in both anadromous and freshwater resident forms (Scott and Scott 1988). Their habitat requirements are similar to those of brook trout (Ryan 1988; Scott and Scott 1988; O'Connell and Dempson 1996), except they tend to have higher tolerances and will occupy streams with warmer or more turbid water (Scott and Scott 1988; Scott and Crossman 1998). Anadromous brown trout either migrate to sea for the summer (2-4 months) or remain there for one or more years before moving into streams to spawn (*Went 1962*; *Jensen 1968*; O'Connell 1982; *Jonsson and Gravem 1985*; Ryan 1988; Scott and Scott 1988; *Jonsson and Jonsson 2002*).

*Spawning* :

They typically spawn in streams (*Hansen 1975* ; *Raleigh et al. 1986* ; *Haraldstad and Jonsson 1983; Jonsson 1985* ; *Jonsson and Gravem 1985* ; Ryan 1988; Scott and Scott 1988; *Clapp et al. 1990* ).

During spawning, largest individuals have been reported to spawn in the deepest areas with the highest velocities (*Ottaway et al. 1981* ) and large females have also been shown to spawn on coarser gravel and bury their eggs deeper than smaller individuals (*Fleming 1996* ).

Spawning has been reported at depths ranging from 0.1-0.9 m (*O'Donnell and Churchill 1943* ; *Waters 1976* ; *Berg 1977* ; *Reiser and Wesche 1977* ; *Shirvell and Dungey 1983* ; *Witzel and MacCrimmon 1983* ; *Raleigh et al. 1986* ; *Fragnoud 1987* ; *Heggberget et al. 1988* ; *Grost et al. 1990* ).

Spawning has been reported at velocities ranging from 0.1-0.8 m/s (*Hooper 1973* ; *Smith 1973* ; *Berg 1977* ; *Reiser and Wesche 1977* ; *Shirvell and Dungey 1983* ; *Witzel and MacCrimmon 1983* ; *Fragnoud 1987* ; *Heggberget et al. 1988* ; *Crisp and Carling 1988* ; *Grost et al. 1990* ; *Beard and Carline 1991* ).

*Raleigh* (*1982* ) recommended a velocity tolerance range of 0.15-0.9 m/s and an optimal range of 0.4-0.7 m/s.

Although brown trout tend to spawn mainly over gravel/cobble substrates (*Stuart 1953* ; *Frost and Brown 1967* ; *Hooper 1973* ; *Berg 1977* ; *Reiser and Wesche 1977* ; *Raleigh et al. 1986; Beard and Carline 1991* ), they also spawn over gravel, cobble, rubble and boulder substrates (*Nihouarn 1983* ; *Witzel and MacCrimmon 1983* ; *Shirvell and Dungey 1983* ; *Fragnoud 1987* ; *Heggberget et al. 1988* ).

*Baglinere et al.* (*1979* ) found that brown trout redds were concentrated in undercut banks, which afforded protection during high flows and they were also found in close proximity to cover, mainly submerged logs and tree branches (*Witzel and MacCrimmon 1983* ).

*Young-of-the-year* :

Fry often remain in their natal stream during their first summer (*Elliot 1986* ).

YOY prefer water velocities <0.2 m/s (*Cunjak and Power 1986* ; *Harris et al. 1992* ; *Gaudin and Heland 1995* ), but have been observed at velocities up to 0.3 m/s (*Maki-Petays et al. 2000* ).

YOY occupy depths <0.5 m (*Lindroth 1955* ; *Bagliniere and Champigneulle 1982* ; *Cunjak and Power 1986* ; *Fragnoud 1987* ; *Heggenes 1988a* ; *Heggenes et al. 1988; Griffith and Smith 1993* ) and prefer gravel, cobble substrates, while avoiding fines (*Bagliniere and Champigneulle 1982* ; *Glova and Duncan 1985* ; *Raleigh et al. 1986* ).

Cobble, rubble and boulders have been shown to provide refuge and winter cover for YOY (*Hartman 1963* ; *Griffith and Smith 1993* ) as well as undercut banks, submerged vegetation and still, deep water (*Euzenat and Fournel 1976* ).

*Juveniles* :

Juveniles have been reported at velocities ranging from 0.05-0.8 m/s (*Wesche 1980* ; *Glova and Duncan 1985* ; *Cunjak and Power 1986* ; Gibson and Cunjak 1986; *Heggenes 1988a* ; *Heggenes and Saltveit 1990* ; *Greenberg et al. 1996* ; *Maki-Petays et al. 1997* ; *Roussel et al. 1999* ).

In NL, Gibson and Cunjak (1986) reported that juveniles occupied velocities ranging from 0.02 m/s in pools to 0.3 m/s in riffles, but preferred a mean water velocity of 0.08 m/s.

Brown trout generally prefer pools over riffles (Gibson 1966; *Jones 1975* ), especially older individuals (*Baglinière and Champigneulle 1982* ; *Kennedy and Strange 1982* ; *Heggenes et al. 1995* ).

| |
|---|
| Juveniles have been found to occupy depths ranging from 0.1-4.0 m (*Glova and Duncan 1985* ; *Cunjak and Power 1986* ; Gibson and Cunjak 1986; *Heggenes 1988b* ; *Heggenes and Saltveit 1990* ; *Greenberg et al. 1996* ; *Bremset and Berg 1997* ; *Roussel et al. 1999* ; *Maki-Petays et al. 2000* ). |
| They tend to prefer gravel, cobble, rubble, boulder substrates (*Bohlin 1977* ; *Heggenes and Saltveit 1990* ; *Greenberg et al. 1996* ; *Maki-Petays et al. 1997* ), while avoiding sand and silt (*Greenberg et al. 1996* ). |
| They have been shown to seek shelter under broken water, logs, boulders, macrophytes and undercut banks (*Cunjak and Power 1986* ; *Raleigh et al. 1986* ; *Maki-Petays et al. 1997* ; *Bremset 2000* ). |
| *Greenberg et al.* (*1996* ) found that the use of overhead cover increased with increasing body size, while use of instream cover decreased. |
| |
| *Adults* : |
| Adults tend to prefer relatively slow velocities (<0.2 m/s) (*Bohlin 1977* ; *Wesche 1980* ; *Bagliniere and Champigneulle 1982* ; *Egglishaw and Shackley 1982* ; *Heggenes 1988c* ; *Clapp et al. 1990* ), but will utilize faster-flowing areas (*Karlstrom 1977* ; *Bagliniere and Champigneulle 1982* ; *Cunjak and Power 1986* ). |
| Adults have been reported to occupy depths ranging from 0.2 to >1.0 m (*Bohlin 1977* ; *Egglishaw and Shackley 1977* ; *Karlstrom 1977* ; *Bagliniere and Champigneulle 1982* ; *Shirvell and Dungey 1983* ; Gibson and Cunjak 1986; *Heggenes 1988c* ; *Clapp et al. 1990* ). |
| They prefer coarse substrates, such as rubble and boulders (*Bagliniere and Champigneulle 1982* ; *Fragnoud 1987* ) and although they have been associated with silt (*Clapp et al. 1990* ), they tend to avoid sand (*Jowett 1990* ). |
| Adults utilize cover in the form of deep water, riffle areas, submerged vegetation, overhanging riparian vegetation, woody debris, boulders and undercut banks (*Hartman 1963* ; *Lewis 1969* ; *Devore and White 1978* ; *Cuinat 1980* ; *Nielsen 1986* ; *Raleigh et al. 1986* ; *Wesche et al. 1987* ; *Mesick 1988* ; *Jowett 1990* ; *Haury and Bagliniere 1990* ). |
| |

Table 21. Habitat requirements data for **lake trout (*Salvelinus namaycush*)**.

