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Recovery Potential Assessment for White Sturgeon (*Acipenser transmontanus)* Upper Fraser Designatable Unit

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

We assessed the recovery potential for the Upper Fraser White Sturgeon DU by examining the current population status, potential threats, and possible results of management strategies. Within the Upper Fraser DU, there are three distinct groups (or sub-DUs): the Mid-Fraser group, the Upper Fraser group, and the Nechako River group.

Prior to 1995, information about the abundance of White Sturgeon in the Upper Fraser DU was limited. Recent abundance estimates of mature (>160 cm) White Sturgeon in the Upper Fraser DU range from 1,177 to 1,564 fish. These estimates are based on the sum of the mature White Sturgeon abundances from the three groups. The most recent estimate of mature White Sturgeon in the Mid-Fraser group was 749 fish and the abundance was believed to be within the historic range, suggesting that the population is currently at equilibrium. The best estimate for mature White Sturgeon in the Upper Fraser group was 185 fish, which is also thought to be within the historic range. For the Nechako River group, the best estimate of adult population size was 630 fish; however, a declining trend in abundance for the Nechako River group reflects ongoing recruitment failure.

Twelve threats to White Sturgeon in the Fraser River are discussed. Abiotic threats include loss of habitat, habitat fragmentation, altered hydrograph, pollution, reduced turbidity, fishing effects, and altered thermal regime. Biotic threats include small population size effects, hatchery and aquaculture, reduced or altered food supply, change in ecological community, and disease.

Metapopulation models were designed to evaluate the effect of changes to mortality or habitat productivity on the abundance of the three groups. The models also consider uncertainty in life history parameters and exchange among groups. Relatively small changes to human-induced mortality or habitat productivity had substantial effects on the abundance of sturgeon in the Mid-Fraser and Upper Fraser, given the parameter and modeling assumptions. Losses here were mitigated by the introduction of individuals from the Nechako group, given the model structure and exchange rate assumptions. Changes to human-induced mortality or habitat productivity had little effect on the Nechako group meeting its abundance target; however, this was dependent on a large number of fish annually stocked and a high survival rate of stocked fish.

Évaluation du potentiel de rétablissement – Esturgeon blanc (*Acipenser transmontanus*), unité désignable du cours supérieur du fleuve Fraser

RÉSUMÉ

Nous avons évalué le potentiel de rétablissement de l'esturgeon blanc, unité désignable du cours supérieur du fleuve Fraser, en examinant l'état actuel de la population, les menaces éventuelles, et les résultats possibles des stratégies de gestion. L'unité désignable du cours supérieur du fleuve Fraser se divise en trois sous-groupes distincts (ou sous-unités désignables) : le groupe du mi-Fraser, le groupe du cours supérieur du Fraser, et le groupe de la rivière Nechako.

On dispose de peu de données sur l'abondance de l'esturgeon blanc, unité désignable du cours supérieur du fleuve Fraser, avant 1995. Les estimations récentes de l'abondance des esturgeons blancs ayant atteint la maturité (> 160 cm) dans le cours supérieur du fleuve Fraser vont de 1 177 à 1 564 individus. Ces estimations se fondent sur la somme de l'abondance des esturgeons blancs ayant atteint la maturité dans les trois groupes. L'estimation la plus récente du nombre d'esturgeons blancs du groupe du mi-Fraser ayant atteint la maturité est de 749 individus, et l'abondance se situe dans la fourchette historique, ce qui laisse entendre que la population a atteint un état d'équilibre. L'estimation la plus exacte du nombre d'esturgeons blancs du groupe du cours supérieur du Fraser ayant atteint la maturité est de 185 individus, ce qui correspond également à la fourchette historique. Quant au groupe de la rivière Nechako, l'estimation la plus exacte de la taille de la population adulte est de 630 individus; toutefois, une tendance à la baisse de l'abondance du groupe de la rivière Nechako est révélatrice de l'échec actuel du recrutement.

On a abordé douze menaces qui pèsent sur l'esturgeon blanc du fleuve Fraser. Les menaces abiotiques comprennent la perte de l'habitat, la fragmentation des habitats, la modification des composantes hydrographiques, la pollution, la turbidité réduite, l'incidence de la pêche et la modification du régime thermique. Les menaces biotiques comprennent l'incidence de la petite taille d'une population, les écloseries et l'aquaculture, la réduction ou la modification de la nourriture disponible, la modification de la communauté écologique et la maladie.

Les modèles de métapopulation ont été conçus pour évaluer l'effet de la modification du taux de mortalité ou de la productivité de l'habitat sur l'abondance des trois groupes. Les modèles tiennent également compte de l'incertitude à l'égard des paramètres du cycle biologique et des échanges entre les groupes. Des modifications relativement faibles à la mortalité d'origine anthropique ou à la productivité de l'habitat ont des conséquences marquées sur l'abondance de l'esturgeon dans le mi-Fraser et le cours supérieur du fleuve, selon les paramètres et les hypothèses de la modélisation. À ces endroits, les pertes étaient atténuées par l'introduction d'individus du groupe de la rivière Nechako, selon la structure du modèle et les hypothèses à l'égard du taux d'échange. Les modifications au taux de mortalité d'origine anthropique ou à la productivité de l'habitat avaient peu d'effet sur l'atteinte des cibles d'abondance du groupe de la rivière Nechako; le grand nombre de poissons stockés annuellement et le taux de survie élevé des poissons stockés avaient cependant une influence sur ce résultat.

1. INTRODUCTION

After the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses an aquatic species as Threatened, Endangered or Extirpated, Fisheries and Oceans Canada (DFO) undertakes a number of actions required to support implementation of the *Species at Risk Act* (SARA). Many of these actions require scientific information on the current status of the wildlife species, threats to its survival and recovery, and the feasibility of recovery. Formulation of this scientific advice has typically been developed through a Recovery Potential Assessment (RPA) that is conducted shortly after the COSEWIC assessment. This timing allows for consideration of peer-reviewed scientific analyses into SARA processes including recovery planning.

