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Narrative description and quantification of the habitat requirements of Lake Sturgeon, *Acipenser fulvescens* in the Great Lakes and upper St. Lawrence River

Description narrative et quantification des besoins de l'esturgeon jaune (*Acipenser fulvescens*) en matière d'habitat dans les Grands Lacs et le cours supérieur du fleuve Saint-Laurent

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ABSTRACT

Lake sturgeon, *Acipenser fulvescens,* that inhabit the Great Lakes and upper St. Lawrence River (DU8) are a large-bodied (100 to 140 cm TL), slow-growing, migratory species that require extensive habitat. Most populations spawn in high-gradient reaches of large rivers, often below obstructions, with current velocities of 0.5 to 1.3 m s^{-1}, water depths of 0.1 to 2 m, and coarse but variable substrate. A study in the St. Lawrence River indicated from 13 to 48 m^2 of spawning habitat was needed for optimal egg survival. Emergent fry move downstream with the river current. Young sturgeon grow rapidly in river habitat from a size at emergence of about 17-18 mm to 123 mm by September, feeding on a diverse fauna from the benthos and drift. Habitat preferences of young sturgeon are largely unknown. Survey catches in the St. Lawrence were highest in water depths of 3-6 m and currents ranging between 0.25–0.5 m s^{-1}. There is evidence that juveniles aggregate at localized areas in rivers, shallow river mouths or adjacent bays during late summer and fall, but are later found in the same habitats as adults after their first year. The habitat of adult lake sturgeon is the highly productive shoal areas of lakes and large rivers; most fishing captures were from about 5 to 9 m, but they are taken occasionally as deep as 43 m. Other studies indicate adults utilize deeper water depths during summer, but prefer shallower water (< 9 m) in winter. Adult sturgeon feed on benthic fauna, often on silt or mud substrate. Mature sturgeon migrate considerable distances (138 to 225 km in the St. Lawrence River) to find suitable spawning habitat. Based on allometric relationships, individual area per adult sturgeon (100 cm TL) was estimated to be 0.05 and 0.15 ha, in rivers and lakes, respectively. Home ranges were estimated to be 20X larger. Despite these large area requirements, adult habitat is unlikely to be limiting to lake sturgeon in the Great Lakes. However, spawning habitat may be limiting for certain populations, because of dams, habitat fragmentation, habitat degradation, or lack of access to spawning habitat. Future research should focus on the quality and quantity of spawning and juvenile habitat of individual populations of lake sturgeon, and confirm that adult habitat is not limiting in the Great Lakes and upper St. Lawrence River.