| **Habitat Features:** | **Ratings**[1] | | | |
|---|---|---|---|---|
| **Categories**[2] | S | Y | J | A |
| **Velocity (m/s):** | | | | |
| **Depths:** | | | | |
| 0-1 meters | *H* | *H* | | |
| 1-2 meters | | | | |
| 2-5 meters | | | | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | *H* | *H* | | |
| Rubble | *H* | *H* | | |
| Cobble | *H* | *H* | | |
| Gravel | *H* | *H* | | |
| Sand | *nil* | *nil* | | |
| Silt | *nil* | *nil* | | |
| Muck(detritus) | *nil* | *nil* | | |
| Clay(mud) | *nil* | *nil* | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | *nil* | *nil* | | |
| Emergents | *nil* | *nil* | | |
| Overhead | | | | |
| *In situ* | | *H* | | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

| **Comments and observations:** |
|---|
| *General*: |
| In its southern range, lake trout are predominantly an inhabitant of deep cold lakes, however, in the north it is abundant in shallow tundra lakes and large, clear rivers (*McPhail and Lindsey 1970*). |
| |
| *Spawning*: |
| Although spawning may occur in streams, lake trout usually spawn in lakes (*McPhail and Lindsey 1970*; *Machniack 1975c*; *Marcus et al. 1984*; Bradbury et al. 1999; *Ford et al. 1995*; Scott and Crossman 1998). |
| Spawning has been reported over large boulders interspersed with coarse gravel (*Loftus 1958*). |
| Spawning occurs mainly rocky substrates (gravel, cobble, rubble and boulders), while areas containing |

| |
|---|
| sand, silt, mud, detritus and vegetation are avoided (*Paterson 1968* ; *Machniak 1975c* ; *Martin and Olver 1980* ; *Marcus et al. 1984* ; *Ford et al. 1995* ). |
| Spawning usually occurs at depths <0.5 m (*Paterson 1968* ; *Machniak 1975c* ; *Marcus et al. 1984* ). |
| |
| *Young-of-the-year:* |
| Newly hatched larvae undergo early development within the protection of the rocks on the spawning grounds (*Machniak 1975c* ). |
| Fry have been observed moving from the spawning area directly towards their nursery lake within a month of emergence (*Paterson 1968* ; *Machniak 1975c* ; *Marcus et al. 1984* ; *Ford et al. 1995* ). |
| |
| *Juveniles:* |
| In the references reviewed, there was no mention of juveniles utilizing rivers. |
| |
| *Adults* : |
| Once the spawning season is complete, adults disperse widely from the spawning grounds (*Machniak 1975c* ). |
| |

Table 22. Habitat requirements data for **lake whitefish (*Coregonus clupeaformis*)**.

| **Habitat Features:** | **Ratings[1]** | | | |
|---|---|---|---|---|
| **Categories[2]** | S | Y | J | A |
| **Velocity (m/s):** | *riffle/rapids* | | | |
| **Depths:** | | | | |
| 0-1 meters | *H* | | | *H* |
| 1-2 meters | *M* | | | *H* |
| 2-5 meters | *L* | | | *H* |
| 5-10 meters | | | | *H* |
| 10+ meters | | | | *H* |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | | | | |
| Rubble | *H* | | | |
| Cobble | *H* | | | |
| Gravel | *H* | | | |
| Sand | | | | |
| Silt | *L* | | | |
| Muck(detritus) | | | | |
| Clay(mud) | *nil* | | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | *L* | | | |
| Emergents | | | | |
| Overhead | | | | |
| *In situ* | | | | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General*:

The existence of dwarf lake whitefish has been reported by several investigators (Bruce 1975a; b; 1984; Parsons 1975; Bruce and Parsons 1979; Ryan 1980).

Although lake whitefish are primarily lake dwellers, they may also be present in large rivers (*Ford et al. 1995*; Scott and Crossman 1998).

*Spawning*:

Although primarily lake spawners, they are also known to spawn in rivers and streams (*Bryan and Kato 1975*; *Machniak 1975a*; *Ford et al. 1995*).

Spawning occurs in relatively shallow (0.1-1.0 m) riffle areas or rapids over a mainly rocky substrate

| |
|---|
| (gravel/cobble), while sand and mud are generally avoided (*Hinks 1943* ; *Fabricius 1950* ; *Fenderson 1964* ; *Machniak 1975a* ; *Ford et al. 1995* ). |
| In the Yukon, spawning has been observed over silt and potamageton at depths of 2.0-2.5 m in areas which had little current (*Bryan and Kato 1975* ). |
| Flowing water is not required for spawning (*Bryan and Kato 1975* ; *Ford et al. 1995* ). |
| |
| *Young-of-the-year:* |
| Most YOY are quickly displaced downstream to estuaries or lakes by spring floods (*Hatfield et al. 1972* ; *Taylor et al. 1982* ; *Reist and Bond 1988* ). |
| |
| *Adults:* |
| Outside the spawning period, adults appear to show no preference for substrate type (*Ford et al. 1995* ). |
| Within the Mackenzie River watershed, adults have been found to overwinter at depths of 0.6-20 m (*Jessop and Lilley 1975* ). |
| |

Table 23. Habitat requirements data for **pink salmon (*Oncorhynchus gorbuscha*)**.

| **Habitat Features:** | **Ratings**[1] | | | |
|---|---|---|---|---|
| **Categories**[2] | S | Y | J | A |
| **Velocity (m/s):** | *0.05-1.0* | *0-1.0* | | |
| **Depths:** | | | | |
| 0-1 meters | *H* | *H* | *H* | *H* |
| 1-2 meters | *L* | | *H* | *H* |
| 2-5 meters | | | *H* | *H* |
| 5-10 meters | | | *H* | *H* |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | | | | |
| Rubble | | | | |
| Cobble | *H* | *H* | | |
| Gravel | *H* | *H* | | |
| Sand | *L* | *M* | | |
| Silt | *Nil* | | | |
| Muck(detritus) | *Nil* | | | |
| Clay(mud) | | *M* | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | | | | |
| Emergents | | | | |
| Overhead | | | | |
| *In situ* | | *H* | | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General*:

There have only been sporadic reports of pink salmon captured in the Arctic charr fisheries of northern Labrador (Lear 1975; Dempson 1980).

*Spawning*:

Spawning usually takes place in freshwater, close to the sea or in intertidal areas (*Bonar et al. 1989*), although it has been commonly reported in upstream areas of large rivers (Scott and Crossman 1998). Spawning usually occurs over a gravel, cobble substrate (*Lucas 1959*; *Collings 1974*) at depths of 0.2-0.5 m (*Hourston and MacKinnon 1957*) and velocities of 0.2-1.0 m/s (*Collings 1974*). In an Ontario stream, nests were located at the upstream end of riffles over pebble/gravel substrates, at

| |
|---|
| depths of 0.2-1.1 m, and water velocities ranging from 0.05-0.16 m/s (*Kwain and Lawrie 1981*). |
| In southeastern Alaska, spawning beds were comprised of cobble (54%), gravel (32%) and sand (14%) |
| (*McNeil and Ahnell 1964*). |
| According to *Heard (1991)*, pink salmon typically avoid spawning in quiet deep water pools, areas of |
| slow current or heavily silted or mud-covered substrates. |
| Although some adults return to their natal rivers to spawn (*Sheridan 1962*), the rate of straying among |
| pink salmon is believed to be much higher than in any other species of salmon (*Bonar et al. 1989*). |
| |
| *Young-of-the-year:* |
| After hatching, alevins remain in the spawning gravel for several weeks until the yolk sac is absorbed |
| (*Bonar et al. 1989*). |
| *Lee (1985)* reported that larvae were found in backwater areas and shallow shoreline areas where |
| water velocity was either nil or slight and substrate was comprised of sand or mud. |
| Immediately after emergence, YOY begin to move downstream towards the sea (*Levy and Northcote* |
| *1982*; Scott and Crossman 1998), although they may remain in freshwater for several months before |
| finally moving to the open ocean (Scott and Crossman 1998). |
| |
| *Juveniles:* |
| Juveniles spend most of their time at sea. |
| |
| *Adults:* |
| After spending about 18 months at sea, adults return to freshwater to spawn (*Bonar et al. 1989*). |
| In an Ontario stream, most 2 and 3 year old pink salmon were caught at and near the water surface at |
| depths <10 m (*Kwain and Lawrie 1981*). |
| |

Table 24. Habitat requirements data for __rainbow trout (*Oncorhynchus mykiss*)__.

| Habitat Features: | Ratings[1] | | | |
|---|---|---|---|---|
| **Categories[2]** | S | Y | J | A |
| **Velocity (m/s):** | *0.3-0.9* | *0.02-0.4* | 0.02-0.7 | 0.2 |
| **Depths:** | | | | |
| 0-1 meters | *H* | *H* | H | *H* |
| 1-2 meters | *H* | *L* | *H* | |
| 2-5 meters | *M* | *L* | | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | | *H* | | |
| Rubble | | *H* | *H* | *H* |
| Cobble | *H* | *H* | *H* | *H* |
| Gravel | *H* | *H* | *H* | *H* |
| Sand | | *L* | *L* | |
| Silt | | *L* | *L* | |
| Muck(detritus) | | | | |
| Clay(mud) | | | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | | *H* | *H* | *H* |
| Emergents | | | | |
| Overhead | | *H* | *H* | *H* |
| *In situ* | | *H* | *H* | *H* |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General*:

Rainbow trout occur in three basic ecological forms: anadromous (or steelhead trout); resident stream; and resident lake or reservoir dwelling (*Raleigh et al. 1984*).