Within Canada, White Sturgeon occur only in British Columbia. Six Nationally Significant Populations (NSPs) were recognized in Canada during the initial SARA listing process for White Sturgeon: Lower Fraser, Mid-Fraser, Nechako, Upper Fraser, Upper Columbia, and Upper Kootenay (COSEWIC 2003). In 2004 COSEWIC switched from the concept of NSP to Designatable Units (DUs), and the COSEWIC reassessment of the status of White Sturgeon in Canada followed the guidelines for recognizing DUs (COSEWIC 2012). Geographic distribution and genetic data supported a division into four DUs: Lower Fraser, Upper Fraser, Upper Kootenay, and Upper Columbia (COSEWIC 2012), with White Sturgeon distribution reflecting post-glacial dispersal more so than anthropogenic effects (Smith *et al*. 2002). Within the Fraser River, microsatellite DNA allele frequencies support a division into upper and lower Fraser River genetic groups, with a geographic split based on Hells Gate (COSEWIC 2012). The Upper Fraser DU therefore encompasses the Fraser River from Hells Gate upstream for a river distance of almost 1,000 km to approximately the confluence with Morkill River, in addition to the Nechako River. The Upper Fraser DU comprises three distinct groups (sub-DUs): Mid-Fraser, Upper Fraser, and Nechako River.

In support of listing recommendations for the Upper Fraser White Sturgeon DU, DFO Science has been asked to undertake an RPA for this DU, based on the National Frameworks (DFO 2007a and b). The advice in this RPA may be used to inform both scientific and socio-economic elements of the listing decision, as well as development of a recovery strategy and action plan, and to support decision-making with regards to the issuance of permits, agreements and related conditions, as per Sections 73, 74, 75, 77 and 78 of SARA. The advice generated via this process will also update and/or consolidate any existing advice regarding White Sturgeon.

This report addresses the requirements of the National Framework for Recovery Potential Assessments. Twenty two elements are addressed within six categories (Table 1). Since a great deal of effort has already gone into reviewing the biology of White Sturgeon as part of recovery efforts, that information is repeated here in summary form.

Table 1. Categories and elements as required in the National Framework for Recovery Potential Assessments.

Biology, Abundance, Distribution, and Life History Parameters of White Sturgeon

Element 1:	Summarize the biology of Upper Fraser White Sturgeon
Element 2:	Evaluate the recent species trajectory for abundance, distribution and number of populations
Element 3:	Estimate the current or recent life-history parameters for Upper Fraser White Sturgeon

Habitat and Resident Requirements of White Sturgeon

Element 4: Provide descriptions of the habitat properties that Upper Fraser White Sturgeon needs for successful completion of all life-history stages. Describe the function(s), feature(s), and attribute(s) of the habitat, and quantify how the biological function(s) that specific habitat feature(s) provides varies with the state or amount of habitat, including carrying capacity limits, if any.

Element 5: Provide information on the spatial extent of the areas in Upper Fraser White Sturgeon's distribution that are likely to have these habitat properties.

Element 6: Evaluate to what extent the concept of residence applies to the species, and if so, describe it.

Element 7: Quantify the presence and extent of spatial configuration constraints, if any, such as connectivity, barriers to access, etc.

Threats and Limiting Factors to the Survival and Recovery of White Sturgeon

Element 8: Assess and prioritize the threats to the survival and recovery of the species

Element 9: Identify the activities most likely to threaten (i.e. damage or destroy the habitat prosperities (identified in steps 4-5) that give the site their value, and provide information on the extent and consequences of these activities.

Element 10: Assess any natural factors that will limit the survival and recovery of the species

Recovery Targets for White Sturgeon

Element 11: Propose candidate abundance and distribution targets for recovery.

Element 12: Project expected population trajectories over a scientifically reasonable timeframe (minimum of 10 years), and trajectories over time to the recovery target (if possible to achieve), given current Upper Fraser White Sturgeon population dynamics parameters

Element 13: Provide advice on the degree to which supply of suitable habitat meets the demands of the species both at present, and when the species reaches targets identified in element 11.

Element 14: Assess the probability that the recovery targets can be achieved under current rates of population dynamics parameters, and how that probability would vary with different mortality (especially lower) and productivity (especially higher) parameters

Scenarios for Mitigation of Threats and Alternative to Activities

Element 15: Develop an inventory of feasible mitigation measures and reasonable alternatives to the activities that are threats to the species and its habitat (as identified in elements 8 and 10)

Element 16: Develop an inventory of activities that could increase the productivity or survivorship parameters (as identified in elements 3 and 14).

Element 17: If current habitat supply may be insufficient to achieve recovery targets (see element 13), provide advice on the feasibility of restoring the habitat to higher values. Advice must be provided in the context of all available options for achieving abundance and distribution targets

Element 18: Estimate the reduction in mortality rate expected by each of the mitigation measures or alternatives in element 15, and the increase in productivity or survivorship associated with each measure in element 16.

Element 19: Project expected population trajectory (and uncertainties) over a scientifically reasonable timeframe and to the time of reaching recovery targets, given mortality rates and productivities associated with the specific measures identified for exploration in element 18. Include those that provide as high a probability of survivorship and recovery as possible for biologically realistic parameter values.

Scenarios for Mitigation of Threats and Alternative to Activities

Element 20: Recommend parameter values for population p7 starting mortality rates, and where necessary, specialized features of population models that would be required to allow exploration of additional scenarios as part of the assessment of economic, social, and cultural impacts in support of the listing process.

Element 21: Discuss the potential ecological impacts of a threat and/or threat abatement, and any associated knowledge gaps. Identify existing monitoring efforts for the target species and its habitat, including biotic and abiotic components that document the potential ecological impacts of a threat and/or threat abatement.

Allowable Harm Assessment

Element 22: Evaluate maximum human-induced mortality and habitat destruction that the species can sustain without jeopardizing its survival or recovery.

2. DISTRIBUTION, BIOLOGY, LIFE HISTORY PARAMETERS, AND ABUNDANCE OF UPPER FRASER WHITE STURGEON

This section of the RPA will address Elements 1 and 2 of the National Framework for Recovery Potential Assessments.

2.1. SPECIES DESCRIPTION

White Sturgeon, *Acipenser transmontanus*, is the largest, longest-lived freshwater fish species in North America (Scott and Crossman 1973). Fish of over 6 m in length and over 100 years of age have been reported in the Fraser River (Scott and Crossman 1973). The most distinguishing features of this species include: a mainly cartilaginous skeleton, long scaleless body covered with rows of large bony plates (called scutes) on the back and sides, shark-like (heterocercal) tail, and four barbels between the mouth and an elongated snout. It has a protrusible mouth with which it creates suction to capture and pick up food. Body colouration ranges from black to olive or light grey on the dorsal surface and upper edge of scutes, but is consistently white on the ventral surface (Scott and Crossman 1973).