RÉSUMÉ

L'esturgeon jaune (*Acipenser fulvescens*) des Grands Lacs et du cours supérieur du fleuve Saint-Laurent (UD8) est une espèce de grande taille (LT de 100 à 140 cm), à croissance lente et migratrice qui a besoin d'un vaste habitat. La plupart des populations fraient dans des tronçons à forte déclivité de grands cours d'eau, souvent sous des obstacles, où la vitesse du courant varie de 0,5 à 1,3 m s^{-1}, où la profondeur oscille entre 0,1 et 2 m et où le fond se compose de substrat grossier mais diversifié. Une étude menée dans le fleuve Saint-Laurent indique qu'un habitat de frai de 13 à 48 m^2 est nécessaire à une survie optimale des œufs. L'alevin se déplace vers l'aval avec le courant. Le jeune esturgeon se développe rapidement dans l'habitat fluvial et passe d'environ 17 ou 18 mm au moment de l'émergence à 123 mm en septembre; il se nourrit de diverses espèces fauniques provenant du benthos et qui se laissent dériver. On connaît très peu son habitat de prédilection. Les prises effectuées dans le cadre de relevés menés dans le Saint-Laurent étaient les plus élevées à une profondeur d'eau allant de 3 à 6 m et dans des courants d'une vitesse allant de 0,25 à 0,5 m s^{-1}. Il a été démontré que les jeunes esturgeons se regroupent dans des zones localisées de cours d'eau, d'embouchures peu profondes de cours d'eau ou de baies adjacentes vers la fin de l'été et à l'automne; on les trouve plus tard dans les mêmes habitats que les adultes, après leur première année de vie. L'esturgeon jaune adulte a pour habitat les zones de haut fond très productives de lacs et de grands cours d'eau; la plupart des prises se font environ entre 5 et 9 m; certaines sont à l'occasion enregistrées à une profondeur pouvant atteindre 43 m. D'autres études indiquent que les adultes descendent dans des eaux plus profondes pendant l'été, mais qu'ils préfèrent les eaux moins profondes (< 9 m) en hiver. L'esturgeon adulte se nourrit d'espèces fauniques du benthos, souvent sur un substrat vaseux ou limoneux. Il migre sur des distances considérables (de 138 à 225 km dans le fleuve Saint-Laurent) pour trouver un habitat de frai approprié. D'après des relations allométriques, on estime que la superficie par esturgeon adulte (LT de 100 cm) est de 0,05 et de 0,15 ha dans les cours d'eau et les lacs respectivement. On estime en outre que le domaine vital des individus est vingt fois plus étendu. Malgré ces besoins importants en matière de superficie, l'habitat des adultes est peu susceptible de constituer un facteur limitatif pour l'esturgeon jaune dans les Grands Lacs. Cependant, l'habitat de frai peut représenter un facteur limitatif pour certaines populations en raison des barrages, de la fragmentation ou de la dégradation des habitats ou, encore, du manque d'accès à l'habitat de frai. Les recherches devraient être concentrées sur la qualité des habitats de frai et leur étendue ainsi que sur l'habitat des juvéniles de différentes populations d'esturgeon jaune et confirmer que l'habitat des adultes ne constitue pas un facteur limitatif dans les Grands Lacs et le cours supérieur du fleuve Saint-Laurent.

INTRODUCTION

Effective conservation measures and restoration of habitat for lake sturgeon (*Acipenser fulvescens)* in the Great Lakes and upper St. Lawrence River are paramount for the survival and recovery of the unique populations in this Atlantic drainage area. There were 63 extant populations of lake sturgeon in Designatable Unit 8 (DU8), but 21 of these are likely extirpated, and most of the remaining populations have exhibited a significant decline in population abundance (COSEWIC 2006). Because of these declines, the status of DU8 sturgeon is designated as Threatened. Direct and indirect effects of dams (habitat fragmentation and degradation) were identified as key threats, second only to fishing exploitation (COSEWIC 2006). Habitat perturbation is a unique challenge in the Great Lakes, as this ecosystem is an international waterway used for shipping, and water levels are managed jointly by Canada and the United States. Knowledge of the habitat requirements of sturgeon is a primary component of the Recovery Potential Assessment (RPA) for lake sturgeon in DU8.

The objective of this report is to provide a narrative description of the habitat requirements of lake sturgeon for all life history stages. In addition, quantitative but provisional estimates of the habitat area needed for two life history stages, spawning and adult feeding, are estimated. Habitat area requirements are estimated both for individual adult fish of different body sizes and for a recovery population target. Finally, recommended research and analysis activities needed for the RPA to address gaps in knowledge of lake sturgeon habitat are identified.

Both the narrative description and the quantification of habitat needs are generic and relevant to all Great Lakes/St. Lawrence sturgeon populations. Determination of the extent and availability of habitat for the individual populations in DU8 (i.e., spatially-explicit habitat requirements needed for the recovery of populations) will be a future priority task after population-specific recovery goals are established.

METHODS

Habitat Requirements

A narrative description of the habitat requirements of Lake Sturgeon for all life history stages was obtained from the literature. To start, references and habitat descriptions were obtained from the Status Report (COSEWIC 2006). Although the Status Report provided information on the eight designatable units (DU) of lake sturgeon in Canada, this report focuses, to the extent possible, on knowledge of habitat use for lake sturgeon in DU8, the Great Lakes/St. Lawrence populations. Geographically, the distribution of sturgeon in this Designable Unit is large, extending from about 42^{o}N (Lake St. Clair) to 50^{o}N (Lake Nipigon) latitude and 90^{o} (Nipigon Bay) to 73^{o} W (Lac St. Pierre) longtitude. Information on habitat requirements was linked to life history function and the ecological needs of reproduction, feeding ecology and growth, and behaviour.