Habitat requirements of stream dwelling and steelhead trout are essentially the same (*Raleigh et al. 1984*).

Rainbow trout are commonly reported as the least acid resistant of all salmonids; their lower tolerance limit is a pH of 5.5-6.0 (*Grande et al. 1978*).

*Raleigh and Duff* (*1980*) characterized optimal rainbow trout riverine habitat as clear, cold water; a silt-free rocky substrate in riffle-run areas; an approximately 1:1 pool-to-riffle ratio, with areas of slow, deep water; well vegetated stream banks; abundant instream cover; and relatively stable water flow, temperature regimes, and stream banks.

*Spawning* :

All forms of rainbow trout utilize streams or rivers for spawning (*Greeley 1933* ; Scott and Crossman 1998).

For Pacific coast steelhead trout, a freshet is usually necessary to initiate upstream spawning migrations (*Withler 1966* ).

*Reiser and Bjorn* (*1979* ) noted that water velocities >3.0-4.0 m/s may hinder upstream migrations and *Thompson* (*1972* ) reported that a minimum depth of 0.2 m is required for spawning migration.

Preferred spawning sites are usually characterized by fine gravel in a riffle above a pool (*McPhail and Lindsey 1970* ; Scott and Scott 1988; Scott and Crossman 1998).

Preferred spawning sites occur in areas having a gravel, cobble substrate with <5% fines (*Delisle and Eliason 1961* ; *McNeil and Ahnell 1964* ; *Orcutt et al. 1968* ; *Hooper 1973* ; *Duff 1980* ; *Raleigh et al. 1984* ).

Optimal water velocity for spawning ranges from 0.3-0.9 m/s (*Raleigh et al. 1984* ) with velocities <0.1 m/s and >0.9 m/s considered unsuitable (*Delisle and Eliason 1961* ; *Thompson 1972* ; *Hooper 1973* ; *Raleigh et al. 1984* ).

Spawning has been reported at depths ranging from 0.2-2.5 m (*Bovee 1978* ; *Raleigh et al. 1984* ).

*Young-of-the-year:*

YOY remain in the substrate for about 2 weeks after hatching (Scott and Crossman 1998).

After emergence, YOY either move downstream to a larger river, lake or the ocean; move upstream from an outlet river to a lake; or disperse within the spawning stream to areas of low velocity and cover (*Raleigh and Chapman 1971* ; Scott and Crossman 1998).

YOY have been found to occupy areas having velocities ranging from 0.02-0.4 m/s (*Griffith 1972* ; *Horner and Bjornn 1976* ; Cunjak and Green 1983; *Johnson and Kucera 1985* ; *Baltz et al. 1991* ) and at depths <0.2-0.7 m (*Griffith 1972* ; Cunjak and Green 1983; *Johnson and Kucera 1985* ; *Baltz et al. 1991* ).

After emergence, cover is critical for survival and is usually provided by the interstices between rocks, vegetation (aquatic and riparian), submerged debris and increased depth or surface turbulence (*Everest 1972* ; *Griffith 1972* ; *Raleigh et al. 1984* ).

*Bradford and Higgins* (*2001* ) reported that YOY moved to stream margins and were often resting on sand or silt substrates as light levels fell to night time levels.

YOY utilize cobble, rubble, boulder substrates for overwintering (*Bustrad and Narver 1975* ).

*Juveniles:*

In NL, Cunjak and Green (1983) observed juveniles at velocities ranging from 0.02-0.7 m/s (mean 0.3 m/s), while in other areas they were reported at velocities ranging from 0.1-0.3 m/s (*Raleigh et al. 1984* ; *Rose 1986* ; *Baltz et al. 1991* ; *Beecher et al. 1993* ).

Juveniles have been encountered at depths ranging from 0.2-2.0 m (*Everest and Chapman 1972* ; *Bovee 1978* ; *Wesche 1980* ; Cunjak and Green 1983; *Baltz et al. 1991* ; *Beecher et al. 1993* ).

Cover may be provided by overhanging or submerged vegetation, undercut banks, pool depth, surface turbulence, and instream objects, such as debris piles, logs and coarse substrates (*Giger 1973* ).

*Bradford and Higgins* (*2001* ) reported that as light levels fell to night time levels, juveniles moved to

| |
|---|
| stream margins and were often found resting on sand or silt substrates. |
| *Hartman (1965)* and *Bustard and Narver (1975)* reported that 1+ steelhead prefer deeper pools |
| during winter. |
| A cover area of 15% of the total stream is considered adequate for juveniles (*Raleigh et al. 1984*). |
| |
| *Adults:* |
| *Baltz et al. (1991)* reported that aduls prefer mean velocities of 0.2 m/s and mean depths of 0.5 m. |
| Adults tend to occur over gravel, cobble or rubble substrates where aquatic insect production is reported |
| to be highest (*Reiser and Bjornn 1979*). |
| In a Pennsylvanian stream, adults were found most frequently over gravel substrates (*Magoulick and* |
| *Wilzbach 1997*). |
| Cover may be provided by overhanging or submerged vegetation, undercut banks, pool depth, surface |
| turbulence, and instream objects, such as debris piles, logs and coarse substrates (*Giger 1973*). |
| A cover area of 25% of the total stream is considered adequate for adults (*Raleigh et al. 1984*). |
| |

Table 25. Habitat requirements data for **round whitefish (*Prosopium cylindraceum*)**.

| **Habitat Features:** | **Ratings**[1] | | | |
|---|---|---|---|---|
| **Categories**[3] | S | Y | J | A |
| **Velocity (m/s):** | *slow-0.6* | *calm* | *steadies* | *0.6-0.9* |
| **Depths:** | | | | |
| 0-1 meters | *H* | H | H | |
| 1-2 meters | *M* | *L* | | |
| 2-5 meters | *M* | *L* | | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | *L* | M | M | *H* |
| Rubble | *L* | M | M | *M* |
| Cobble | | M | M | *H* |
| Gravel | *H* | H | H | *L* |
| Sand | *L* | H | H | |
| Silt | *H* | | | |
| Muck(detritus) | | | | |
| Clay(mud) | *L* | H | H | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | *L* | | | *M* |
| Emergents | | | | *M* |
| Overhead | | *H* | | *H* |
| *In situ* | | *H* | | *H* |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General:*

Round whitefish are widely distributed in lakes and ponds throughout their southern range and rivers in their northern range as well as brackish waters (*McPhail and Lindsey 1970*; *Becker 1983*; Scott and Crossman 1998).

*Spawning*:

Although normally a lake species, round whitefish will move considerable distances against strong currents during the spawning run (*Becker 1983*).

Spawning takes place in the gravelly shoals of lakes, river mouths or occasionally in rivers (*McPhail and Lindsey 1970*; Bradbury et al. 1999; Scott and Crossman 1998).

They spawn by broadcasting their eggs over a variety of substrates ranging from mud (*Bryan 1973*), silt and potamogeton (*McPhail and Lindsey 1970*) to gravel and boulders (*Bryan and Kato 1975*). Although deposited in a range of habitats, eggs seem to be most abundant on gravel in fast currents (0.6 m/s) at depths <1m. However, eggs have been found in both fast and slow currents at depths ranging from 0.7-2.5 m (*Bryan and Kato 1975*).

*Young-of-the-year:*

In an artificial stream enclosure, *McKinley (1984)* found that larvae preferred a sand substrate when resting on the bottom.

Fry have been captured over gravel areas in streams shortly after spring break-up (*Bryan and Kato 1975*).

In NL, LGL Limited (1999) captured YOY at depths ranging from 0.1-0.8 m over mud, sand, gravel, cobble, rubble, and boulder substrates. Highest catches were in areas of slow water velocity, such as steadies or backwaters, at depths of 0.2-0.6 m and substrates comprised mainly of fine gravel and sand.

Larvae were found in backwater areas and shallow shoreline areas where water velocity was either nil or slight and substrate was comprised of sand or mud (*Lee 1985*).

*Normandeau (1969)* reported that when disturbed, fry seek shelter from rubble and boulders.

*Suchanek et al. (1984)* found that young seek cover from cobble or boulders, debris and overhanging vegetation at water depths ranging from 5 cm to 3 m (optimal 5-15 cm) in relatively calm areas.