2.2. DISTRIBUTION

The Upper Fraser DU occurs upstream of Hells Gate and includes the mainstem Fraser River, plus the Nechako River and tributaries including the Stuart River (a tributary of the Nechako River), Seton River (a tributary of Fraser River) (Steve McAdam, pers. comm. 2016[1]), and Thompson River (a tributary of Fraser River) (Steve McAdam, pers. comm.2016[1]) (Figure 1). The Seton River presence is based on a single observation at the Seton trash rack (Steve McAdam, pers. comm.2016[1]). Fin ray analysis of this single fish determined that it was a long-term resident of the Seton, but did not originate from the Seton River (Steve McAdam, pers. comm. 2016[1]). Within the Upper Fraser DU, there are three distinct groups: the Mid-Fraser group downstream of the Nechako River confluence, the Upper Fraser group upstream of the Nechako River confluence, and the Nechako River group (COSEWIC 2012). Tagging data indicate movement between these three groups although genetic data indicate that the groups are distinct (COSEWIC 2012, Smith *et al*. 2002).

[1] Steve McAdam, Hydro Impacts/Sturgeon Specialist, BC Ministry of Environment, Vancouver, BC

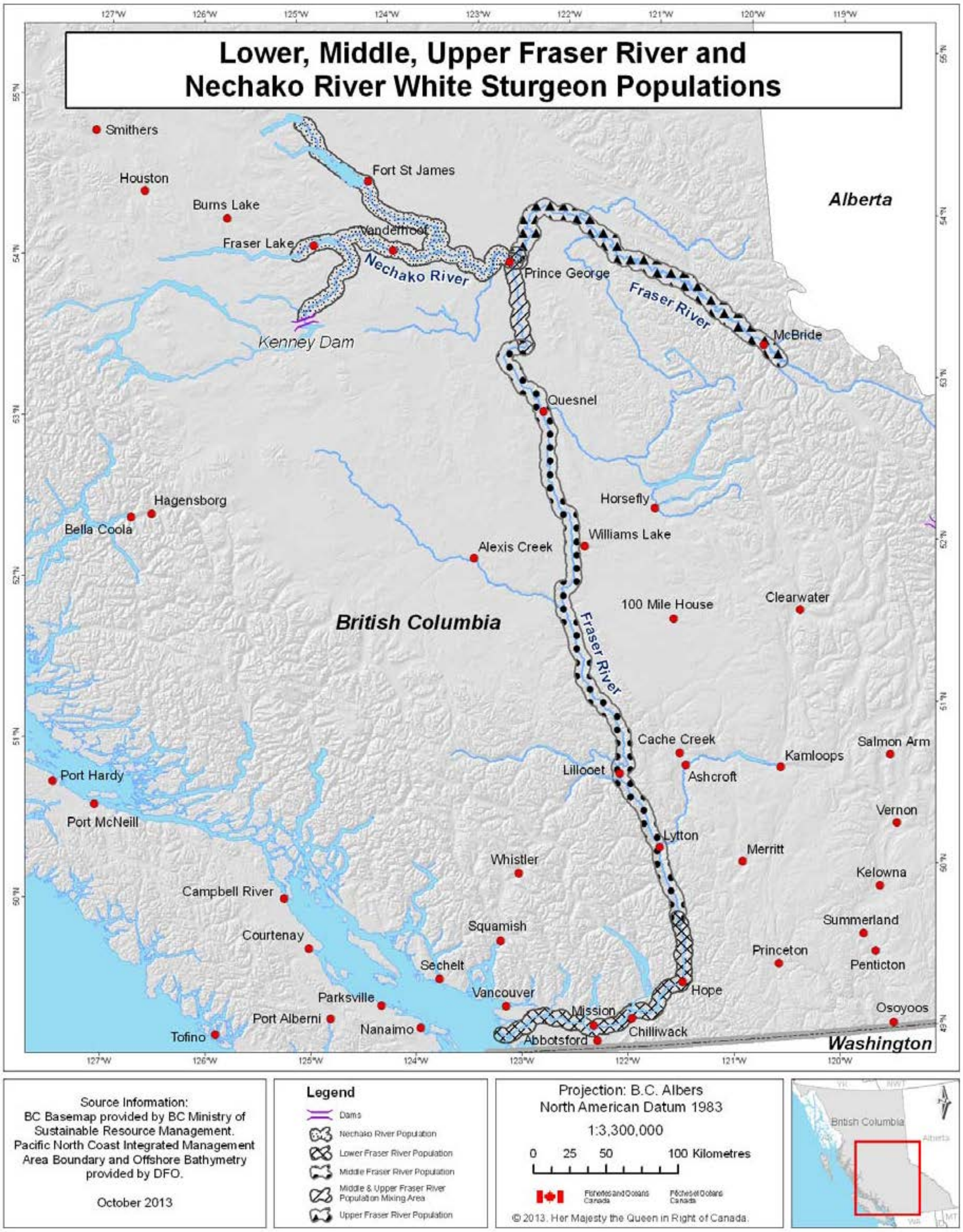

Figure 1. Distributions of White Sturgeon populations (groups) in the Fraser River. The Upper Fraser Designatable Unit comprises three separate groups: Mid-Fraser, Upper Fraser and Nechako River (map from DFO 2014).

2.3. LIFE STAGES

The following major life stages are described in DFO (2014), but a variety of other terms may be used in the literature. These life stages are useful for discussing life stage-specific biotic processes, threats, habitats and recovery goals.

2.3.1. Spawning

The spawning life stage refers to the primary period of active reproduction for mature individuals. Typically this is shortly after the peak of the spring freshet, but the actual timing varies among locations.

2.3.2. Incubation

The incubation life stage refers to the period from fertilization to hatch. Hatch occurs 5 to 10 days after fertilization depending on water temperature, with temperatures in excess of 20° C leading to abnormal development (Wang *et al.* 1985).

2.3.3. Yolk sac larvae (0 – 12 days post-hatch)

During the yolk sac larvae period individuals tend to remain hidden (e.g., within interstitial spaces in river bed substrates) until the yolk sac is exhausted, but at the beginning of this period drift may occur until yolk sac larvae find appropriate hiding locations. The life stage ends at the onset of exogenous feeding.