Quantification of Habitat Requirements

Population Targets: To estimate habitat requirements for sturgeon populations, a recovery target of 1188 spawning females per year was used (Vélez-Espino and Koops 2008). With a 1:1 sex ratio and a five year spawning periodicity (Winemiller and Rose 1992; cited in Vélez-Espino and Koops 2008), a total population target of 11,880 mature adult lake sturgeon would be required.

Spawning: The area needed for reproduction was estimated as the product of area per individual female spawner and the number of target female spawners. Fortin *et al*. (2002; cited in COSEWIC 2006) indicated 13 to 48 m^2 of spawning habitat per average female was needed to maximize the egg to fry survival rate. This estimate of spawning area was from observations at Rivière des Prairies, Québec, located at 45^o N latitude, about mid range of latitude for DU8 sturgeon. Although based on observations from one location, this range in spawning area per female sturgeon was assumed to apply generally to lake sturgeon populations in DU8.

Adults: The quantity of lake or river habitat needed for adult sturgeon for growth and survival was determined by multiplying the population recovery target by the habitat area needed per individual sturgeon. Individual area was determined using published allometric relationships between body size (weight) and fish density (Randall *et al*. 1995) and home range (Minns 1995). These empirically-based regressions provided individual and home range areas for lake and river habitat separately, and were consistent in showing that habitat capacity was higher in rivers than in lakes (Randall *et al.* 1995; Minns 1995). For lake sturgeon, average size at age 20 (an indicator of growth rate) and size at maturity varied with latitude and location (Fig. 1). Total length (TL, cm) at maturity was estimated from an equation from Fortin *et al*. (1996), where $TL_{23\text{-}27}$ = 2569.6 – 49.1LATITUDE + 11.4LONGITUDE. For the latitude range of sturgeon populations in DU8 (42^oN to 50^oN; Lake St. Clair to Nipigon), the size of sturgeon at maturity varied from approximately 117 to 144 cm (Fig. 1). Size at maturity of sturgeon observed at Lake Nipigon was smaller than predicted (80-100 cm; COSEWIC 2006), but these populations were being exploited at the time of sampling. Nevertheless, for quantifying habitat requirements based on allometry with fish size, a range of sizes from 100 to 144 cm was used (Table 1). For this range in TL, the average weight of adult sturgeon calculated from a length-weight regression provided by Fortin *et al.* (1991; cited in Froese and Pauly 2008) ranged from 5.4 and 17.8 kg (Table 1).

RESULTS

Narrative Description of Habitat

Acipenser fulvescens is a large, slow-growing, migratory species that requires spatially extensive habitat. The quantity and quality of habitat needed to support the life functions of reproduction, feeding and growth, refugia and movement varies during its extended life history. Functional habitat is defined as the physical, chemical and biological attributes of the living space of sturgeon that determine the population vital rates (survival, growth, reproduction), that together determine population production. To be comprehensive, a narrative description of the functional habitat of lake sturgeon must be done for each life stage separately, but with the realization that an open connection between habitats for migration is paramount for the survival of this species.

Habitat for spawning, *eggs and larvae:* In terms of reproductive guild, lake sturgeon are non-guarders and open water substratum egg scatterers (Sokolov, L.I. and L.S. Berdicheskii 1989; cited in Froese and Pauly 2008). Sturgeon spawn in spring as temperatures reach 10-18 ^{o}C (Auer 1996a; Scott and Crossman 1998), and successful spawning depends on suitable flow and temperature regimes (Peterson *et. al.* 2007). Most populations spawn in high-gradient reaches of large rivers, often below waterfalls, with current velocities of 0.5 to 1.3 m sec^{-1}, water depths of 0.1 to 2 m, and substrates of coarse gravel, cobble, boulders, hardpan or sand (Auer 1996a; Lane *et al.* 1996a; McKinley *et al*. 1998; Peterson *et al.* 2007). Observations in the Rivière des Prairies near Montreal indicated individual females utilized from 13 to 48 m^2 of spawning habitat (Fortin *et al.* 2002). Adults move quickly downstream after spawning (Peterson *et al.* 2006).