*Juveniles:*

In NL, LGL Limited (1999) captured juveniles at depths ranging from 0.1-0.8 m over mud, sand, gravel, cobble, rubble, and boulder substrates. Highest catches were in areas of slow water velocity, such as steadies or backwaters, at depths of 0.2-0.6 m and substrates comprised mainly of fine gravel and sand.

Although juveniles were found in highest densities over silt substrates, at velocities of 0.2 m/s and depths up to 0.5 m, they also occurred in low numbers over sand, gravel and rubble substrates (*Lee 1985*).

*Adults:*

In NL, adults were captured most frequently in fast-flowing areas (Ryan 1980).

Adults were found at optimal water velocities ranging from 0.6-0.9 m/s and were reported using the following cover types in order of most to least preferred: cobble and boulder, undercut banks, overhanging vegetation, debris/deadfall, submergent and emergent vegetation, rubble and large gravel (*Suchanek et al. 1984*).

Table 26. Habitat requirements data for **mottled sculpin (*Cottus bairdi*)**.

| **Habitat Features:** | **Ratings**[1] | | | |
|---|---|---|---|---|
| **Categories**[2] | S | Y | J | A |
| **Velocity (m/s):** | | *<0.3* | *med-fast* | *med-fast* |
| **Depths:** | | | | |
| 0-1 meters | *H* | *H* | *H* | *H* |
| 1-2 meters | | | | |
| 2-5 meters | | | | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | *L* |
| Boulder | *H* | | | *M* |
| Rubble | *H* | *H* | *H* | *H* |
| Cobble | *H* | *H* | *H* | *H* |
| Gravel | *H* | *H* | *H* | *H* |
| Sand | *M* | *H* | *H* | *H* |
| Silt | *M* | *H* | | *H* |
| Muck(detritus) | *M* | | | *M* |
| Clay(mud) | *M* | *H* | | *H* |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | *H* | *H* | *H* | *H* |
| Emergents | | | | |
| Overhead | | | | |
| *In situ* | *H* | *H* | *H* | *H* |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General*:

Mottled sculpin occur in cool, headwater streams and lakes across Canada (*Becker 1983*; Scott and Crossman 1998), but do not usually occur as far up headwater streams as the slimy sculpin (Scott and Crossman 1998).

*Spawning*:

Nests consist of cavities beneath flat rocks or ledges (*Downhomer and Brown 1979*; *Becker 1983*; Scott and Crossman 1998) at depths of 0.2 m, in areas of sufficient current to prevent siltation (*Ricker 1934*; *Koster 1936*; *Ludwig and Norden 1969*; *Downhomer and Brown 1979*; *Becker 1983*; Scott and Crossman 1998).

Other nests were observed in crevices among large gravel/cobble or on submerged vegetation in tunnels within loam material (*Becker 1983*).

Nest substrate usually consists of small gravel, although rock, sand and silt may also be present (*Ludwig and Norden 1969*).

Since females have been reported to deposit adhesive eggs on the ceilings of nests while upside down (*Becker 1983*; Scott and Crossman 1998), any reporting of females spawning under rocks was assumed to be rocks of boulder, rubble or cobble size.

*Young-of-the-year:*

Fry, as well as other individuals, seem to distribute themselves in streams in accordance with the coarseness of the substrate (i.e., larger individuals are found in cobble areas, whereas smaller individuals are found in areas characterized by more finely divided materials) (*Downhomer and Brown 1979*).

YOY have been observed over mud, cobble and rubble substrates, at depths between 0.05-0.3 m and velocities <0.3 m/s (Scott and Crossman 1998; *van Snik Gray and Stauffer 1999*).

Some small individuals obtain protection by hiding in the quiet water near shore where they stir up clouds of silt which settles and covers them (*Becker 1983*).

*Juveniles/Adults:*

Mottled sculpin are considered to be a relatively sedentary species with typical average yearly movements of <55 m from home (*Bailey 1952*; *McCleave 1964*; *Brown and Downhomer 1980*; *Hill and Grossman 1987*).

They are found in pools and medium to fast riffles near cover, which may be in the form of vegetation, gravel, or rubble (*Becker 1983*). Distribution appears to be more dependent on available shelter than on bottom type (*Becker 1983*) or velocity (*Matheson and Brooks 1983*).

In North Carolina, *Hill and Grossman* (*1987*) reported that they occupied areas having average velocities of 0.25 m/s and depths <70 cm, while *Facey and Grossman* (*1992*) reported mean nose velocities ranging from 0.4-0.9 m/s.

In Pennsylvanian streams, *van Snik Gray and Stauffer* (*1999*) observed mottled sculpins over cobble and rubble substrates, at depths <16 cm and velocities <0.4 m/s, while in eastern Tennessee, they were observed over mainly rubble substrates, at mean depths of 50 cm and velocities <0.31 m/s (*Greenberg 1991*).

According to *Becker* (*1983*), adults were encountered most frequently in clear or slightly turbid water at depths of 0.1-0.5 m over the following substrates listed in descending order of utilization: sand, gravel, silt, rubble, mud, boulders, detritus, and bedrock.

They prefer substrates comprised mainly of sand, cobble, and rubble (*Becker 1983*; *Grossman and Freeman 1987*; *Greenberg 1991*; Scott and Crossman 1998; *van Snik Gray and Stauffer 1999*) and have been shown to hide under cobble and rubble and utilize large growths of aquatic vegetation as secondary hiding places (*Becker 1983*; *van Snik Gray and Stauffer 1999*).

They have been found overwintering beneath rubble and boulders in streams when water temperatures drop below 5.0$^0$C in the fall (*Cunjak and Power 1986*).

Table 27. Habitat requirements data for **slimy sculpin** (*Cottus cognatus*).

| **Habitat Features:** | **Ratings**[1] | | | |
|---|---|---|---|---|
| **Categories**[2] | S | Y | J | A |
| **Velocity (m/s):** | | *<0.3* | *<0.9* | *0.4-1.7* |
| **Depths:** | | | | |
| 0-1 meters | *H* | *H* | *H* | *H* |
| 1-2 meters | | | | |
| 2-5 meters | | | | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | *H* |
| Boulder | *H* | | | *H* |
| Rubble | *H* | *H* | *H* | *H* |
| Cobble | *H* | *H* | *H* | *H* |
| Gravel | *H* | | *H* | *H* |
| Sand | *M* | | | *H* |
| Silt | *M* | | *H* | *H* |
| Muck(detritus) | | | | |
| Clay(mud) | | | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | | | | *H* |
| Emergents | | | | |
| Overhead | | | | |
| *In situ* | *H* | *M* | *H* | *H* |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General:*

Slimy sculpin prefer swift, rocky-bottomed streams (*Becker 1983*) and often occur in small springs as well as headwater pools and riffles (*Becker 1983*; Scott and Crossman 1998).

According to *Becker (1983)*, slimy sculpin are commonly found in association with trout or salmon.

*Spawning*:

Nests are located in cavities under rocks and ledges, in crevices among substrate 5-8 cm in diameter (cobble), or in tunnels within loam material, at an average depth of 22 cm, in areas with sufficient current to prevent siltation (*Koster 1936*; Scott and Crossman 1998).

Nest substrate usually consists of small gravel although rock, sand, and silt may also be present

(*Ludwig and Norden 1969*).

Since females have been reported to deposit adhesive eggs on the ceilings of nests while upside down (*Becker 1983*; Scott and Crossman 1998), any reporting of females spawning under rocks was assumed to be rocks of boulder, rubble or cobble size.

*Young-of-the-year*:

Upon hatching, young fall to the bottom of the nest where they remain for 3-6 days until the yolk sac is absorbed (*Koster 1936*).

YOY occupy shallow water (<0.2 m) habitats with velocities <0.2 m/s, mainly cobble, rubble substrates and <10% cover (*Johnson et al. 1992*; *van Snik Gray and Stauffer 1999*).

*Juveniles/Adults:*

According to *Johnson et al.* (*1992*), juveniles and adults prefer areas having moderate water depths (0.05-0.2 m) and velocities (0.1-0.3 m/s), mainly cobble/rubble substrates and >10% cover.

Slimy sculpin are typically found over substrates comprised of silt, sand, gravel, rubble, boulders and bedrock (*McPhail and Lindsey 1970*; *Becker 1983*), where these are associated with dense growths of aquatic plants or filamentous algae in moderate to fast currents and at average depths of 0.1 m (*Becker 1983*).

*Baldigo and Lawrence* (*2001*) reported that they were common over gravel and fine-grained substrates at velocities of 0.43-1.72 m/s, while *Hughes and Penden* (*1984*) reported that they were commonly found over cobble and smooth stones.