2.3.4. Feeding Larvae (12 – 40 days post-hatch)

During this period, individuals emerge from hiding habitats, show nocturnal drift, and initiate exogenous feeding. First feeding varies from 8–16 days post-hatch, depending on water temperature (Doroshov *et al.* 1983, Buddington and Christofferson 1985, Gawlicka *et al.* 1995). A larva's first feeding occurs after about 200 accumulated temperature units (Boucher 2012). The highest daily mortality rate for larval sturgeon occurs in the days of first and early feeding under culture conditions (Gisbert and Williot 2002); high predation induced mortality is likely similar under wild conditions at this stage.

2.3.5. Early Juvenile (40 days to 2 years)

White Sturgeon are morphologically similar to later life stages after metamorphosis, but habitat use and diets may be substantially different than later life stages, primarily due to differences in body size. The 40 days to 2 years stage is one during which young fish become less susceptible to predation and, by one year old, fish can be observed holding in habitats that are similar to adult habitat types. The division between this life stage and the next has been set somewhat arbitrarily at two years of age.

2.3.6. Late Juvenile and Adult (>2 years)

Individuals greater than two years old differ in size and sexual maturity, but habitat use is similar. Food resource use likely shifts during this stage, with an increasing trend toward piscivory in older fish. This life stage may include activities such as staging, overwintering, migration and rearing.

2.4. REPRODUCTION

Males tend to mature at a younger age and smaller size than females. Information on sexual maturity for the Upper Fraser DU exists, but suggests that males may mature as early as their late teens and females in their late 20s (RL&L Environmental Services Ltd 2000). Information from the Lower Fraser DU indicates that females and males may spawn for the first time at 26 and 11 years respectively, but often it is later (Semakula and Larkin 1968).

For the Mid-Fraser group, sparse data collected during the Fraser River White Sturgeon Monitoring Program (FRWSMP) indicated that female White Sturgeon reach reproductive maturity aged 25–30, while male White Sturgeon mature at less than 20 years old (RL&L Environmental Services Ltd. 2000).

For the Upper Fraser group, insufficient data were available from the FRWSMP to characterize spawning ages for White Sturgeon.

For the Nechako River group, data collected during the FRWSMP suggested that White Sturgeon become sexually mature at a substantially older age than other groups, with both sexes found to spawn only at age 40 or older (RL&L Environmental Services Ltd. 2000). There is high uncertainty with this result, however, as it may reflect a skewed age distribution for the fish that were sampled.

White Sturgeon release large numbers of eggs and sperm over bottom substrates in the water column of turbulent river habitats. Spawning occurs in the late spring and early summer, typically following the highest water levels of freshet, as water temperatures are rising (Parsley *et al.* 1993, RL&L Environmental Services Ltd. 1994, Parsley and Kappenman 2000, Paragamian *et al.* 2002, Parsley *et al.* 2002, Perrin *et al.* 2003). Recent studies indicate that spawning (egg deposition), site velocity and depth preferences supersede substrate preferences (Paragamian *et al.* 2009, McDonald *et al.* 2010, Sykes 2010), though substrate conditions appear to have a critical effect on survival of eggs and very early life stages (Paragamian *et al.* 2009, McAdam 2011, Boucher 2012, McAdam 2012). In the mainstem Columbia and Snake Rivers, spawning has occurred largely in the tailwater areas of large dams (e.g., Parsley *et al.* 1993, Parsley and Kappenman 2000, Lepla *et al.* 2001, Terraquatic Resource Management 2011) or at the confluences of large tributaries.

Specific data about reproduction are limited for the Upper Fraser DU, and there is high uncertainty about the age of sexual maturity or the interval between spawning events for the Mid-Fraser and Upper Fraser groups. The number of eggs that White Sturgeon females can produce (i.e., fecundity) is directly proportional to body size and has been reported by Scott and Crossman (1973) to range from 0.7 to 4.0 million eggs for the species in general. For example, a 239 cm female (provenance unknown) contained approximately 0.7 million eggs (Migdalski 1962 cited in Scott and Crossman 1973). Eggs are approximately 3.5 mm in diameter, adhesive, and demersal (Deng *et al.* 2002).

White Sturgeon spawn multiple times throughout their life. For example, limited data for White Sturgeon in the lower Fraser River suggest that spawning intervals for females may vary from 4 to 11 years, with the interval increasing with age (Semakula and Larkin 1968, Scott and Crossman 1973). A few spawning female fish have been re-sighted at a spawning interval of 4 years (McAdam, pers. comm. 2016[1]); however, the full range of spawning interval length is unknown.

Adult and juvenile White Sturgeon are adapted to feeding in dark, benthic habitats, where prey are often located through direct contact, facilitated by highly sensitive taste receptors on barbels near the mouth (Brannon *et al.* 1985). Juvenile White Sturgeon are primarily benthic feeders and prey include a variety of aquatic insects, isopods, mysids, clams, snails, small fish, and fish eggs (Scott and Crossman 1973, McCabe *et al.* 1993), but diets also vary throughout the year and among locations. Adult White Sturgeon feed predominantly on fish, particularly migratory salmonids where available, although crayfish and chironomids are also consumed (Scott and

Crossman 1973). The range of food sources available to White Sturgeon is more constrained within the Upper Fraser DU range compared with the lower Fraser DU, where marine and estuarine fish and invertebrates are present, as well as seasonally abundant Eulachon and Pacific salmon runs.

Movement and migrations for adult and late juvenile White Sturgeon are linked to feeding, overwintering, and spawning activities. Movement patterns appear primarily related to food type and availability, and habitat type and availability. The presence of dams and river regulation may alter natural movement patterns (DFO 2014); however, this issue is not an issue in the Upper Fraser DU.

2.5. LIFE HISTORY PARAMETERS

2.5.1. Survival

Survival rates are very low during the first year and then become substantially higher in later juvenile and adult life stages (Gross *et al*. 2002). The combined effect of low early survival and the compounding effects of subsequent mortality over many years mean that relatively few individuals actually reach the old ages often cited for this species. Estimated survival is very low during the first year (estimated at 0.000396% in Gross *et al.* 2002). Survival rates are substantially higher in the juvenile and adult life stages, with estimates ranging between 91% and 97% (Gross *et al.* 2002, Irvine *et al.* 2007). Most recently, DFO (2014) present adult survival rates that range from 94% (Nechako group) to 97% Mid-Fraser and Upper Fraser groups), based on survival rates presented by Whitlock (2007) and Irvine *et al*. (2007).

