Northern Pike (*Esox lucius*) Habitat Enhancement in the Northwest Territories

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ABSTRACT

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Fish habitat was developed and enhanced, as required under a *Fisheries Act* Authorization, to compensate for habitat loss due to infilling in the Stagg River associated with highway works north of Yellowknife, Northwest Territories (NWT). Through assessing the habitat requirements of northern pike (*Esox lucius*), the habitat enhancement area was specifically designed to provide specialized spawning and nursery habitat for pike, but it was anticipated that other fish species and invertebrates would also benefit from the area. A shallow irregular shaped pond was excavated and connected to two well vegetated off-line ponds that were then connected to the Stagg River through excavated channels. A monitoring program was initiated to assess site stability, revegetation, and utilization by fish. The constructed pond was left to naturally vegetate, and therefore wasn't anticipated to be viable spawning habitat for a few years. However, in all three years of post construction monitoring , adult pike were observed during spawning surveys and young-of-the-year (YOY) pike were collected during mid-summer surveys along with spottail shiners and invertebrates. YOY pike exhibit strong natal site fidelity in their first few months of life and thus their presence in the ponds confirms successful spawning and the utilization of nursery habitat. Also, within two years of construction, the infilled area had settled below the waterline and re-vegetated, and adult pike were observed. Habitats were ranked using a relative productivity scale and multiplied with area (m^2) of habitat lost and gained. The habitat gain was calculated to be approximately 3:1. However, after the infilled area had largely reverted back to fish habitat and the habitat gain was recalculated to be over 11:1. This type of compensation can be utilized anywhere within the circumpolar range of pike assuming suitable habitat parameters exist. Although relatively small in scale, this project the only documented example in the NWT where pike habitat has been constructed, monitored, and proven to be successful at achieving no-net-loss of fish habitat.

Key Words; Northwest Territories; NWT; fish habitat; northern pike, pike, compensation, habitat construction, habitat enhancement, spawning

RÉSUMÉ

Cott, P. A. 2004. Northern pike (*Esox lucius*) habitat enhancement in the Northwest Territories. Can. Tech. Rep. Fish. Aquat. Sci. 2528: vii + 32 p.

Pour compenser la perte d'habitat causée par le remblayage dans la rivière Stagg lors de la construction d'une route au nord de Yellowknife (Territoires du Nord-Ouest), de l'habitat du poisson a été créé et aménagé, tel qu'exigé par une autorisation délivrée en vertu de la *Loi sur les pêches*. Grâce à l'évaluation des caractéristiques d'habitat nécessaires pour le grand brochet (*Esox lucius*), la zone d'aménagement d'habitat a été expressément conçue pour offrir de l'habitat de fraie et d'alevinage au brochet, mais on prévoit qu'elle profitera aussi aux invertébrés et à d'autres espèces de poisson. Un étang de forme irrégulière a été creusé et relié à deux étangs autonomes possédant une végétation abondante que l'on a ensuite reliés à la rivière Stagg en creusant des chenaux. Un programme de surveillance a été lancé pour évaluer la stabilité du site, sa remise en végétation et son utilisation par le poisson. Comme on a laissé la végétation s'établir naturellement dans l'étang construit, on ne s'attendait pas à ce qu'il constitue une frayère viable avant quelques années. Toutefois, à chacune des trois années de surveillance depuis la construction de l'étang, des brochets adultes y ont été observés lors de relevés de fraie, et des jeunes brochets de l'année y ont été recueillis, avec des queues à tache noire et des invertébrés, lors de relevés effectués au milieu de l'été. Au cours des premiers mois de leur vie, les jeunes brochets de l'année présentent une forte fidélité à leur lieu de naissance : leur présence dans les étangs confirme donc que la fraie y a eu lieu et que l'habitat d'alevinage est utilisé. En outre, deux ans après la construction, la zone remblayée s'est tassée sous le niveau de l'eau, la végétation s'y est établie, et des brochets adultes y ont été observés. Les habitats ont été classés sur une échelle de productivité relative, et les indices ainsi obtenus ont été multipliés par la superficie (m^2) d'habitat perdu et créé. Le gain en habitat a été estimé à environ 3:1, mais ce chiffre est passé à 11:1 une fois que la zone remblayée étaient largement redevenue un habitat du poisson. Ce type de compensation peut être utilisé partout dans l'aire circumpolaire du brochet où les paramètres sont convenables. Ce projet de petite ampleur constitue le seul exemple documenté de création et de surveillance d'habitat du brochet dans les T.N.-O. ayant permis d'atteindre l'objectif d'aucune perte nette d'habitat du poisson.

Mots clés : Territoires du Nord-Ouest; T.N.-O.; habitat du poisson; grand brochet, brochet, compensation, création d'habitat, aménagement de l'habitat, fraie.

INTRODUCTION

In 1999 construction was undertaken on Highway 3 in the vicinity of the Stagg River, north of the city of Yellowknife in the Northwest Territories (NWT; Figure 1). These highway works resulted in a harmful alteration, disruption or destruction (HADD) of 2600 m^2 of fish habitat. A HADD of fish habitat is prohibited under s.35(1) of the *Fisheries Act*, unless authorized by Department of Fisheries and Oceans (DFO) under s.35(2). Such authorizations are typically only issued if it can be demonstrated that "no-net-loss of the productive capacity of fish habitat" can be achieved through habitat compensation (Department of Fisheries and Oceans 1986). The *Policy for the Management of Fish Habitat* (1986; the Policy) defines productive capacity as "the maximum natural capacity of habitats to produce healthy fish…or to support aquatic organisms on which fish depend". A hierarchy of preferences relating to no-net-loss strategies is also outlined in the Policy, with compensation of "like for like" habitat being the preferred option - replacing lost habitat with the same type of natural habitat at or near the site where the habitat loss occurred.

Adjacent to the HADD, a previously disturbed area presented the opportunity to initiate compensation efforts that would replace habitat used by northern pike (*Esox lucius*), the species that would be most effected by the HADD. A s.35(2) *Fisheries Act* Authorization that outlined compensation, monitoring and mitigation measures for the proposed works was developed and issued to the proponent, the Government of the Northwest Territories – Department of Transportation (DOT) prior to the onset of the works that would result in the HADD.