Hatching of eggs takes 8-14 days, depending on temperature (Kempinger 1988; Peterson *et al.* 2007). Newly hatched larvae are negatively phototactic, and remain burrowed in the substrate (interstitial spaces) until the yolk sac is absorbed (Kempinger 1988). Within 13-19 days after hatching, the larvae emerge from the substrate at night and disperse downstream with the current (several kilometres) and then return to a benthic habitat (Kempinger 1988; Peterson *et al*. 2007). Before this downstream dispersal, the utilization of the benthic spawning habitat for the egg incubation, hatching and larval stages lasts for a period of about one month.

A few populations are known to spawn on rocky lake shores exposed to wave action (COSEWIC 2006; Peterson *et al.* 2007). In DU8, the status of the Amherst Island shoal population in Lake Ontario is unknown (Holey *et al.* 2000; cited in COSEWIC 2006).

Habitat of juveniles: Young of the year sturgeon grow rapidly from a size at emergence of about 17-18 mm (Peterson *et al.* 2007) to 123 mm by September (Scott and Crossman 1998). To achieve this growth, habitat that provides an adequate food supply is essential for this life stage. Sturgeon are generalist, benthic feeders; the diet of juvenile sturgeon in the St. Lawrence River includes a diversity of benthic fauna, such as amphipods, chironomids, oligocheates, ephemeroptera, trichoptera, molluscs and fish eggs (Nilo *et al.* 2006). Observations in rivers suggest there is a preference for drifting prey (Nilo *et al.* 2006).

There is a gap in the knowledge of the habitat preference of young sturgeon during the age 0 growth period (Auer 1996b; Peterson *et al.* 2007), particularly in lakes. Age 0 sturgeon prefer flat and sand bottom conditions (Peake 1999), that may be linked to food acquisition (Kempinger 1996). Lane *et al.* (1996b) indicated a depth preference of 2.5 m to greater than 5 m. In the St. Lawrence River, catches of juveniles in autumn were highest in water depths of 3-6 m and currents ranging between 0.25–0.5 m sec^{-1} (Nilo *et al.* 2006). There is some evidence that juveniles gather at localized areas in rivers, shallow river mouths or adjacent bays during late summer and fall, but are later found in the same habitats as adults after their first year (references cited by Peterson *et al.* 2007). The tendency for juvenile sturgeon to aggregate locally in the St. Lawrence River cannot be linked solely to their food habits, as their diverse prey items are widely distributed (Nilo *et al.* 2006). Habitat preferences for certain depths and currents as noted previously must be related in part to life history functions other than feeding.

COSEWIC (2006) hypothesized that young of the year was the most likely life history stage to be preyed upon by other fishes. If predation mortality is confirmed to be

significant, habitat that provides refugia from predators may be important for juvenile sturgeon.

Habitat of adults: Lake sturgeon adults feed primarily on benthic invertebrates that they detect using their barbels as they swim in contact with the bottom (Harkness and Dymond 1961; COSEWIC 2006; Peterson *et al.* 2007). Sturgeon feed actively throughout the year, although consumption may decline during winter. Prey abundance is probably a factor in determining habitat selection. Lane *et al.* (1996c) reported that lake sturgeon are found in water depths > 5 metres year round, and utilize fine (silt or mud) substrate, but are also found over a variety of substrates (COSEWIC 2006; Peterson *et al.* 2007). Some studies indicate that adults prefer depths < 9 m during winter, but move into deeper water in summer (Harkness and Dymond 1961; cited in Peterson *et al*. 2007). In contrast, Scott and Crossman (1998) observed that the usual habitat of lake sturgeon is the highly productive shoal areas of lakes and large rivers. Most captures (by commercial fisheries) are from about 5 to 9 m, but they are taken occasionally as deep as 43 m.

Seasonal movements in lakes are not well known. Mark recapture studies in the St. Lawrence River fluvial lakes (Lac Saint-Louis, Lac Saint Pierre and Lac des Deux Montagnes) indicated that movements were limited (sedentary populations), except during spawning migrations (Fortin *et al.* 1993). However some movement of sturgeon among these fluvial lakes was observed.