2.5.2. Growth

White Sturgeon are slow-growing with a delayed onset of sexual maturity. Growth rates and maturity vary significantly throughout the White Sturgeon's range. Growth rates tend to be highest where waters are warmer, growing seasons are longer, and food is abundant. White Sturgeon in the upper Fraser and Nechako rivers exhibit slower growth than populations in the middle and lower Fraser River, potentially due to the shorter growing season and/or reduced availability of food resources such as spawning salmon (*Oncorhynchus* spp.) and Eulachon (*Thaleichthys pacificus*) (RL&L Environmental Services Ltd. 2000).

Maximum lengths for Upper Fraser DU were: 251 cm for the Mid-Fraser group, 237 cm for the Upper Fraser group and 228 cm for the Nechako River group (RL&L Environmental Services Ltd. 2000).

2.6. ABUNDANCE TRENDS

Prior to initiation of the FRWSMP in 1995–1999 (RL&L Environmental Services Ltd 2000), information about the abundance of White Sturgeon stocks in the Upper Fraser DU was very limited, with previous monitoring focused on the Nechako River group (Dixon 1986). The FRWSMP involved using a range of sampling techniques to estimate group-specific population sizes based on mark recapture data analyzed with a modified Schnabel estimation technique (cf. Krebs 1989). Insufficient data for the Upper Fraser group meant that a total population for the Upper Fraser DU was not estimated as part of the FRWSMP. COSEWIC (2012) later presented estimated 2012 population sizes of mature (>160 cm) White Sturgeon in the Upper Fraser DU based on: the FRWSMP data; an estimated mortality rate (0.04), and; sampling conducted in the upper Fraser River during 2001–2002 (Yarmish and Toth 2002) and 2007–2008 (Lheidli T'enneh First Nation 2008, 2009). The 2012 abundance of mature (>160 cm)

White Sturgeon in the Upper Fraser DU ranges from 1,177 to 1,564 fish (Table 2). This estimate is based on the sum of estimated mature White Sturgeon abundances from each group.

For the Mid-Fraser group, the estimated abundance in 1999 based on data collected during 1995–1999 as part of the FRWSMP (with 95% C.I.) was 3,745 (3,064–4,813) (RL&L Environmental Services Ltd 2000). In 2012, there were an estimated 749 mature (>160 cm) White Sturgeon in the Mid-Fraser group (COSEWIC 2012, DFO 2014) (Table 2). Data were insufficient to indicate abundance trends although abundance was believed to be within the historic range (DFO 2014).

For the Upper Fraser group, data collected during 1995–1999 as part of the FRWSMP were insufficient to estimate abundance for 1999 (RL&L Environmental Services Ltd 2000). In 2012, there were an estimated 185 mature (>160 cm) White Sturgeon in the Upper Fraser group (COSEWIC 2012, DFO 2014) (Table 2). Data were insufficient to indicate abundance trends although abundance was believed to be within the historic range (DFO 2014).

For the Nechako River group, the estimated abundance in 1999 based on data collected during 1995–1999 as part of the FRWSMP (with 95% C.I.) was 571 (421–890) (RL&L Environmental Services Ltd 2000). In 2012, COSEWIC (2012) estimated that there were 336 mature (>160 cm) White Sturgeon in the Nechako group, although DFO (2014) revised this to 243 based on applying a lower survival rate to extrapolate the 1999 data (0.94 rather than 0.96) (Table 2). Abundance seems to be declining in the Nechako River (COSEWIC 2012) and this trend is supported by recent analysis, which shows that the population size of this group declined by approximately one third between 2001 and 2012 (Carruthers *et al*. in preparation[2]). Note that these authors estimated that the adult population size for the Nechako River group in 2012 was 630 (median of model predictions), which is substantially higher than previous estimates (Table 2).

The declining trend in abundance for the Nechako River group reflects recruitment failure. Data from the FRWSMP (1995–1999) showed a scarcity of younger (< 30 years old) White Sturgeon in the Nechako River group, indicating that recruitment of juvenile fish has been extremely low and unsustainable in recent decades (RL&L Environmental Services Ltd 2000, Korman and Walters 2001, French *et al*. 2004). Comparison of data from this period with data collected in 1982 indicates that there was an almost complete failure in recruitment for the Nechako River group over 25 years prior to the 1995–1999 sampling (Korman and Walter 2001). By contrast, size distribution data for the Upper and Mid-Fraser River groups show a greater occurrence of individuals younger than 20 years, consistent with an age distribution expected for a healthy population. Possible reasons for the recruitment failure are discussed in Section 4. To support short-term recovery actions, a Recovery Plan for Nechako River White Sturgeon identified the need to culture and release wild origin, hatchery-reared juvenile fish to maintain adult abundance (Nechako White Sturgeon Recovery Initiative 2004). Pilot fish culture operations were completed in 2006–2008, and the long-term Nechako White Sturgeon Conservation Facility commenced hatchery operations in 2014 (Nechako White Sturgeon Recovery Initiative 2014).

[2] Carruthers, T.R., D.S.O. McAdam, and C. Williamson. *In preparation*. Estimating movement in spatial capture–recapture models: an application to endangered Nechako River white sturgeon. Manuscript under peer review.

Table 2. Abundance of mature (>160 cm) White Sturgeon in 2012.

Upper Fraser Section	Mature White Sturgeon Abundance	Reference
Upper Fraser DU	1,177-1,564	
Mid-Fraser Group	749	DFO (2014)
Upper Fraser Group	185	DFO (2014)
Nechako Group	243-630	COSEWIC (2012), DFO (2014); Carruthers *et al*[2.] (in preparation)

3. HABITAT AND RESIDENCE REQUIREMENTS OF WHITE STURGEON

This section addresses elements 4, 5, 6, and 7 of the National Framework for Recovery Potential Assessments.

White Sturgeon require suitable habitats, an abundant food base, and appropriate flows and water conditions. These needs are discussed in detail in COSEWIC (2012) and DFO (2014), and are briefly summarized here. Identified and proposed critical and important habitats are described in DFO (2014) and are also briefly summarized here. We note that there are some outstanding tasks with respect to identifying critical habitat for all groups in the Upper Fraser DU, and these tasks will occur outside of the RPA process.