Pike have a circumpolar distribution and have the broadest range of any member of the Esocidae family, occurring in waters throughout the Northern Hemisphere north of 40° latitude (Raat 1988; Crossman 1996). In freshwater systems within the NWT pike are ubiquitous with the exception of the northern tundra and the Arctic islands (McPhail and Lindsay 1970; Scott and Crossman 1973; Richardson et al. 2001; Evans et al. 2002). Pike spawn shortly after ice-out in shallow weedy areas and flooded terrestrial vegetation (Scott and Crossman 1973; Casselman and Lewis 1996). In the NWT spawning usually occurs in May to June, depending on latitude, and in shallow waters (<1m) that have shelter from wind and current (Richardson et al. 2001; Evans et al. 2002). In shallow rivers, pike populations are relatively sedentary but will make migrations to reach spawning grounds (Billard 1996; Evans et al. 2002). Riverine pike seek out low-gradient pools, marshy areas connected to rivers, gradual sloping banks and floodplains as spawning habitat (Bry 1996).

If water levels will allow, pike tend to remain in the protection of dense flooded vegetation for part of their larval period and sometimes into advanced juvenile stages (from 20mm onwards), before they begin to migrate to areas with sparser vegetation and new foraging areas (Franklin and Smith 1963; Inskip 1982, Bry 1996). This type of habitat should be adjoining their natal grounds (Casselman and Lewis 1996).

Few projects designed to create or enhance fish habitat have been properly documented (Smokoroski et al. 1998). The of recent work by Jones et al. (2003) on Arctic grayling (*Thymallus arcticus*) habitat in a diversion channel at a diamond mine being the only habitat project in the NWT described in primary literature. It is essential that habitat enhancement projects are monitored, and results are published so that fisheries managers can draw from collective experiences, learn from mistakes, and direct their efforts into effective habitat enhancement or restoration endeavors (Minns et al. 1996; Minns 1997; Smokoroski et al. 1998; Jones et al. 2003).

The intent of this paper is to document the implementation and monitoring of a northern based fish habitat enhancement initiative that has successfully met its goal of "no-net-loss" of fish habitat.

MATERIAL AND METHODS

Location and Site Description

The Stagg River fish habitat enhancement area is located adjacent to the Stagg River Bridge on Highway 3 between the Stagg River and Frank's Channel in the NWT (Figure 1). The Stagg River flows through boreal forest and Pre-Cambrian shield into Great Slave Lake. The forest surrounding the Stagg River is composed of black spruce (*Picea mariana*), jack pine (*Pinus banksiana*) and white birch (*Betula papyrifera*), with river alder (*Alnus rigosa*) and willow (*Salix* sp.) proliferating along the river banks.

Macrophytic growth along the shoreline of the Stagg River and adjacent ponds include willow, common cattail (*Typha latifolia*), arrowhead (*Sagittaria cuneata*), pond weed (*Potamogeton* spp.), vernal water starwart (*Callitriche verna*), hornwort (*Ceratophyllum demersum*), spiked water milfoil (*Myriophyllum spicatum*), common duckweed (*Lemna minor*), submerged common scouring-rush (*Equisetum hyemale*), common horsetail (*Equisetum arvense*), flat leaved bladderwart (*Utricularia intermedia*), and sedges (*Carex* sp.) (Dillon 2000).

The area selected for the excavation of the Upper Pond was a vacant piece of disturbed land (approximately 100m X 100m) adjacent to the highway that was being used intermittently as a car turn around (Figure 2). This area was sparsely vegetated on a primarily clay substrate, and had an access route leading from it to a traditional camp area.

The vehicle access and use of this area, particularly during wet conditions, was a point source for sediment being released into the Middle and Lower ponds and the Stagg River (Figure 2).

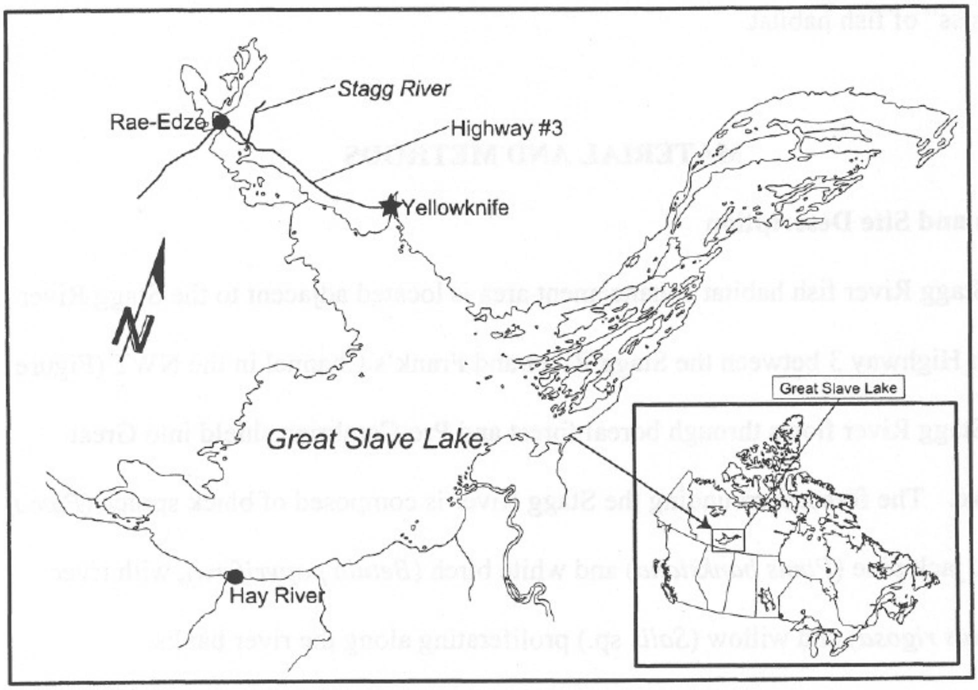

Figure 1. Location of the Stagg River fish habitat enhancement area, NWT.