The migration of adult lake sturgeon is functionally linked to movement between the adult feeding and the spawning habitat. Open connections between habitats is critical for lake sturgeon, as adults migrate considerable distances to find suitable spawning habitat. Studies in the St. Lawrence River indicated sturgeon move 138 to 225 km (Dumont *et al.* 1987; Fortin *et al.* 1993). Based on observations of natural populations with unrestricted access to lake and river habitats, Auer (1996b) recommended that management strategies should allow lake sturgeon access to a minimum of 250 to 300 km of unobstructed habitat (linear), to provide open access to feeding, overwintering and spawning habitat.

Peterson *et al*. (2007) described two patterns of spawning migration in the Great Lakes, one-step or two-step movements, each of which have different implications to habitat management. One-step populations migrate in spring and spawn within a few days of reaching their spawning habitat. Two-step populations begin their spawning migration in autumn, overwinter in deep pools, and spawn in the following spring. Pool habitats (depth not specified) would be critical for survival of sturgeon that overwinter in rivers before spawning. Determination of ecologically significant base flows would be needed for both migration strategies, but for different periods and durations.

Quantity of Required Habitat

Spawning: Assuming a recovery target of 1188 female spawners per year (Vélez-Espino and Koops 2008), and assuming each female requires from 13 to 48 m^2 of spawning habitat (Fortin *et al*. 2002), the estimates of required spawning habitat ranged from 15,444 m^2 (1.54 ha) to 57,024 m^2 (5.70 ha).

Adults: Large adult sturgeons in rivers require individual areas that range from 0.05 to 0.15 ha depending on body size (Table 1). Adult sturgeon inhabiting lakes require about 3 times more habitat (0.15 to 0.47 ha). Estimates of Individual home ranges were much

larger than estimates of individual area, ranging from 0.4 to 16.1 ha. Consistent with habitat-dependent density, home ranges were about 20 times greater in lakes than in rivers.

Adult population habitat needs were estimated as the product of individual area and the population recovery target. For populations inhabiting rivers (e.g., upper St. Lawrence), and assuming a recovery population target of 11,880 sturgeon, the total required area ranged from 582 ha (adult size of 100 cm) to 1806 ha (adult size of 144 cm) (Table 2). For populations inhabiting lakes, the corresponding area requirements ranged from 1794 ha to 5595 ha. Home range areas for the target populations were not estimated because home ranges would overlap among individual sturgeon.

Residence

Residence is defined in SARA as 'a dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating'. Residence is interpreted by DFO as being a *constructed* place. An example for teleosts might be salmon spawning redds which are excavated by the females prior to egg deposition and fertilization. The eggs are protected in the redds until the alevins emerge, and thus this constructed residence affects survival during reproduction.

In the context of the above narrative description of habitat requirements during spawning, rearing and adult feeding, lake sturgeon do not construct residences during their life cycle.

DISCUSSION

Adult lake sturgeon (*Acipenser fulvescens*) in DU8 are large: clinal trends and available literature indicate a likely range in size at first maturity from about 100 to 150 cm TL. Several traits of fishes relevant to habitat requirements are a function of body size, including the upper limits to abundance (density, and inversely, individual area), home range, geographic range and mobility (Peters 1983). Required spawning area is also likely a function of body size, but this has not been quantified for sturgeon. For these reasons, the area needed by lake sturgeon for successful life history processes is extensive relative to other fishes. In addition, the functional habitat of sturgeon changes dramatically with age and life cycle stage. A population recovery target of 1188 female spawners per year (Vélez-Espino and Koops 2008) require large areas, both for spawning and in particular for adult habitat, as sturgeon spawning periodicity is five years on average (Winemiller and Rose 1992) and thus large populations of adults are needed to maintain the annual female spawning target. Home ranges, estimated to be twenty times larger than individual areas, provided an upper limit of the habitat area required for precautionary management. Home ranges overlap among individuals (Peters 1983; Minns 1995) and the calculation of a population home range based on the product of home range and population target would therefore overestimate the population habitat area needs. In addition, it is important to emphasize that the estimates of individual area and home range are provisional because the large body size of adult sturgeon, the largest freshwater fish in Canada, was outside the size range used to develop the allometric relationships (Randall *et al.* 1995; Minns 1995); the estimates were therefore based on extrapolation. Nevertheless, the large habitat areas calculated in this study were consistent with observations of the extensive

migration distances of sturgeon (Fortin *et al.* 1993) and the recommended large open distances (250 to 1000 km) needed to support self-sustaining populations (Auer 1996b).