3.1. PHYSICAL HABITAT REQUIREMENTS

White Sturgeon inhabit large rivers where they are associated with particular habitat features: slow, deep mainstem channels interspersed with zones of swift and turbulent water; extensive floodplains with sloughs and side channels; and, a snowmelt-driven hydrograph with prolonged spring floods (Coutant 2004). Most habitat use studies have been conducted on regulated rivers. The few studies completed on the Fraser River, which is the only unregulated system in the species' range, indicate that habitat use there may be quite different, although the majority of these studies have been conducted in the Lower Fraser River (e.g., Perrin *et al.* 2003, Triton Environmental Consultants 2013). The Middle Fraser River is distinct from the Lower Fraser in that much of its length is canyonized. Other canyonized systems with White Sturgeon are highly regulated, such as the Snake River (Idaho Department of Fish and Game 2008). For the Upper Fraser DU, information about habitat preferences is relatively limited, particularly for the Mid-Fraser and Upper Fraser groups. Nonetheless, DFO (2014) has identified important habitat for the Lower Fraser group and defined critical habitats for the Upper Fraser (Figure 2), and for the Nechako River groups (Figure 3). Maps of important habitat for the Mid-Fraser group are available (DFO 2014); however, no summary map was available for inclusion in this report. Important habitat has the same definition as critical habitat but has no legal status under SARA. Critical habitats were defined using the 'critical habitat parcel approach', and correspond to specific reaches that contain the functions and features necessary for White Sturgeon survival. Separate maps of each habitat are presented in DFO (2014).

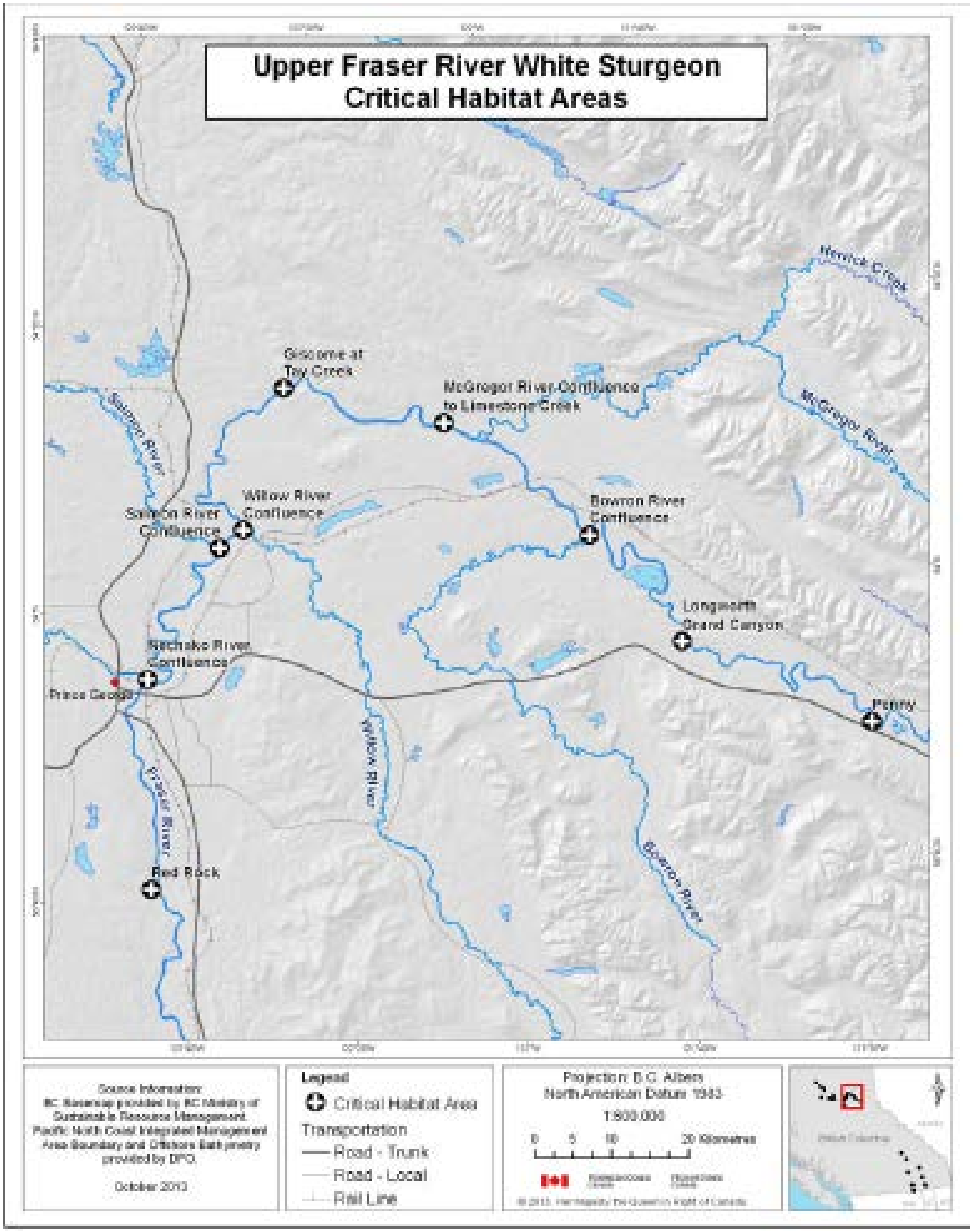

Figure 2. Critical habitat areas for the Upper Fraser White Sturgeon group. Reproduced from DFO (2014).