Enhancement

$2600m^2$ of fish habitat was lost due to infilling of the Stagg River. Although the river's edge in the HADD area prior to the infilling, was well vegetated with emergent and submergent vegetation. The relatively steep slope of the river bank (approximately 2:1) made the area poorly suited as pike spawning and nursery habitat. The remainder of the adjacent river bottom area that was infilled had limited potential for spawning but would have provided foraging habitat (a habitat type not limiting in the area). The habitat enhancement concept used for this project was designed by DFO (adapted from Vincent, 1995) and implemented by Pelly Construction and DOT. Pike are highly adaptable creatures and can spawn in a wide range of conditions (Raat 1988). Therefore the template for a pike compensation area should be plastic making it easily tailored to take advantage of on-site variations. However, in order to optimize spawning and nursery success there are a variety parameters that must be incorporated into the development of an enhancement area. Pike spawning and nursery habitat should have: little or no flow and be shelter from wind; water depths of less than 1.0m with gently sloping banks and pond bottom, with access to gradually deepening water to 1.0-2.0m; stable water levels; abundant vegetation (submergent or emergent) comprising 25-75% of total coverage; silt, clay or detritus substrate; spawning habitat that is contiguous to nursery habitat; access to adult habitat; and a pH range between 6.5 and 9.0 (Inskip 1982; Casselman and Lewis 1996; Richardson et al. 2001; Evans et al. 2002). Temperature is also an important variable, with ideal temperatures for YOY pike growth ranging between 19°-21° C (Casselman 1978). It is important that consideration be given to the orientation of an enhancement area to maximize solar energy during mid-summer. If temperatures become too high, riparian vegetation may be required to provide shade.

Approximately 1960 m^2 of specialized northern pike spawning and nursery habitat, as well as valuable habitat for other aquatic organisms, was constructed or made accessible through the following means (Figure 2):

- providing access to the Lower and Middle ponds; 900m^2 of established, well vegetated habitat previously unavailable to fish
- constructing a spawning and nursery pond (Upper Pond); 960m^2 of habitat connecting to the Middle Pond

- constructing and enhancing access between all three ponds and the Stagg River; $100m^2$ of migratory corridor habitat

The Upper Pond was constructed by excavating a shallow basin from clay soil. The Upper Pond was then connected to the already existing, well vegetated and shallow (0.1–1.5m) Middle and Lower ponds, which were then connected to the Stagg River via excavated channels approximately 2.0m wide and 2.0m deep. The irregular shape of the Upper Pond was designed to have maximum edge habitat to surface area, with finger channels dug into the point at the eastern side of the pond. The shoreline of the pond was graded, gently sloping into the pond. The deepest point in the pond was approximately 1.5m in the centre of the basin. The shallow grade of the shoreline was intended to facilitate seasonal flooding of shoreline vegetation. Finger channels were intended to provide the security of shallow-water habitat while allowing larval pike to migrate into gradually deeper water as water levels recede. Initially, finger channels were to be excavated around the entire perimeter of the Upper Pond, however topographical characteristics of the site made that impractical as it would have required extensive grading and earth removal. The three ponds were surveyed to determine the required elevation of the Upper Pond to ensure stable water levels. The borrow-pit pond adjacent to the Upper Pond was left undisturbed. With a water level approximately 1.0m above that of the enhancement area much of the borrow-pit pond would drain destroying valuable habitat for wildlife such as waterfowl and muskrat (*Ondatra zibethicus*), and providing little gain of fish habitat. Rip-rap was placed at the seepage area between the borrow-pit pond and the Upper Pond to provide stability while allowing water to percolate into the enhancement area. The seepage from the borrow-pit pond allowed for water to pass through the rip-rap into the Upper Pond providing some circulation and freshwater recharge minimizing the risk of stagnation (Figure 2).

The access route, from Highway 3 to a traditional campsite area and bisected the habitat enhancement site, was properly re-constructed as a raised roadway to facilitate traffic while reducing erosion and runoff. An 800mm diameter corrugated steel culvert was installed under the access route to provide fish passage between the Middle and Upper ponds, and to further reduce the sediment inputs (Figure 2).

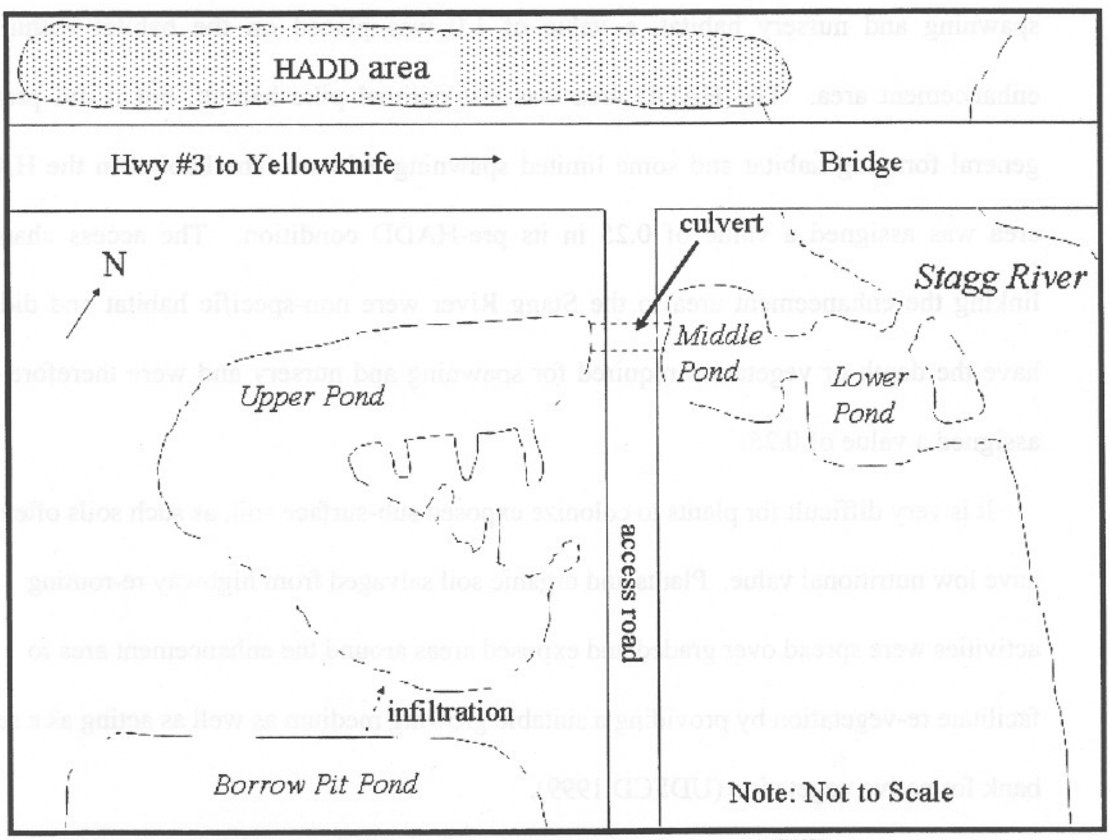

Figure 2. Stagg River fish habitat enhancement area site map, NWT.