Despite the spatially extensive habitat areas needed by adults, it is unlikely that lake area *per se* is limiting to population viability of lake sturgeon in the Great Lakes. Loss of habitat, with the exception of habitat fragmentation (below), is considered to be of less importance to population declines than overfishing (COSEWIC 2006). The lake habitat available to adult sturgeon for feeding and overwintering in all five Great Lakes is extensive and connected (Table 3). Maximum yield of lake sturgeon (historically) was not correlated with lake area (Fig. 2), which is consistent with the hypothesis that lake habitat was not limiting to population abundance.

Spawning habitat rather than adult habitat is more likely a limiting factor for lake sturgeon in DU8. Lake sturgeon are vulnerable to population reduction based on two of the risk criteria discussed by Musick *et al.* (2000): 1) population productivity of sturgeon is low (r_m, intrinsic rate of increase = 0.14 yr^{-1}; Froese and Pauly 2008), and 2) although its area of occupancy is large (about 600,000 km^2; COSEWIC 2006), sturgeon require specialized habitat for spawning, specifically, access to large rivers with flowing water. Both of these risk criteria emphasize that effective spawning and adequate recruitment are critical for sturgeon. The specialized spawning habitat in large rivers may be subject to fragmentation (dams) or degradation (flow modification). Both the quantity and quality of spawning habitat have been negatively impacted by dams and by water level management in the Great Lakes. Dams have been constructed on all known spawning tributaries in the Great Lakes (Peterson *et al*. 2007). Populations of sturgeon have been restored in northern Michigan by stocking wild age 0 juveniles (reared in hatcheries to increase survival; Peterson *et al.* 2007), suggesting that recruitment was a bottleneck for these populations. Research on the availability of spawning habitat and the ecological links between habitat conditions and successful reproduction is a priority for restoration programs in the United States (Peterson *et al.* 2007).

Because sturgeons need large open areas, habitat fragmentation, flow modification and other habitat perturbations that affect spawning are key threats to the restoration in the Great Lakes and the upper St. Lawrence River. Although the current spawning habitat for lake sturgeon is fragmented and possibly limiting for some populations, recovery of certain populations in DU8 is feasible from a habitat perspective. The extent and availability of adult habitat is sufficient for recovery. The identification of the extent and availability of spawning and juvenile habitat and confirmation of adult habitat, for all populations of DU8 is a priority and prerequisite for the RPA for this Designated Unit. It is evident from this review that much habitat and population data is available for the St. Lawrence River (Fortin *et al*. 1993; 1996; Nilo *et al.* 2006), and this region would be a good starting point for determining the extent of essential habitat for all life history stages, and to determine if habitat supply is sufficient to achieve population targets for recovery. Estimates of the individual area requirements from this study may be useful for providing a spatial context for this task.

The brief narrative description of habitat requirements for lake sturgeon indicated that there are significant knowledge gaps for all life stages (Table 4). Spawning and juvenile habitat in rivers are relatively more impacted by human activities than adult habitat in the Great Lakes, and therefore research on the early life stages is a priority. Specifically, for effective restoration of individual populations in DU8, information is urgently needed to determine: 1) if access to and the quantity and quality of spawning

habitat for individual populations is sufficient; 2) the magnitude of impact of altered flow regimes in large rivers on egg, larval and juvenile survival, and corresponding mitigation measures if needed; 3) geo-referencing, spatial boundaries and habitat conditions of localized aggregations of juveniles; 4) magnitude of impacts of lampricide on early life stage mortality; and 5) suitability of upstream passage of adults and habitat connectivity. Focusing research on access to, quality and quantity of spawning habitat is consistent with restoration programs in the United States (Peterson *et al.* 2007). Habitat concerns for lake sturgeon populations inhabiting the Great Lakes and St. Lawrence River are significant, but these concerns can be addressed and managed if sufficient knowledge of life stage-specific habitat for individual populations is known.