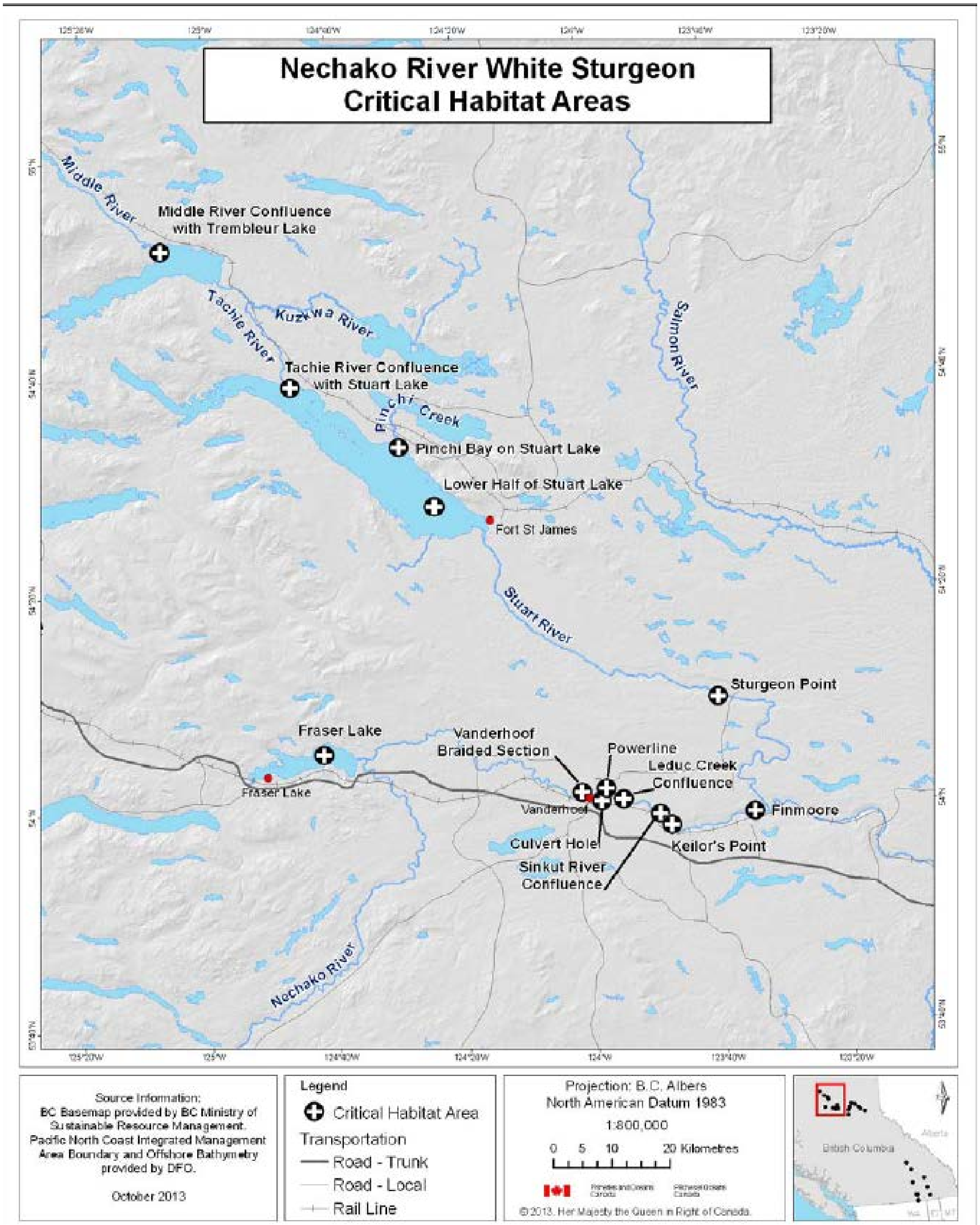

Figure 3. Critical habitat areas for the Nechako River White Sturgeon group. Reproduced from DFO (2014).

3.1.1. Spawning and Incubation Habitat

White Sturgeon naturally spawn during the snow melt-driven, descending limb of the spring freshet, which is typically after peak flows. There has been a considerable amount of work done to characterize White Sturgeon spawning habitats, but much of the information has come from regulated rivers in the US (e.g., Parsley *et al.* 1993, Parsley and Beckman 2004, Paragamian *et al.* 2001). These studies indicate strict requirements for deep, swift water and coarse substrates. Studies conducted in the lower Fraser River indicate that White Sturgeon spawning may occur over a wider range of habitat conditions than previously reported for impounded areas, with shallow (depth: 1.5 m to 4.0 m), moderate to high velocity (mean near-bed velocity: 0.8 $m \cdot s^{-1}$ to 2.1 $m \cdot s^{-1}$) side channel habitats with sand/gravel substrates shown to be important in this section of the river (Perrin *et al.* 2003). Data regarding spawning habitat for the Upper Fraser DU are limited to the confirmed spawning site on the Nechako River (described below).

For the Mid-Fraser group, DFO (2014) lists the Cottonwood River and Hawks Creek areas as the only identified spawning areas. The area near the Seton River confluence is considered to be a potential important spawning and incubation site.

For the Upper Fraser group, DFO (2014) lists five suspected spawning sites. These are: Longworth Grand Canyon, Bowron River confluence, Willow River confluence, the Nechako River confluence and the Red Rock site downstream of the Nechako River (Figure 2).

For the Nechako River group, DFO (2014) lists a single known spawning site at the braided section at Vanderhoof (Figure 3). This is the only confirmed spawning site in the Upper Fraser DU and is confirmed as high-use (DFO 2014). Physical habitat data for the site at Vanderhoof are broadly consistent with those for the lower Fraser River, and they indicate that spawning occurs in side channel habitats, in addition to the main channel thalweg (Sykes 2010). At the 59 sites sampled, median depth was 1.65 m (range: 0.60–3.80 m) and median near-bed water velocity was 0.85 m/s (range: 0.13–1.15 m/s). The dominant substrates were gravel (40–65%) and fines (10–60%), with cobble (20–65%) present in upstream areas (Sykes 2010).

3.1.2. Early Juvenile Habitat

Early juvenile habitat for White Sturgeon varies considerably with stage of development. In general, little is known about natural early juvenile habitat use for White Sturgeon populations in British Columbia, with most information coming from laboratory studies, research conducted on other river systems, and within regulated river reaches. Overall, data suggests that early juvenile White Sturgeon may be found over a wide range of depths, but that they prefer slow to moderate water velocities with finer substrates (e.g., Parsley *et al.* 1993, Bennett *et al.* 2005, Glova *et al.* 2008). Extensive use of deep, low velocity mainstem habitats also occurs (RL&L Environmental Services Ltd. 2000, Golder Associates Ltd. 2003, Neufeld and Spence 2004, Bennett *et al.* 2005, Glova *et al.* 2008), especially as fish grow larger.

For the Mid-Fraser group, early juvenile habitat is assumed to be near identified spawning and incubation sites and therefore, should be Cottonwood River, Hawks Creek, and the area near the Seton River confluence. Important juvenile habitat has also been identified in Cottonwood River, Quesnel River, Hawks Creek, Chilcotin River, Word Creek, Grinder and Long Cabin Creek, and French Bar Creek.

For the Upper Fraser group, only a single early juvenile habitat is identified by DFO (2014). This is the Bowron River confluence (Figure 2) where early juvenile use has been confirmed, although the extent of use and specific habitat attributes at this site are unknown.