Project Assessment

For assessment of this habitat enhancement area, both quantification by area of habitat (m^2) and a rating of the habitat types by a relative productivity scale were used.

The area of habitat was multiplied by the relative productivity scale value selected for each habitat type and the product was expressed as a habitat unit (HU). Being a subjective rating, the assignment of a value to habitat required review of literature as well as professional judgment to determine what different habitats should rate (Minns 1997). This rating was based upon depth, substrate, cover, flow and water chemistry (Inskip 1982; Evans 2002).

Since the habitat enhancement area was designed specifically as optimal pike spawning and nursery habitat, a value of 1.0 was placed on the habitat within the enhancement area. The HADD area was not optimal pike habitat, but it did provide general foraging habitat and some limited spawning habitat. The habitat in the HADD area was assigned a value of 0.25 in its pre-HADD condition. The access channels linking the enhancement area to the Stagg River were non-specific habitat and did not have the depth or vegetation required for spawning and nursery and were therefore also assigned a value of 0.25.

It is very difficult for plants to colonize exposed sub-surface soil, as such soils often have low nutritional value. Plants and organic soil salvaged from highway re-routing activities were spread over graded and exposed areas around the enhancement area to facilitate re-vegetation by providing a suitable growing medium as well as acting as a seed bank for native vegetation (UDFCD 1999).

DFO required that an interpretive sign be erected to indicate the purpose of the enhancement area and promote public awareness of fish habitat (Figure 3).

Figure 3. Interpretive sign, Stagg River fish habitat enhancement area, NWT.

Monitoring

Post construction monitoring of the Stagg River fish habitat enhancement area was required for three years. The monitoring was designed to evaluate the following:

a) habitat utilization, function and performance
b) site stability
c) water quality

Monitoring was conducted during ice-free conditions to coincide with spawning periods (spring), and post-spawning periods (summer and fall) when YOY pike would likely be present (Table 1, Appendix 1). Habitat utilization, function and performance in the enhancement area were assessed through fish surveys using a backpack electrofishing (Smith-Root Model 12D) and visual observation. Visual observations were also conducted in the Stagg River adjacent to the enhancement area. In the northern parts of their range pike reach sexual maturity at 5-6 years of age. Pike length ranges of <110mm for YOY, 110-334mm for year 2-4, and >300mm for year 5+ have been reported in the NWT (Scott and Crossman 1973). For monitoring purposes of pike were described as YOY if <110mm fork length, juveniles if between 110-300mm fork length, and adults if >300mm fork length.

Visual observations of the entire enhancement area and adjacent road shoulders and side-slopes were used to assess site stability, particularly re-vegetation success, erosion and slumping. During each monitoring period photographs were taken from fixed vantage points to assess and document changes over time. Basic water chemistry parameters (pH, conductivity, temperature, and dissolved oxygen) were measured using portable YSI meters. Conductivity was monitored to assist electrofishing calibration. Due to public concern of arsenic and mercury contamination from exposed soils, these parameters were also monitored at the enhancement site upstream and down stream of the Stagg River Bridge. Water samples were analyzed for mercury and arsenic at the Taiga Laboratory in Yellowknife (Dillon 2000; Appendix 2). Water levels were also documented using staff gauges set at different locations (Appendix 3).

RESULTS

Habitat Usage and Stability

2000

Only one adult pike was observed in the habitat enhancement area during spawning surveys in May and early June. However, adult pike were observed in the Stagg River adjacent to the newly constructed access channels. Five YOY pike were collected in the Lower Pond during post-spawning surveys in July indicating that spawning did occur in the habitat enhancement area. Two juvenile pike were observed in the Middle Pond during post-spawning surveys in July. No pike were observed or collected during sampling in late September (Table 1, Appendix 1).

2001

Juvenile and adult pike were observed in the Upper, Middle and Lower ponds during spawning surveys in late May. YOY pike were captured in all three ponds during post spawning surveys in late June, July and mid-August, including six collected (and then released) and over twenty observed in the Upper Pond alone. A school of spottail shiner (*Notropis hudsonius)* was observed in the Middle Pond during the August survey marking the first time a fish species other than pike had been observed within the enhancement area (Table 1, Appendix 1).

2002

During a spawning survey in mid-May adult pike were observed in all three of the ponds within the enhancement area (Table 1, Appendix 1). In 2002, approximately three quarters of the rip-rap fill HADD area had subsided into the riverine substrate below the waterline, returning much of that area to fish habitat. The submerged HADD area and the adjacent side-slope had begun to be colonized by both emergent and submergent aquatic vegetation. An adult pike was observed in this area during the mid-June survey (Table 1, Appendix 1).

Table 1: Pike observed and captured in the Stagg River fish habitat enhancement area, NWT.

Survey Season	Date	Location	Survey Method	Life Stage	Number
Spring	00/05/29	MP	EF	Juvenile	1
	01/05/24	UP	OBS	Juvenile	2
	01/05/24	MP	OBS	Juvenile	2
	01/05/24	LP	OBS	Adult	1
	02/06/14	UP	OBS	Adult	1
	02/06/14	MP	OBS	Adult	4
	02/06/14	LP	OBS	Adult	3
Summer	00/07/07	MP	OBS	Juvenile	2
	00/07/07	LP	EF	YOY	5
	01/06/20	UP	OBS	YOY	>20
	01/06/20	UP	EF	YOY	6
	01/06/20	MP	OBS	Adult	2
	01/06/20	MP	EF	YOY	5
	01/06/20	LP	EF	YOY	2
	01/07/20	MP	EF	YOY	1
	01/08/14	UP	EF	YOY	2
	01/08/14	MP	EF	YOY	1

UP – Upper Pond; MP – Middle Pond; LP – Lower Pond
OBS – observed; EF – electrofished