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Table 1. Estimates of habitat area per individual (ha) and home range size (ha) of lake sturgeon inhabiting lakes (L) or rivers (R) and ranging in size at maturity from 100 to 144 cm.

Length (TL, cm)	Weight (W, g)[1]	Habitat (H)	Habitat Requirements (ha)	
			Individual area[2]	Home range[3]
100	5458	L	0.151	8.089
117	9087	L	0.247	10.871
130	12794	L	0.342	13.258
144	17834	L	0.471	16.074
100	5458	R	0.049	0.411
117	9087	R	0.080	0.552
130	12794	R	0.111	0.673
144	17834	R	0.152	0.816

[1] from equation: weight (g) = 0.0018 $TL^{3.247}$ (Fortin *et al.* 1991; cited in Froese and Pauly 2008)
[2] from equation: $\log_e$ area (m^2) = -2.07 + 1.13(H) + 0.96 $\log_e$ W, where H is 1 for lakes and 0 for rivers (Randall *et al.* 1995)
[3] from equation: $\log_e$ HR (m^2) = 3.33 + 2.98(H) + 0.58 $\log_e$ W, where H is 1 for lakes and 0 for rivers (Minns 1995)

Table 2. Habitat area requirements of adult lake sturgeon for sizes (TL) ranging from 100 to 144 cm and a population recovery of 11880 adult sturgeon. Estimates are for sturgeon inhabiting lakes or rivers.

	Area requirements in ha			
Total Length	100 cm	117 cm	130 cm	144 cm
Lake	1794	2934	4063	5595
River	582	950	1319	1806

Table 3. Total lake area, area < 50 metres water depth, and historic harvest of lake sturgeon in the Great Lakes (combined for Canadian and American waters).

Lake	Total area[1] (ha)	Area < 50 metre depth [2] (ha)	Max catch (kg)[1]	Minimum catch (kg)[1]
Ontario	1,955,000	934,928	26,090	909
Erie	2,567,000	81,609	2,357,727	3,636
Huron	5,983,000	2,830,506	473,181	6,818
Michigan	5,775,000	2,111,250	1,745,454	455
Superior	8,200,000	1,313,800	108,118	3,636
St. Clair	127,000	127,000	495,909	16,363
Lake of the Woods	384,600		>800,000	<1,000

[1] data from COSEWIC 2006. [2] Lake area for water < 50 metres depth are from C. Bakelaar (DFO, Burlington, pers. comm.).

Table 4. Research needed to address gaps in knowledge of functional habitat of lake sturgeon in DU8. Proposed priority research activities are shaded.

Life stage	Research
Spawning	1. Confirm spawning area needed per female for optimal egg survival (m^2)
	2. Is supply of riverine spawning habitat a limiting factor for certain DU8 lake sturgeon populations?
	3. Occurrence, habitat characteristics, and viability of lake spawning
	4. Spawning site fidelity
Eggs/larvae	5. Impact of flow alteration (timing, frequency, magnitude, duration, rate of change) on survival
	6. Lampricide mortality in river habitat
Juveniles	7. Depth and habitat characteristics in the Great Lakes
	8. Mechanism/function of localized aggregations (essential habitat) in St. Lawrence (and Great Lakes?).
	9. Habitat-dependent predation mortality
	10. Extent of movements for feeding and overwintering (non-impacted populations)
	11. Is juvenile rearing habitat limiting for certain populations in DU8?
Adults	12. Seasonal depth and substrate preferences in Great Lakes
	13. Extent of movements for feeding and overwintering (non-impacted populations)
	14. Is adult habitat limiting for certain populations in DU8?
	15. Is vulnerability to lamprey habitat-dependent?
	16. Survival during upriver fish passage