*van Snik Gray and Stauffer* (*1999*) observed them at depths <0.2 m, velocities <0.3 m/s and cobble/rubble substrates.

They have also been observed over substrates comprised mainly of silt, gravel and cobble, at depths <0.4 m and velocities ranging from 0-0.9 m/s (*Mecum 1984*).

Table 28. Habitat requirements data for **rainbow smelt (*Osmerus mordax*)** .

| **Habitat Features:** | **Ratings**[1] | | | |
|---|---|---|---|---|
| **Categories**[2] | S | Y | J | A |
| **Velocity (m/s):** | *0.6-0.8* | | | |
| **Depths:** | | | | |
| 0-1 meters | *H* | | | |
| 1-2 meters | *M* | | | |
| 2-5 meters | | | | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | | | | |
| Rubble | | | | |
| Cobble | *H* | | | |
| Gravel | *H* | | | |
| Sand | *H* | | | |
| Silt | | | | |
| Muck(detritus) | | | | |
| Clay(mud) | *M* | | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | *H* | | | |
| Emergents | | | | |
| Overhead | *H* | | | |
| *In situ* | *H* | | | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

| **Comments and observations:** |
|---|
| *General* : |
| Rainbow smelt are primarily an anadromous species that ascend freshwater streams in the spring to spawn (*Buckley 1989* ; Scott and Crossman 1998), however, it can live its entire life in freshwater (Scott and Scott 1988; Scott and Crossman 1998). |
| Landlocked populations may exist as normal or dwarf forms (Bruce 1975; Whelan and Wiseman 1975). |
| Smelt are essentially a schooling, pelagic fish, inhabiting mid-waters of lakes, estuaries or inshore coastal waters (Leim and Scott 1966; Scott and Scott 1988; Scott and Crossman 1998). |
| Smelt do not inhabit the flowing waters of streams or rivers except during spawning (Scott and Crossman 1998; Bradbury et al. 1999). |

*Spawning*:

Anadromous smelt typically spawn in the lower reaches of streams and rivers (Templeman 1966) and near the mouths of rivers, mainly above tidal influence (*McKenzie 1964*; Scott and Crossman 1964; Nhwani 1973; *Murawski and Cole 1973*; Scott and Scott 1988; *Buckley 1989*).

Spawning typically occurs in coastal streams over a gravel substrate at water depths of 0.1-1.3 m during low tide (*Murawski et al. 1980*) in areas with moderate to swift currents (0.6-0.8 m/s) (*Hulbert 1974*; *Sutter 1980*; *Buckley 1989*; Scott and Crossman 1998; Bradbury et al. 1999).

Spawning has been shown to occur over a variety of substrates including sand, mud, gravel, cobble, submerged logs as well as vegetation, although gravel appears to be preferred (*Rupp 1959*; Scott and Crossman 1964; *Ivanova and Polovkova 1972*; Nhwani 1973; *Morrow 1980*; *Murawski et al. 1980*).

In NL, landlocked smelt have been reported to spawn at depths of 0.6-1.2 m, and the eggs have been deposited on debris and rocks (Bruce 1975).

It has been suggested that water velocity rather than depth or substrate largely influences spawning site selection (*Clayton 1976*; *Buckley 1989*).

Adults often seek shelter under banks during their spawning migrations (*Becker 1983*).

*Young-of-the-year*:

After hatching, young drift downstream to the lake or estuary where they grow and mature (*Becker 1983*; Scott and Scott 1988; *Buckley 1989*; *Nellbring 1989*; Scott and Crossman 1998).

In a NB estuary, *McKenzie* (*1964*) found that larvae were located in bottom layers during the day and surface layers at night, allowing them to take advantage of selective tidal transport when maintaining position.

*Juveniles:*

As young grow, they move into waters of increased salinity in the lower estuary or nearshore coastal waters where they are associated with sand/gravel substrates (*Buckley 1989*; Scott and Crossman 1998) and eelgrass beds (*Crestin 1973*).

*Adults:*

Adults usually occupy estuaries and coastal areas within 2 km of shore (*Bigelow and Schroeder 1953*; *Buckley 1989*).

They have been shown to overwinter in estuaries (*Buckley 1989*) or coastal areas (*Bond 1982*; *Haldorson and Craig 1984*).

Table 29. Habitat requirements data for **blackspotted stickleback** (*Gasterosteus wheatlandi*).

| Habitat Features: | Ratings[1] | | | |
|---|---|---|---|---|
| **Categories[2]** | S | Y | J | A |
| **Velocity (m/s):** | | | | |
| **Depths:** | | | | |
| 0-1 meters | *H* | | | |
| 1-2 meters | | | | |
| 2-5 meters | | | | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | | | | |
| Rubble | | | | |
| Cobble | | | | |
| Gravel | | | | |
| Sand | *H* | | | |
| Silt | | | | |
| Muck(detritus) | | | | |
| Clay(mud) | *H* | | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | *H* | | | |
| Emergents | | | | |
| Overhead | | | | |
| *In situ* | *H* | | | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

| **Comments and observations:** |
|---|
| *General* : |
| Blackspotted stickleback are mainly distributed in coastal marine waters, tidal pools, brackish waters and occasionally in freshwater (*Wootton 1976* ; Scott and Scott 1988). |
| |
| *Spawning* : |
| It is assumed that they spawn within a year after birth and then die shortly thereafter (*Wootton 1976* ; *Worgan and Fitzgerald 1981* ; *Ward and Fitzgerald 1983* ; Scott and Crossman 1998). |
| Spawning occurs in brackish waters (*Wootton 1976* ; Scott and Scott 1988), typically over a sand or coarse mud substrate in the vicinity of abundant rooted vegetation or sunken logs and where there is |

| |
|---|
| suitable thread-like plant debris and algae for nest construction (*McInerney 1969*). |
| Nests are constructed at water depths of 0.05-0.6 m at low tide (*McInerney 1969*; Scott and Scott 1988). |
| |
| *Young-of-the-year:* |
| Prior to hatching, males have been observed adding an extra 'loose' layer of plant material to nests, presumably to provide emergent fry with a safe area in which to move about (*McInerney 1969*). |
| |
| *Juveniles/Adults:* |
| *Audet et al.* (*1986*) reported that in a Quebec tidal creek, adults immediately returned to estuaries after breeding. |
| Juveniles and adults usually occupy estuaries and coastal areas (Scott and Crossman 1998). |
| |

Table 30. Habitat requirements data for **fourspine stickleback (*Apeltes quadracus*)**.

| **Habitat Features:** | | **Ratings**[1] | | |
|---|---|---|---|---|
| **Categories**[2] | S | Y | J | A |
| **Velocity (m/s):** | | | | |
| **Depths:** | | | | |
| 0-1 meters | *H* | | | |
| 1-2 meters | | | | |
| 2-5 meters | | | | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | | | | |
| Rubble | | | | |
| Cobble | | | | |
| Gravel | | | | |
| Sand | | | | |
| Silt | | | | |
| Muck(detritus) | | | | |
| Clay(mud) | | | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | *H* | | | |
| Emergents | *H* | | | |
| Overhead | | | | |
| *In situ* | | | | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

| **Comments and observations:** |
|---|
| *General*: |
| Fourspine stickleback are a euryhaline species (Scott and Scott 1988; Scott and Crossman 1998). |
| Although they are primarily a marine species and are usually restricted to a narrow coastal zone, they |
| also occur in brackish and estuarine waters and occasionally in freshwater (*Blouw and Hagen 1981*; |
| Scott and Scott 1988). |
| They usually occur in vegetated areas with calm water and are rarely found in swift currents or along |
| coastlines exposed to strong wave action or large tidal flux (*Blouw and Hagen 1981*). |
| In NL, they occur in anadromous (Scott and Crossman 1964; Garside 1970; Hanek and Threlfall 1970; |
| van Vliet 1970; Lewis 1978) and freshwater resident (Dadswell 1972a; Rombough et al. 1981; |

Campbell 1992) forms.

*Spawning* :
Anadromous species typically spawn in intertidal areas, while freshwater dwellers spawn along shorelines (*Wootton 1976* ; Scott and Scott 1988; Scott and Crossman 1998).
Nests are constructed in the branches or on the stems of plants in shallow water using small twigs and aquatic plants, which are bound together by a kidney secretion (*Hall 1956* ; *Rowland 1974a* ; *Wootton 1976* ; *Courtenay 1983* ; Scott and Scott 1988).
According to *Rowland* (*1974a; b* ), nests are either constructed directly on the bottom or 0.2 m or more above the substrate depending on available vegetation.
In laboratory experiments, they have been reported to spawn over seaweed and eelgrass (*Courtenay and Keenleyside 1983* ).