Water Chemistry and Water Levels

The mean dissolved oxygen levels and ranges measured in 2000 and 2002 were 8.1mg/l (4.9-12.1mg/l) for the Upper Pond, 8.0mg/l (5.6-11.3mg/l) for the Middle Pond, 8.0mg/l (5.3-11.1mg/l) for the Lower Pond, and 9.1mg/l (6.9-11.4mg/l) for the Stagg River (Appendix 2). The mean pH levels and ranges measured in 2000 and 2002 were 8.0 (7.1-8.9) for the Upper Pond, 7.9 (7.3-8.6) for the Middle Pond, 7.8 (6.3-9.1) for the Lower Pond, and 7.5 (7.1-8.1) for the Stagg River (Appendix 2). No water chemistry parameters exceeded the Canadian Environmental Quality Guidelines (Canadian Council of Ministers of the Environment, 1999) (CCME) for the protection of freshwater or aquatic life, with the exception of low dissolved oxygen levels in June and July of 2001 in the Lower Pond (4.9 and 5.3 mg/l respectively) and an elevated pH of 9.1 during July 2000, also in the Lower Pond. Mean arsenic and mercury levels sampled in the Upper Pond (2000) and the Stagg River (2000-2001) were below detection limits and therefore never exceeded CCME guidelines for the protection of freshwater or aquatic life (Dillon 2000, Dillon 2001).

There are no CCME Guideline parameters for temperature or conductivity. Temperatures ranged between 1.4 and 13.1°C during spring spawning surveys (2000-2002), 16.3 and 22.1°C for summer post-spawning surveys (2000-2001), and 3.3 and 5.0°C for fall post-spawning surveys (2000-2001) (Appendix 2). Temperatures were consistent between ponds.

The 800mm culvert had sufficient depth to allow for fish passage during all sampling periods, being completely submerged during high water periods and approximately two thirds submerged during low water periods. Water levels fluctuated after major rain events but remained relatively stable throughout the monitoring period (Dillon 2001), and provided ample depth for incubating eggs and larval pike (Appendix 3). Flow through the enhancement area was not measured but it was very low by design. No further sediment runoff was observed once the access route to the traditional camp area was constructed.

Project Assessment

The habitat gains were the previously inaccessible habitat of the Lower and Middle ponds ($900m^2$ X 1.0), construction of the Upper Pond ($960m^2$ X 1.0), and the construction of the access channels ($100m^2$ X 0.25). The habitat losses were the preexisting habitat of the HADD area at ($2600m^2$ X 0.25). The sum of the habitat gains (1885 HU) versus the sum of habitat losses (650 HU) results in a net-gain of 1235 HU, or 2.9:1. Although by no means part of the habitat enhancement area plan, with at least 75% of the HADD area submerged, the actual losses more accurately calculate to be 162.5 HU ($650m^2$ X 0.25), resulting in a net gain of 1722.5 HU or a habitat gain of 11.6:1 (Table 2).

The submerged HADD area was assigned a value of 0.25 because it was not optimal habitat, particularly with the rip-rap substrate, but since adult pike were observed there, it was clear that the area was being used by pike.

Table 2. Summary of habitat gains versus losses, Stagg River fish habitat enhancement area, NWT.

Habitat Type	**Description**	**Area (m^2)**	**RPSV[1]**	**Habitat Units**
Initial analysis				
Gain	Upper Pond	900	1.0	900
Gain	Middle & Lower ponds	960	1.0	960
Gain	access channels	100	0.25	25
Loss	Stagg R. infill	2600	0.25	650
Gain vs. Loss				**1885/650**
				2.9:1
Analysis after infill subsidence				
Gain	Upper Pond	900	1.0	900
Gain	Middle & Lower ponds	960	1.0	960
Gain	access channels	100	0.25	25
Loss	Stagg R. infill	650	0.25	162.5
Gain vs. Loss				**1885/162.5**
				11.6:1

[1]Relative productivity scale value

DISCUSSION

Habitat Usage and Stability

It is important to identify a measure for success in developing an enhancement project. For example, increases of habitats critical to a particular life stage of a particular species may not produce measurable changes in the abundance of that species (Minns et al. 1996). Likewise, success may be measured incorrectly if an increase in productive capacity is assumed by the presence of fish in a newly created habitat, where in reality the presence of fish may represent a redistribution of the local population and not an increase in productive capacity at all (e.g. fish staging on a reef structure immediately after it was constructed are more likely to have moved there from another location – the reef structure would not have produced those fish). It is also important to try to predict a qualifiable outcome (Minns et al. 1996). For this project the primary objective was to compensate for lost habitat through the creation of new habitat and the enhancement of existing, unavailable habitat that would serve as spawning and nursery habitat for northern pike. The primary indicator of success was deemed to be the production of fish in the enhancement area (i.e. successful spawning and utilization of nursery habitat by pike). This measure of success is readily measurable by virtue of the natal site fidelity of YOY pike. YOY pike were sampled within all of the ponds in the enhancement area shortly after hatching; therefore it is fair to presume that spawning occurred within the habitat enhancement area. This is critical, as it provides proof that fish are using the enhanced and newly constructed habitat as nursery habitat and were likely spawned there.

The importance of vegetation to pike spawning and larval development has been well documented (Witcomb 1965; Scott and Crossman 1973; Benson 1980, Inskip 1982; Bry 1996; Casselman and Lewis 1996). Research conducted in the upper Mississippi River (Holland and Huston 1984) found that catches of YOY pike were ten times greater in vegetated areas compared to non-vegetated areas. Pike eggs adhere to vegetation in floodplain areas of rivers or lakes, keeping them protected from lake-bottom sediments (Bry 1996; Casselman and Lewis 1996; Farrell et al. 1996).

In addition to encouraging the presence of invertebrate food sources, dense vegetation provides cover for pike fry. Dense vegetation also provides for spatial separation of the fry, reducing the chance of cannibalism from their siblings and larger pike (Franklin and Smith 1963; Bryan 1967; Inskip 1982; Raat 1988). Invertebrates appeared to be abundant in all of the ponds.

Vegetation that is extremely dense can be undesirable as it can hinder the ambush hunting tactics of adult pike (Headrick and Carline1993; Casselman and Lewis 1996), or prevent access to spawning habitat, as was likely the case with the Lower Pond where vegetation growth eventually cut off connection to the Stagg River.