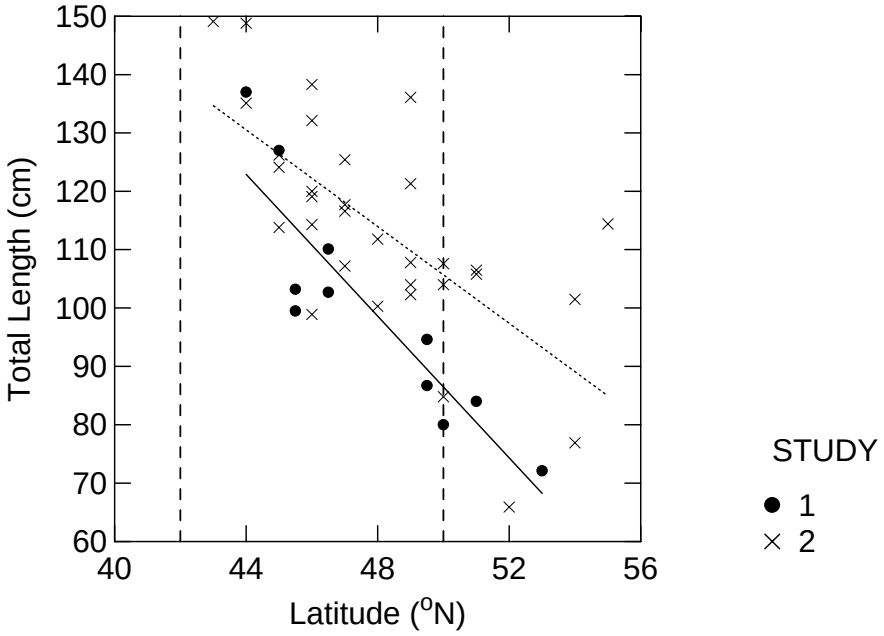

Figure 1. Relationship between total length (TL, cm) of lake sturgeon at age 20 (study 1), age at maturity $_{(23\text{-}27)}$ (study 2) and latitude. Data are from Noakes *et al*. (1999; study 1) and Fortin *et al*. (1996; study 2). The size at age data are used to illustrate the latitudinal cline in growth and size at maturity of this species. The vertical dashed lines indicate the approximate lower and upper limits of latitude for lake sturgeon inhabiting the Great Lakes and upper St. Lawrence River (DU8).

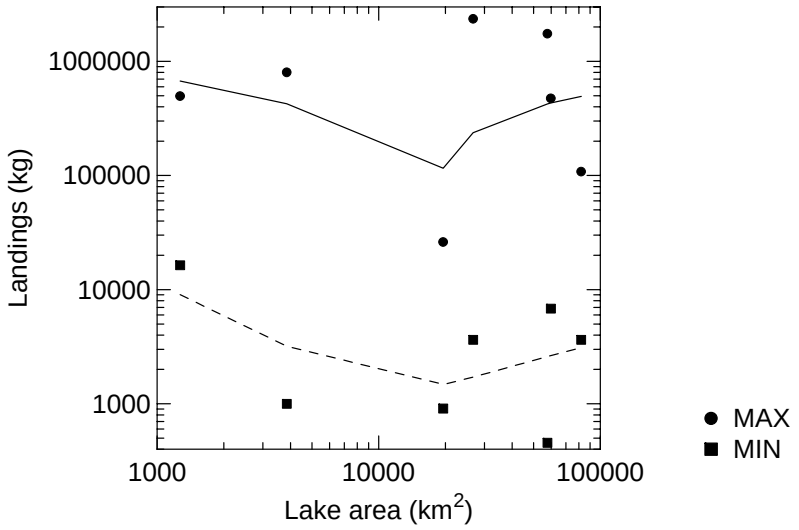

Figure 2. Lack of a relationship between lake area and yield (landings in kg) of lake sturgeon (from COSEWIC 2006, Table 6). Landings are maximum and minimum harvests (kg) for combined Canadian and American waters when commercial fisheries were operating in both countries (late 1800's). Most lakes were from DU8 (listed in order of decreasing area: Superior, Huron, Michigan, Erie, Ontario, and St. Clair); the exception was Lake of the Woods (DU6; second smallest lake area in figure). Trend lines are based on locally weighted scatterplot smoothing (LOWESS; Wilkinson *et al*. 1996).