*Young-of-the-year/Juveniles/Adults:*
After hatching, young remain on the bottom for several days before swimming (*Breder and Rosen 1966* ; *Wootton 1976* ; *Blouw and Hagen 1981* ; Scott and Scott 1988).
In the literature reviewed, there were no reports of river utilization by YOY, juveniles or adults.

Table 31. Habitat requirements data for **ninespine stickleback (*Pungitius pungitius*)** .

| **Habitat Features:** | **Ratings[1]** | | | |
|---|---|---|---|---|
| **Categories[2]** | S | Y | J | A |
| **Velocity (m/s):** | *<0.3* | | | *<0.3* |
| **Depths:** | | | | |
| 0-1 meters | *H* | *H* | | *H* |
| 1-2 meters | *M* | | | *H* |
| 2-5 meters | | | | *M* |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | | | | |
| Rubble | | | | |
| Cobble | *M* | | | |
| Gravel | *M* | | | *M* |
| Sand | *M* | *H* | | *H* |
| Silt | *H* | *H* | | |
| Muck(detritus) | | | | *H* |
| Clay(mud) | *H* | *H* | | *H* |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | *H* | *H* | | *H* |
| Emergents | *H* | *H* | | *H* |
| Overhead | | | | |
| *In situ* | | | | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General* :

Ninespine stickleback are typically found in shallow vegetated areas of lakes, ponds and pools of sluggish streams, although sometimes they may occur in open water over sand (*Page and Burr 1991* ).

*Spawning* :

Spawning usually occurs in lakes, occasionally at the mouths of tributaries (*Becker 1983* ) or brackish water estuaries (Scott and Scott 1988; Scott and Crossman 1998).

Spawning is typically associated with dense vegetation (*McPhail and Lindsey 1970*); the male builds a nest among the weeds, usually 10-15 cm off the bottom, using fragments of aquatic vegetation, algae and debris (*McPhail and Lindsey 1970* ; *Wootton 1976* ; Scott and Crossman 1998; *Pinder 2001* ).

| |
|---|
| Spawning has been reported along shallow shorelines and sluggish pools (*Wootton 1976*; *Morrow 1980*; *Becker 1983*; *Page and Burr 1991*) among dense aquatic vegetation and substrates comprised mainly of silt and mud (*McPhail and Lindsey 1970*; *Wootton 1976*; *Morrow 1980*; Scott and Scott 1988; Scott and Crossman 1998), but may also occur in sparsely vegetated areas over sand, gravel or rocky substrates (*McPhail and Lindsey 1970*; *Wootton 1976*). |
| Nests are usually suspended <10 cm above the bottom at depths ranging from 0.3-1.4 m (*McKenzie and Keenleyside 1970*; *McPhail and Lindsey 1970*; *Wootton 1976*; *Foster 1977*; Scott and Scott 1988; Scott and Crossman 1998), however, they may be constructed upon the substrate in areas of sparse vegetation (*Becker 1983*). |
| *Worgan and Fitzgerald* (*1981*) reported spawning at depths <0.5 m and water velocities <0.3 m/s. |
| |
| *Young-of-the-Year/Juveniles:* |
| Newly hatched young typically remain within the vicinity of the nest for approximately 2 weeks (*McPhail and Lindsey 1970*; *Wootton 1976*; *Keenleyside 1979*; Scott and Scott 1988). |
| When the young are about 2 weeks old, the male can no longer control their wanderings and the small fish typically move into the open water (Scott and Crossman 1998). |
| Young typically congregate in shallow, sandy areas moving to deeper waters in the fall to overwinter (*Becker 1983*). |
| Although most mature during their first year of life (Scott and Crossman 1998), some do not reach sexual maturity until after one year (*McPhail and Lindsey 1970*). |
| |
| *Adults:* |
| Adults typically inhabit cool, quiet waters (*McPhail and Lindsey 1970*; *Becker 1983*). |
| Dense aggregations are often associated with heavy vegetation, while smaller numbers of individuals may be found over sand or gravel and other areas of sparse vegetation (*McPhail and Lindsey 1970*). |
| They are typically found at depths of 0.1-2.5 m, velocities <0.3 m/s over mud, clay, detritus or sand substrates and occasionally gravel in the vicinity of emergent or submergent vegetation (*Worgan and Fitzgerald 1981*; *Copp et al. 1998*). |
| |

Table 32. Habitat requirements data for **threespine stickleback (*Gasterosteus aculeatus*)**.

| **Habitat Features:** | | **Ratings[1]** | | |
|---|---|---|---|---|
| **Categories[2]** | S | Y | J | A |
| **Velocity (m/s):** | *0.03-0.2* | | | *0.1-1.0* |
| **Depths:** | | | | |
| 0-1 meters | *H* | *H* | | *H* |
| 1-2 meters | | | | |
| 2-5 meters | | | | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | *L* | | | |
| Rubble | | | | |
| Cobble | | | | |
| Gravel | *L* | | | *H* |
| Sand | *H* | *H* | | *H* |
| Silt | | | | |
| Muck(detritus) | *H* | | | *H* |
| Clay(mud) | *H* | *H* | | *H* |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | *H* | *H* | | *H* |
| Emergents | *H* | *H* | | *H* |
| Overhead | | | | |
| *In situ* | | | | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General*:

In NL, threespine stickleback are found in most shallow waters and are tolerant of marine, brackish and fresh water (Scott and Scott 1988; Scott and Crossman 1998).

Typically an inhabitant of still or relatively slow-flowing areas (*McPhail and Lindsey 1970*; *Wootton 1976*; Bradbury et al. 1999), they are usually associated with aquatic vegetation, although this association is not as strong as with other sticklebacks (*McPhail and Lindsey 1970*).

In NL, they exist as both freshwater resident and anadromous marine-dwelling forms (Scott and Scott 1988; Scott and Crossman 1998).

*Spawning* :

Anadromous populations migrate into fresh or brackish waters to spawn, while freshwater populations migrate from deep to shallow waters of lakes or from larger rivers into smaller, slower tributaries and backwaters (Scott and Scott 1988; Scott and Crossman 1998).

Spawning has been reported at water velocities ranging from 0.03-0.2 m/s, depths <1 m, on a mud, sand substrate near sparse or abundant vegetation (*Hagen 1967* ; *Snyder and Dingle 1989* ; *Mori 1994* ; *Virgl and McPhail 1994* ).

Gravel or boulder substrates have also been used sparingly by males during nest construction (*Mori 1994* ).

This species, unlike other members of the gasterosteid family, may build its nest directly on the bottom, preferably in shallow water (i.e., only a few centimeters deep - *Wootton 1976* ) over a mud (*McPhail and Lindsey 1970* ; *Wootton 1976* ) or sandy bottom (Scott and Crossman 1998), within or on the downstream edge of a bed of pond weed (*Wootton 1976* ).

The nest is usually built near aquatic plants, but is more exposed than those of other sticklebacks (*McPhail and Lindsey 1970* ; *Wootton 1976* ) and is constructed of small twigs, plant debris, sand grains and algae (*McPhail and Lindsey 1970* ; *Wootton 1976* ; Scott and Crossman 1998).

*Young-of-the-Year:*

YOY remain within the vicinity of the nest shortly after hatching and then become free-swimming and join schools of other young sticklebacks (*Wootton 1976* ).

*Juveniles/Adults* :

They typically inhabit vegetated areas, usually over mud or sand (*Page and Burr 1991* ).

Adults are commonly found at depths of 0.1-1.0 m, in nil to weak currents, over substrates of mud, clay, detritus, sand and gravel in the vicinity of emergent or submergent vegetation (*Copp et al. 1998* ).

Table 33. Habitat requirements data for **Atlantic sturgeon (*Acipenser oxyrinchus*)**.

| **Habitat Features:** | **Ratings[1]** | | | |
|---|---|---|---|---|
| **Categories[2]** | S | Y | J | A |
| **Velocity (m/s):** | | | | |
| **Depths:** | | | | |
| 0-1 meters | *H* | | | |
| 1-2 meters | *H* | | | |
| 2-5 meters | *M* | | *H* | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | | | | |
| Rubble | *H* | | | |
| Cobble | *H* | | | |
| Gravel | *H* | | | |
| Sand | *M* | *H* | *H* | |
| Silt | *M* | | | |
| Muck(detritus) | | | | |
| Clay(mud) | | | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | | | | |
| Emergents | | | | |
| Overhead | | | | |
| *In situ* | | | | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General*:

Atlantic sturgeon are an anadromous, bottom living species, entering rivers and estuaries to spawn (Scott and Scott 1988).