It was anticipated that pike utilization of the enhancement area would increase with the reestablishment of vegetation. The number of pike observed in the ponds increased as vegetation established in the enhancement area. Similar observations have been made by the author where YOY pike numbers increased in a spawning area that was previously denuded of seasonally flooded vegetation as a result of a forest fire (Cott et al. in prep.). Any increase in the relative abundance of fish is typically indicative of a response to positive change in life conditions or a stress being reduced (Regier and Loftus 1972).

Surprisingly, adult pike were observed by the author and the construction foreman in the pond as early as August of 1999, immediately after the Upper Pond was dug and a connection was made between the pond complex and the Stagg River. Frost and Kipling (1967), Bryan (1967), Bry (1996) and Cott et al. (in prep.) reported that pike spawn over a variety of habitat types if ideal spawning habitat is not available.

The enhancement site was observed to be fairly stable with both aquatic and terrestrial vegetation establishing well. There was some initial slumping of the finger channels prior to any vegetative growth, however the extent was limited and did not affect the viability of the pond. It is suspected that the vegetation cover will increase in density, diversity and coverage with time. Habitat compensation measures such as this should not be though of as a short-term investment. Effort should be made to monitor and maintain the habitat in the long term. For this enhancement area the culvert should be monitored periodically to ensure that it still provides unimpeded fish passage. Likewise for the channels connecting the ponds to the Stagg River, as they will likely infill with detritus and vegetation over time and may need to be re-excavated.

Within two years of the highway construction and resulting HADD, approximately 75% of the rip-rap infill of the HADD area had subsided below the waterline and was being colonized by emergent and submergent vegetation. During a spawning survey in 2002 an adult pike was observed in the HADD area. This means that the majority of the HADD area had reverted back to fish habitat. Since the post construction monitoring plan did not include assessing this HADD area for fish habitat (as it was assumed to be above water), it is not known if the HADD area is being used for spawning. However, transient use of habitat by fish does not diminish that habitat's value (Minns 1997). The bank of the now submerged HADD area now has a much gentler slope (1:6 vs. 2:1) due to the widening of the highway shoulders, and is now likely better pike spawning and nursery habitat. The rip-rap may also be beneficial for other fish species by providing habitat diversity to the area. It should be noted that the steep bank of the HADD area prehighway widening was not a natural condition but a result of the construction of the original highway in the 1960's.

Water Chemistry and Water Levels

A temperature range of 4°-25°C is tolerated for embryonic development of pike (Willsemsen 1959 *In* Raat 1988). During the time period when pike would have been depositing their eggs, temperatures in the enhancement area were consistently within this range. Likewise during mid-summer, the formative time for YOY pike growth, temperatures were between 18.5° and 22.1°C. Casselman (1978) reported that temperatures between 19°-21°C are ideal for YOY growth. It appears that the shallow design of the pike habitat enhancement ponds is ideally suited to obtain optimal temperatures for pike larval development and growth.

The lowest measurement of dissolved oxygen was 4.9 mg/l (Appendix 2). Pike can survive oxygen levels as low as 0.3 mg/l (Raat 1988), but begin avoiding areas of <3.0-4.0 mg/l (Casselman and Lewis 1996). Lower dissolved oxygen levels were anticipated during periods of higher water temperature due to warmer water having a reduced capacity to retain oxygen (Wetzel 2001). This is true for normally well oxygenated riverine habitat such as the Stagg River as well. Since the range of dissolved oxygen measurements were well within the range of pike tolerance, and the pike had direct access to the Stagg River, the dissolved oxygen levels do not represent a problem despite being below CCME guidelines on two occasions. The range of pH levels in the habitat enhancement area all fell within a pH range of 6.5–9.0, which yields the highest habitat suitability index possible (1.0) for this parameter in relation to pike (Inskip 1982). The relatively high pH values in the enhancement area are desirable, and the measurement of 9.1, which is above the CCME Guidelines, should not be an issue for pike as they are one of the more alkaline tolerant of freshwater fishes, tolerating waters of 9.5–9.8 (McCarraher 1962, 1971).

Site re-vegetation and the re-construction of the access route were implemented to stabilize the enhancement area and thereby minimize the release of sediment into fish habitat. It has been documented that the removal of riparian vegetation through logging practices can inundate spawning habitat with sediments (St-Onge and Magnan 2000). It is likely that the sediment runoff associated with the access route and the car turn around would have had similar effects to adjacent habitats prior to the access route reconstruction in the habitat enhancement area.

From visual monitoring of the site, upgrading of access to the traditional campsite area south of the highway adjacent to the Stagg River and site re-vegetation appeared to have substantially reduced the amount of sediment runoff, likely improving water quality in the enhancement area.

Since the borrow-pit pond is at a higher gradient than the enhancement area, water seeping from the constructed spillway likely helped to stabilize the water levels and may have provided some water circulation.

Project Assessment

There are no similar northern examples of pike enhancement work to draw upon, so, like much of the habitat enhancement conducted throughout North America, this initiative was experimental (Minns et al. 1996). Habitat enhancement is difficult to accomplish in northern and remote environments: the costs associated with construction activities and logistics are far greater than they are in more populated areas; and remote northern areas are sparsely populated and have remained for the most part pristine, therefore there are fewer degraded candidate sites than in urbanized or agricultural areas. Another problem with any enhancement work associated with "design build" developments, such as the Highway 3 project, is often that the specific impacts are not known until time of construction. In this case, as the highway construction crew reached the Stagg River Bridge, an engineering decision was made to increase the area of the side slopes adjacent to the bridge to try and prevent permafrost degradation and thereby enhance the safety of the highway. This left little time to assess the potential impacts and develop a compensation plan. However, the opportunity to excavate the Upper Pond in the disturbed area close to where the HADD was to occur lent itself to the type of enhancement contemplated, particularly with the ability to connect the Upper, Middle and Lower ponds to the Stagg River. The presence of heavy machinery such as back-hoes and bull dozers on site made the project logistically and financially feasible. Some latitude in the enhancement area construction (within the acceptable range of parameters discussed above) was given to the construction foreman as site conditions dictated that the enhancement design might need to be altered. If it is not possible for a biologist to be on site and supervise the construction of the enhancement area, he or she must be available to the forman to answer questions and discuss modifications as required. Good communication and a clear understanding of the goals and objectives are critical to a successful habitat enhancement project. Efforts should be made by the biologist to adequately explain to the proponent and construction staff the importance of the biological principals and parameters involved in order to foster an understanding of why the enhancement efforts are being conducted and buy-in from all parties involved. For example, in this project the foreman understood the rationale behind the finger channels but was unable to construct them around the entire pond due to the grade on site. However, through discussions it was decided that it was still possible within the confines of the site to incorporate finger channels and have ample edge habitat by constructing the pond in a horseshoe shape (Figure 2).