Most of its life is spent in saltwater, where the majority of growth takes place (Scott and Scott 1988).

*Spawning*:

Spawning occurs at depths up to 3 m, usually over gravel/rubble substrates or other hard objects, in pools below water falls (*Dees 1961*; *Vladykov and Greeley 1963*; *Leland 1968*; *Huff 1975*; *Smith 1985*), but has been observed over sand and silt (*Van Den Avyle 1984*).

Eggs are demersal and highly adhesive, attaching to rocks, gravel, plants, roots, etc. within 20 minutes

| |
|---|
| of being broadcasted (*Smith 1985* ). |
| |
| *Young-of-the-year* : |
| Newly hatched larvae are free swimming until yolksacs are absorbed (9 to 10 days after hatching), after which they adopt a benthic lifestyle (*Smith et al. 1981* ). |
| Since subadults (>30 cm) are regularly captured in tidally influenced lower river and estuarine areas (*Dovel and Beggren 1983* ; *Lazzari et al. 1986* ; *Collins et al. 1996* ), it is assumed that YOY move slowly downstream from spawning sites (*Smith and Clugston 1997* ). |
| YOY have been captured in tidally influenced transition zones having hard sand and shale substrates (*Smith et al. 1982* ). |
| |
| *Juveniles* : |
| Juveniles generally remain within their natal stream, but move progressively seaward over time (*Vladykov and Greeley 1963* ; *Holland and Yelverton 1973* ; *Huff 1975* ; *Murawski and Pacheco 1977* ; *Hoff 1980* ; *Rulifson and Huish 1982* ; *Smith 1985* ). |
| In rivers, juveniles typically occur at depths ranging from 2-3 m (*Van Den Avyle 1984* ) where they may remain up to 6 years before migrating to sea (*Smith 1985* ). |
| |
| *Adults* : |
| Except during spawning, adults spend their entire lives at sea (Scott and Scott 1988). |
| |

Table 34. Habitat requirements data for **longnose sucker (*Catostomus catostomus*)**.

| **Habitat Features:** | **Ratings**[1] | | | |
|---|---|---|---|---|
| **Categories**[2] | S | Y | J | A |
| **Velocity (m/s):** | *0.3-1.0* | *<0.6* | *0-0.9* | |
| **Depths:** | | | | |
| 0-1 meters | *H* | *H* | *H* | H |
| 1-2 meters | | | | |
| 2-5 meters | | | | |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | | *H* | | H |
| Rubble | *H* | *H* | *M* | H |
| Cobble | *H* | *L* | *M* | H |
| Gravel | *H* | *L* | *H* | H |
| Sand | *L* | *M* | *H* | |
| Silt | | *H* | *M* | |
| Muck(detritus) | | | | |
| Clay(mud) | | | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | | *H* | | |
| Emergents | | *H* | | |
| Overhead | | | | |
| *In situ* | | *H* | | |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General*:

Longnose suckers inhabit streams, lakes and reservoirs, with lacustrine inhabitants moving into rivers to spawn or overwinter (*Harris 1962*; *Walton 1980*; *Edwards 1983*).

They are mainly bottom feeders (Scott and Crossman 1998).

*Spawning*:

Spawning occurs in the spring, usually in riffle areas of rivers and inlet streams, but can also take place in outlet streams of lakes or shallow lake margins (*Geen et al. 1966*; *McPhail and Lindsey 1970*; *Smith 1979*; *Walton 1980*; *Becker 1983*; *Edwards 1983*; *Dion et al. 1994*; Scott and Crossman 1998).

Spawning typically occurs at depths of 0.1-0.3 m, with a current between 0.3-0.45 m/s and a gravel, cobble or

| |
|---|
| rubble substrate (*Harris 1962* ; *Geen et al. 1966* ; *McPhail and Lindsey 1970* ; *Walton 1980* ; *Becker 1983* ; |
| Scott and Crossman 1998). |
| *Edwards* (*1983* ) reported eggs being broadcast over clean gravel, cobble or rubble substrates in riffle areas |
| having velocities of about 0.3-1.0 m/s, while *Dion et al.* (*1994* ) observed spawning at velocities averaging |
| 0.35-0.43 m/s, average depths of 60-65 cm and substrates comprised mainly of gravel, with some sand. |
| |
| *Young-of-the-year:* |
| In streams, newly hatched young begin to drift downstream within a week or two of hatching (*Becker 1983* ; |
| *Geen et al. 1966* ; Scott and Crossman 1998). |
| In lakes, YOY seek cover, usually in the form of vegetation, boulders or rubble, during daylight hours in |
| shallow, quiet waters (*Hayes 1956* ; *Edwards 1983* ), therefore it is assumed that similar habitats are |
| occupied in streams. |
| In Alaska, YOY were most abundant over silt and sand substrates in shallow (<0.2 m) backwaters having |
| velocities <0.1 m/s, although they were also captured at varying densities over silt, sand, gravel, cobble and |
| rubble substrates at depths <0.6 m and velocities ranging from 0-0.6 m/s (*Mecum 1984* ). |
| |
| *Juveniles* : |
| Juveniles seek out areas with some current and may enter the lower reaches of streams (*Johnson 1971* ). |
| In Alaska, although juveniles were captured over silt, sand, gravel, cobble and rubble substrates at depths |
| <0.6 m and velocities ranging from 0-0.9 m/s, they tended to prefer sand/gravel substrates at depths <0.1 m |
| and velocities between 0.6-0.9 m/s (*Mecum 1984* ). |
| |
| *Adults* : |
| Since longnose suckers typically return to lakes within a week after spawning is complete (*Geen et al. 1966* ; |
| Scott and Crossman 1998), there is little or no use of stream habitat by adults. |
| Because they are well adapted to high current velocities (*Walton 1980* ), they are often found in swift rivers |
| with stony bottoms (*Edwards 1983* ). |
| LGL Limited (1999) reported adults in lake tributaries at depths ranging from 0.2-0.8 m over gravel, cobble or |
| boulder substrates. |
| |

Table 35. Habitat requirements data for **white sucker (*Catostomus commersoni*)**.

| **Habitat Features:** | **Ratings**[1] | | | |
|---|---|---|---|---|
| **Categories**[2] | S | Y | J | A |
| **Velocity (m/s):** | *0.1-0.9* | *<0.3* | *0.3-0.6* | *<0.4* |
| **Depths:** | | | | |
| 0-1 meters | *H* | *H* | *H* | *H* |
| 1-2 meters | | | *M* | *H* |
| 2-5 meters | | | *L* | *L* |
| 5-10 meters | | | | |
| 10+ meters | | | | |
| **Substrate:** | | | | |
| Bedrock | | | | |
| Boulder | *L* | *H* | *H* | *H* |
| Rubble | | | *H* | *H* |
| Cobble | | | | *H* |
| Gravel | *H* | *H* | | *H* |
| Sand | *H* | *H* | *H* | *H* |
| Silt | | | | *H* |
| Muck(detritus) | | | | |
| Clay(mud) | | | | |
| Pelagic | | | | |
| **Cover:** | | | | |
| None | | | | |
| Submergents | | *H* | | *L* |
| Emergents | | *H* | | *L* |
| Overhead | | *H* | | *M* |
| *In situ* | | *H* | *H* | *H* |
| Other | | | | |

[1]Ratings are Nil (default), L-low, M-medium or H-high.

[2]Categories are S-spawning, Y-young-of-the-year, J-juveniles and A-adults.

**Comments and observations:**

*General*:

White suckers usually inhabit warmer, shallower (2-6 m) littoral areas of lakes or tributaries of larger lakes (*McPhail and Lindsey 1970*; Scott and Crossman 1998).

They are a common inhabitant of the most highly polluted and/or most turbid, stagnant or high alkalinity waters (*Becker 1983*).

White sucker abundance has been shown to be positively correlated with amount of shade and large woody debris in streams (*Hubert and Rahel 1989*).

*Spawning*:

Spawning generally occurs in inlets, outlets, small creeks, and rivers with relatively swift, shallow waters running over a gravel or coarse sand bottom (*Forbes and Richardson 1920*; *Dence 1948*; *Nelson 1968*; *Carlander 1969*; *McPhail and Lindsey 1970*; *Schneberger 1977*; *Twomey et al. 1984*), but has been shown to occur over a boulder substrate as well (*Dion et al. 1994*).

White suckers are bottom-spawners (*Corbett and Powles 1983*) and prefer to spawn in shallow, gravel, riffle sections, but may even spawn in swift water or rapids (*Geen et al. 1966*; *Becker 1983*; *Corbett and Powles 1983*; *Twomey et al. 1984*; Scott and Crossman 1998).

Spawning has been reported at depths ranging from 0.1 to <1 m (*Nelson 1968*; *Fuiman 1978*; *Curry 1979*; *Corbett and Powles 1983*; *Twomey et al. 1984*; *Aadland 1993*; *Dion et al. 1994*).

Although spawning has been reported at water velocities ranging from of 0.1-0.9 m/s (*Minckley 1963*; *Nelson 1968*; *Curry 1979*; *Twomey et al. 1984*; *Aadland 1993*; *Dion et al. 1994)*, in an artificial stream, *Symons* (*1976*) found that spawning occurred most often at modal velocities of 0.3-0.5 m/s.

The demersal and adhesive eggs either adhere to the substrate in the immediate spawning area or drift downstream and adhere to the substrate in quieter areas (*Becker 1983*; *Corbett and Powles 1983*; *Twomey et al. 1984*; Scott and Crossman 1998).

*Young-of-the-year*:

YOY are usually found over a sand/gravel substrate in areas with moderate currents (*Thompson and Hunt 1930*; *Twomey et al. 1984*).

They are commonly found in shallow pool areas having velocities <0.3 m/s and depths <0.6 m, along channel margins where boulder, vegetation, woody debris and undercut banks are the primary cover types (*Aadland 1993*).

Although some young migrate to lakes approximately one month after spawning (*Geen et al. 1966*; *Becker 1983*; Scott and Crossman 1998; Bradbury et al. 1999), others remain within their natal stream (*Aadland 1993*).

*Juveniles*:

Juveniles prefer slow riffles where the depth is <0.6 m and the water velocities range from 0.3-0.6 m/s (*Aadland 1993*) and have been found in shallow backwaters and riffles with moderate water velocities (~0.5 m/s) and a predominantly sand/rubble substrate (*Propst 1982*).

Juveniles overwinter beneath rubble and boulders in streams when water temperatures drop below 5°C and have also been found occupying slow, deep (>2 m) steadies (*Cunjak and Power 1986*).

*Adults*:

Although adults are common in pools with slow to moderate velocities (~ 0.4 m/s) (*Scherer 1965*; *Pflieger 1975*; *Propst 1982*; *Twomey et al. 1984*) at depths up to 2.4 m, they appear to prefer depths of 0.6-0.9 m *Propst 1982*; *Twomey et al. 1984*).

They occur mainly over gravel, sand, silt and rubble substrates (*Becker 1983*; *Twomey et al. 1984*).

Adults have been shown to use boulders, vegetation, large woody debris in shady sections of streams, exposed tree roots and undercut banks as sources of cover (*Thompson and Hunt 1930*; *Dence 1948*; *Minckley 1963*; *Propst 1982*; *Becker 1983*; *Twomey et al. 1984*; *Hubert and Rahel 1989*).

When present in shallow water with an appreciable current, they are usually found in the shelter of vegetation, either instream or overhanging (*Twomey et al. 1984*).

# Appendix 2 – Glossary of Terms

**Fish** - Includes finfish, shellfish, crustaceans, marine animals and the eggs, sperm, spat, larvae and juvenile stages of finfish, shellfish, crustaceans and marine animals.

**Fish Habitat** - Spawning, nursery, rearing, food supply, over-wintering and migration areas on which fish depend, directly or indirectly, in order to carry out their life processes.

**Gillnet** - A monofilament net consisting of a single mesh size (see also experimental gillnet). Generally set in shallow water areas of lakes; however, bottom sets are possible at depths exceeding 50 m. Gillnet sampling is usually limited to areas free of obstructions, snags and floating debris as well as locations with little or no current.

**Grilse** – Term used to refer to Atlantic salmon returning to freshwater to spawn after spending one winter at sea.

**Habitat Requirements** - The specific environmental conditions which a species needs to survive, grow and reproduce.

**Head of Tide** – The highest point in the river that water levels are affected by tidal flows.

**Incubation Period** – The time interval between egg fertilization and hatching.

**Juveniles** – Fish older than one year of age, which are fundamentally like adults in appearance, but smaller and not sexually mature.

**Kelts** – Term used to refer to Atlantic salmon after they have spawned and turned black in colour.

**Lacustrine Habitat** – Pertaining to or living in lakes or ponds.

**Landlocked** – Populations of fish that are prevented from making return migrations to the ocean because of natural obstructions. It also categorizes fish that spend their entire life cycle within freshwater regardless of whether they have access to the ocean.

**Larvae** – Post embryonic state of an organism that is markedly different in appearance from the adult and which undergoes metamorphosis before assuming adult characteristics.

**Lentic** – Refers to standing or slow-moving water, as in ponds and lakes.

**Life Cycle** - The various phases an individual passes through from birth to maturity and reproduction.

**Life Stage** - An extended period during the life cycle of an organism that is characterized by little or no change in development (e.g., egg, larval, fry, juvenile, adult, etc.).

**Macrophytes** - Algae and rooted aquatic plants that can be seen with the naked eye.

**Metamorphosis** – Change in form and structure that fish undergo from the embryo to adult stage.

**Migration** – The deliberate movement of fish from one habitat to another usually at a definite stage in the life cycle (e.g. anadromous, catadromous, etc.).

**Natal River** – The river or stream in which a fish was born.

**Native (indigenous)** – Fish that originate in the area in which they live.

**Nose Velocity** – Velocity measured at the actual fish location within the water column.

**Nursery (or Rearing) Habitat** - Fish habitat which provides food and cover for immature fish.

**Oligotrophic** – Condition of water being low in nutrients and not able to support much plant life.

**Ontogenetic** – Size-related shifts that occur during the growth and development of an individual.

**Organic** – Derived from living organisms.

**Overhead Cover** - Includes riparian vegetation overhanging stream margins, undercut banks and woody debris at the surface of the water.

**Pelagic** - Open-water areas, either middle or surface water levels, which are not directly influenced by the stream margin or bottom.

**Phytoplankton** - Microscopic plant life that floats in the open ocean.

**Planktonic** – Pertaining to small aquatic plants (phytoplankton) and animals (zooplankton), sometimes microscopic, drifting within the surrounding water.

**Population** – A group of individuals with a common ancestry that are much more likely to breed with one another than with individuals from another such group.

**Redd** – The nest of salmonid fishes where the eggs are deposited.

**Resident** – Fish which remain in freshwater throughout their entire life cycle (non-migratory).

**Riparian (overhanging) Cover** – Cover provided by mature trees, alders, shrubs, grasses, etc. bordering the stream edge or hanging out over the stream.

**Salmon** – Term used to refer to Atlantic salmon returning to freshwater to spawn after spending two or more years at sea.

**Shoal** – Offshore shallow areas.

**Silt** – Very fine sediment particles, usually < 0.06 mm in diameter, which can be carried or moved by stream currents and deposited in slower moving water. This material is particularly harmful to invertebrates and extremely detrimental to spawning habitat.

**Smolt** – A one or more year old juvenile salmonid having undergone physiological changes to cope with shifting from a freshwater to a marine environment. Usually refers to salmonids exhibiting silvery coloration and undertaking downstream migration to the sea.

**Spawning** – Life stage of fish that are in spawning condition.

**Spawning Habitat** - Various substrates, vegetation, woody debris, etc. used by fish for egg deposition during spawning and includes the incubation of fertilized eggs.

**Spawning Substrate** - the bottom type required by a fish for spawning.

**Submergent Vegetation** - Aquatic plants that grow entirely below the water surface (e.g., elodea, bladderwort, pipewort, potamogeton) and includes numerous mosses and macroalgae.

**Substrate** - The materials that comprise a stream bottom including; bedrock, boulder, rubble, cobble, gravel, sand, silt, clay and detritus.

**Sympatric** – Species inhabiting the same or overlapping geographic areas and are not denied the opportunity to breed by any geographic barrier.

**Tributary** – Refers to any stream that flows into another, larger stream above its confluence with saltwater, or a lake (river mouth).

**Upwelling Groundwater** - Water present below the surface of the ground that percolates up through the substrate. It appears to be an important determinant for brook trout spawning in most geographic areas and may also play a role in over-wintering survival of certain species.

**Water Column** - The water mass between the surface and the bottom.

**Watershed** – The catchment area for a stream or river system, together with its land and water resources; often used to mean a drainage basin.

**Young-of-the-Year** (**YOY**) - Fish that are under one year of age (age 0+).

**Zooplankton** - Animals (mostly microscopic) which drift freely in the water column.