The concept of this habitat enhancement area was roughly adapted from Vincent (1995). In the Vincent project, finger channels were dug into the shoreline of a warm water pond in the Toronto Islands Lagoon on Lake Ontario to provide a warm backwater nursery area for pike. Following channel construction, a berm enclosing the pond from the lagoon was breached allowing seasonal flooding of the shoreline. The breach provided access for a variety of fish species resident to Lake Ontario, including the target species – pike.

Few fish habitat enhancement projects are assessed in terms of "no-net-loss" or a gain in productive capacity (Jones et al. 2003, Smokorowski et al. 1998, Minns 1997, Minns et al, 1995), and none, save research conducted by Jones et al. (2003) on the Panda Diversion Channel, has attempted to assess habitat enhancement in this manner in the NWT.

An extensive literature search conducted by Smokorowski et al. (1998), amassed all available literature (including government reports and grey literature) on fish habitat enhancement projects. Each enhancement project was assessed for completeness, both in terms of the project itself (completeness, the measure of success, successfulness) and the reporting of project details (costs, timing, associated effects, aesthetics). Of the 78 habitat enhancement projects reported, 65 projects had been completed, with only 27% of those projects noting an increase in biomass or abundance, and 5% detecting an increase in fish production. The majority of the 78 projects reported were in North America; however there were no fish habitat enhancement projects reported in the NWT, Nunavut, the Yukon or Alaska.

The destruction of fish habitat creates a net loss of production capacity of fish habitat. However, the creation of new fish habitat where fish habitat did not previously exist creates a net gain of productive capacity of fish habitat (Minns 1997). Net gain is difficult to measure quantitatively and professional judgment is often required when assessing the success of a project. Simple quantification of area of habitat lost versus area of habitat gained is more appropriate than relying exclusively on non-quantifiable assessments (Minns 1997). A subjective numerical ranking system can be used to document and quantify the relative importance of different habitat types (Casselman and Lewis 1996). For instance, assessing no-net-loss of a compensation initiative due to a HADD is comparative to a natural system and as such a relative productivity scale can be used. In a relativity scale, the most productive habitat type is assigned a value of 1.0 (Inskip 1982; Minns 1997).

By determining the optimal habitat requirements for pike spawning and nursery habitat it was possible to design an enhancement area according to those parameters and assess the relative value of the habitat lost versus the habitat gained. To account for incremental losses and the difficultly in accurately quantifying productive capacity, habitat managers often apply the precautionary principle and ask for a 2:1 or greater area ratio when negotiating compensation initiatives (Minns 1997).

After the initial habitat enhancement was completed the projected habitat gain was roughly 3:1. However, due to a change in the lost habitat over time the habitat gain was re-calculated to be over 11:1. This is an important point as fisheries managers need to be aware that habitat enhancement areas will change over time. For instance, as vegetation in the Upper Pond continues to develop, the quality of the habitat within will increase, but if the habitat is not maintained the access channels fill in, then the entire enhancement area is rendered useless for spawning and nursery habitat since access by adult pike would be prevented.

Environmental consultants were hired to monitor the Stagg River fish habitat enhancement site and report on the findings. This monitoring requirement cost approximately $12,000 for the first year and $8,000 for the second year of monitoring (P. Moore, personal communication). In May 2003, DFO agreed to a request by DOT that the third year of monitoring be dropped since the habitat enhancement had started functioning as intended, satisfying the fish habitat compensation goals specified within the *Fisheries Act* Authorization issued to DOT. A spawning survey was conducted by DFO in the third year during post-construction monitoring of the Highway 3 project. Despite the unexpected monitoring costs incurred by DOT, the overall cost of the project was low since no specialized equipment or material was required beyond what was at the site for the purpose of highway construction, and the no-net-loss concept and enhancement design was developed by DFO. Besides providing valuable spawning and nursery habitat for pike, the enhancement area had several incremental spin-off benefits:

the area is being used by other fish species, invertebrates and other wildlife; no pristine areas were disturbed through compensation initiatives; the area is now far more aesthetically pleasing since a muddy rutted turn-around area has been replaced by a naturalized vegetated pond complex; the reconstructed access to the traditional campsite area is now safer and easier to travel on during wet weather without risk of releasing sediment into the Stagg River or getting stuck; the erected sign educates motorists and travelers of the project and heightens public awareness of fish and fish habitat issues in relation to development.

CONCLUSIONS

Through an understanding of the habitat requirements of pike it was possible to design and implement an effective habitat enhancement plan. There was an initial loss of overall habitat area due to infilling, however, there was a significant improvement in habitat quality (3:1) in the area through habitat creation and enhancement which translates into the potential for increased productive capacity, keeping with the "no net loss" Guiding Principle indicated in the *Policy for the Management of Fish Habitat* (1986). The enhancement area is being used by fish as intended and has adequately compensated for lost habitat with a gain of newly created and enhanced habitat. Much of the infill that constituted the HADD became submerged and is once again available as habitat for fish, which reduces the footprint of the HADD area, equalling a net gain of over 11:1. Also, while the target species of the enhancement area was pike, the habitat created is being utilized by other fish species and aquatic organisms.

Although relatively small in scale, this project is the only example documented in the NWT where pike habitat has been enhanced/ constructed, monitored, and proven to be successful. It is a relatively inexpensive and easily constructed habitat enhancement method. It should be noted that the pike habitat enhancement techniques outlined are not specific to the NWT but could be employed anywhere in the circumpolar range of northern pike where appropriate parameters exist.

Despite its success, this habitat enhancement could have been improved on in the following areas: obtaining baseline data in the HADD area prior to development and monitoring the area after development; determining a relative value for lost productivity over time; selecting a site with a gentler overall grade to facilitate the development of finger channels and further increasing the edge habitat; and incorporating a long term maintenance plan as part of the project design and/or DFO Authorization requirements.

This project also illustrates the benefits of cooperation between regulators, government departments and developers. More documentation of habitat enhancement projects is required to move forward with no-net loss initiatives while learning from past experiences.

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PERSONAL COMMUNICATIONS

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Appendix 1. Fish survey results at Stagg River fish habitat enhancement area, NWT

Date	Location	Species	Survey Method	Comments
00/05/12	all	N/A	OBS	
00/05/19	SR	3 NRPK	OBS	2 juveniles approx 10m downstream from EA, 1 adult (> 500mm FL) found in gillnet downstream of EA
00/05/29	MP	1 NRPK	EF	260 mm FL
00/06/19	all	N/A	OBS, EF	
00/07/07	MP	2 NRPK	OBS	5 YOY
00/07/07	LP	5 NRPK	EF	2 juveniles
00/07/07	SR	2 NRPK	OBS	Adults (> 500mm FL) under SR bridge
00/09/25	all	N/A	OBS,EF	
01/05/24	UP	2 NRPK	OBS	2 juveniles (150-200mm FL)
01/05/24	MP	2 NRPK	OBS	2 juveniles (150-200mm FL)
01/05/24	LP	1 NRPK	OBS	1 adult > 500mm FL
01/06/20	UP	>26 NRPK	OBS, EF	EF 6 YOY (32-35mm FL), OBS > 20 YOY
01/06/20	MP	7 NRPK	OBS, EF	EF 5 YOY (32-35mm FL), OBS 2 adults (> 500mm FL) near culvert
01/06/20	LP	2 NRPK	EF	EF 2 YOY (34-35mm FL)
01/07/20	MP	1 NRPK	EF	EF 1 YOY (75mm FL)
01/08/14	UP	2 NRPK	EF	EF 2 YOY (51-124mm FL)
01/08/14	MP	1 NRPK SPSH	OBS,EF	EF 1 YOY (85mm FL), OBS small schools of SPSH (approx 30mm FL)
02/06/14	UP	1 NRPK	OBS	Adult (> 500mm FL)
02/06/14	MP	4 NRPK	OBS	Adults (> 500mm FL)
02/06/14	LP	3 NRPK	OBS	Adults (> 500mm FL)
02/06/14	SR	1 NRPK	OBS	Adult (> 500mm FL) in HADD area were rock infill had settled below waterline

UP – Upper Pond; MP – Middle Pond, LP – Lower Pond, SR – Stagg River
NRPK – northern pike; SPSH – spottail shiner
OBS – observed; EF – electrofished; EA – enhancement area, FL – fork length
N/A – not applicable
Adapted from Dillon Consulting Ltd (2000) and Dillon Consulting Ltd (2001)

Appendix 2. Water chemistry results at the Stagg River fish habitat enhancement area, NWT.

Date	Water Temp (C°)	Dissolved Oxygen (mg/l)	pH	Conductivity (µS)
		Upper Pond		
00/05/05	2 0	--	--	--
00/05/12	7 6	10 6	7 8	60 3
00/05/19	10 7	9 6	7 4	74 1
00/05/29	13 0	9 5	7 8	130 2
00/06/19	19 1	6 9	8 1	233 3
00/07/07	22 1	6 9	7 1	221 1
00/09/25	4 2	12 1	--	--
01/05/24	11 6	7 7	--	--
01/06/20	18 6	**4.9**	8 7	236 0
01/07/20	19.3	6 2	8 9	259.7
01/08/14	16.3	6 9	8 0	243.7
02/06/19	18.0	--	--	--
		Middle Pond		
00/05/05	1 7	--	--	--
00/05/12	7 6	10 7	7 5	60 2
00/05/19	10 6	9 4	7 5	73 5
00/05/29	13 1	9 3	7 5	130 1
00/06/19	18 5	7 7	7 3	125 9
00/07/07	21 4	6.7	7 7	221.5
00/09/25	3 3	11 3	--	--
01/05/24	10 3	7 0	--	--
01/06/20	18.0	5 7	8 4	132.0
01/07/20	19.3	5 6	8.6	98 5
01/08/14	18.8	6 2	8 3	126 0
02/06/19	18.0	--	--	--
		Lower Pond		
00/05/05	1 6	--	--	--
00/05/12	7 5	10 7	7 8	59 1
00/05/19	10 6	9 6	7 5	73 5
00/05/29	13 1	9 2	7 5	107 6
00/06/19	19 2	7 3	6 3	118 0
00/07/07	20 9	6 6	7 7	132 5
00/09/25	3 6	11 1	--	--
01/05/24	8 3	7.6	--	--
01/06/20	17.2	5 6	8.0	80 3
01/07/20	19 3	**5.3**	**9.1**	80 6
01/08/14	18 2	6 8	8 1	80 8
02/06/19	18.0	--	--	--
		Stagg River		
00/05/05	1 4	--	--	--
00/05/12	7 0	10 7	7 1	85.0
00/05/19	10 1	9 2	7 4	93 7
00/05/29	13 0	9 0	7 5	95 0
00/06/19	19 1	7 6	7 6	87 3
00/07/07	21 8	6 9	8 1	96 3
00/09/25	5.0	11.4	--	--
CCME criteria	--	>5.5	6.5-9.0	--

Bold: indicated values not within CCME Water Quality Guidelines for Freshwater and Aquatic Life (1999)
Adapted from Dillon Consulting Ltd (2000) and Dillon Consulting Ltd (2001)

Appendix 3. Water staff gauge elevations (cm) - Stagg River fish habitat enhancement area, NWT.

Date	Upper Pond	Middle Pond	Lower Pond	Stagg River	Borrow-Pit
00/05/12	83.0	57.5	83.5	--	--
00/05/19	86.0	60.5	86.0	76.0	84.0
00/05/29	85.5	60.5	86.0	75.0	82.5
00/06/19	84.5	59.5	84.5	73.5	76.0
00/07/07	83.5	58.0	82.5	72.0	72.0
00/09/25	88.5	61.0	78.5	--	--
01/05/24	104.5	113.5	136.0	--	95.5
01/06/20	127.0	131.5	150.0	--	103.0
01/07/20	98.0	202.0	227.5	--	84.0
01/08/14	86.5	99.0	114.5	--	80.0
02/06/14	95.0	109.0	132.0	--	--

Adapted from Dillon Consulting Ltd. (2000) and Dillon Consulting Ltd. (2001).