For the Nechako River group, DFO (2014) lists four confirmed early juvenile habitats (high-use) and two additional suspected early juvenile habitats (high-use). These sites have sufficient food for growth (predominantly invertebrates), depth > 15 cm and cover (e.g., large substrate) to provide refuges from predators. Monitoring of hatchery-reared four month old fish released in the Nechako River supports the observation made elsewhere that juveniles prefer low velocity habitats, as fish were found in glides with water velocity < 0.5 m/s (Triton Environmental Consultants 2007). Larvae released into the Nechako River 15 days post hatch displayed a preference for sites dominated by gravel where they were able to find refuge/resting habitat in interstitial spaces (Courtier 2010).

3.1.3. Late Juvenile and Adult Habitat

Evidence from throughout the Fraser River indicates that late juvenile (>2 years) and mature adult habitat use is variable, depending on time of year and activities such as spawning, feeding, overwintering, and movements to and from these key habitats (RL&L Environmental Services Ltd. 2000). Fish may move extensively among spawning, feeding and overwintering areas.

In the Upper Fraser DU, adult fish can be widely dispersed although fish are commonly found near the confluences of major tributaries (RL&L Environmental Services Ltd. 2000). Sampling shows that White Surgeon are predominantly present in the mainstem of the Fraser River, although fish are known to use the lower reaches of major tributaries such as the Stuart and McGregor Rivers (RL&L Environmental Services Ltd. 2000) and Seton (McAdam, pers. comm. 2016[1]) and Thompson Rivers (McAdam, pers. comm. 2016[1]). Use of lakes has also been documented (notably in the Nechako River group; Toth and Yarmish 2003, Yarmish and Toth 2005).

For the Mid-Fraser group, DFO (2014) proposed several areas as important habitats for feeding including Cottonwood River, Quesnel River, Hawks Creek, Chimney Creek, Riske Creek, Chilcotin River, Word Creek, Grinder and Lone Cabin Creek, French Bar Creek, rkm[3] 405-407, rkm 395-401, rkm 368, rkm 350, rkm 320-344, rkm 317-320, rkm 310-315, rkm 282, rkm 273-274, and rkm 250-255.

For the Upper Fraser group, DFO (2014) lists an additional seven confirmed high-use late juvenile/adult habitats including downstream of the Nechako River (Red Rock) and a second confirmed high-use habitat at the Nechako River confluence, which is the boundary between the Mid-Fraser and Upper Fraser groups. These areas are moderately deep or deep (2–16 m) and have relatively high abundance of food, including invertebrates and fish.

For the Nechako River group, by DFO (2014) lists six confirmed high-use late juvenile/adult habitats and four confirmed medium use late juvenile/adult habitats. Notably, these include several lakes (Stuart, Trembleur and Fraser Lakes; Figure 3). Juvenile indexing in the Nechako River shows that habitat use by juvenile fish (fork length < 1 m) overlaps considerably with areas used by sub-adult and adult fish (Courtier 2010).

3.1.4. Summer

In the Upper Fraser DU range, summer habitat use is variable between individual groups, and is linked to the migration of important prey species, which include spawning anadromous Pacific salmon and Kokanee (*O. nerka*) (COSEWIC 2012). Pacific Lamprey (*Entosphenus tridentatus*) was likely an important prey species for White Sturgeon in the Upper Fraser DU range, although populations are now greatly depleted relative to historic sizes (COSEWIC 2012).

[3] rkm = river kilometre

3.1.5. Overwintering

Reduced activity is generally observed during winter months (RL&L Environmental Services Ltd. 2000, Golder Associates Ltd. 2005). Individuals in all DUs tend to congregate in deeper, lower-velocity, depositional areas during this period, with high fidelity shown to specific sites (COSEWIC 2012).

For the Mid-Fraser group, DFO (2014) lists the following as important overwintering habitat: Quesnel River, Hawks Creek, Chimney Creek, Chilcotin River, Word Creek, Grinder and Lone Cabin Creek, and French Bar Creek.

For the Upper Fraser group, DFO (2014) lists an additional five confirmed high-use overwintering habitats and two suspected high-use overwintering habitats including the one suspected high-use overwintering habitat downstream of the Nechako River (Red Rock) and a second suspected high-use habitat at the Nechako River confluence, which is the boundary between the Mid-Fraser and Upper Fraser groups (Figure 2).These areas are moderately deep or deep (2–16 m), typically with low water velocity during winter and spring.

For the Nechako River group, DFO (2014) lists seven confirmed overwintering habitats (medium or high-use) and four suspected medium use overwintering habitats. Data about habitat use in known overwintering areas on the Nechako River were collected in 2005 using a remotely operated underwater vehicle (Golder Associates Ltd. 2005). This survey was conducted in late November, and identified groups of 50–100 White Sturgeon present in high densities. Fish displayed low activity and were holding on, or just off, the river bed in areas with predominantly fine substrate. White Sturgeon captured at these sites were found at depths of 1.79–7.9 m, with water velocities of 0.10–0.56 m/s at a depth of 1.5 m. Substrate types were sands, gravel and hard clay (Golder Associates Ltd. 2006).

3.1.6. Migration Movements

Spring migrations in the Upper Fraser DU range are associated with ice breakup, freshet flows and the onset of spawning of prey species (e.g., cyprinids), which starts in March and continues to early May. Fall and early winter migrations of White Sturgeon in the middle and upper Fraser River can be extensive, and are related to upstream migration of spawning salmon and movements towards over-wintering areas (DFO 2014). Overflights to monitor radio tagged fish at overwintering habitats in the Nechako River in 2009 showed that most fish had left these habitats by May 21 (Sykes 2010).

3.2. PREY BASE REQUIREMENTS

Sustainable White Sturgeon populations require an abundant and healthy food base. Juvenile food requirements are not well-studied, but they reportedly feed on chironomids, and a range of other invertebrate and fish species, which vary among seasons and locations (Scott and Crossman 1973, McCabe *et al.* 1993, Bennett *et al.* 2005). Juvenile sturgeon diets would likely be impacted by habitat loss, substrate changes, sediment- and water-borne toxins, or other actions (e.g., river regulation) that alter distribution and abundance of benthic organisms.

Late juvenile and adult White Sturgeon feed predominantly on fish, including cyprinids, lamprey, and especially migratory Eulachon and salmon where available, although benthic invertebrates such as shellfish, crayfish and chironomids are also consumed (Scott and Crossman 1973). White Sturgeon in the Upper Fraser DU have access to a reduced range of food sources than fish in the lower Fraser River. Important food sources include Sockeye Salmon (*O. nerka*), Chinook Salmon (*O. tshawytscha*) and Kokanee (COSEWIC 2012).

3.3. WATER CONDITIONS HABITAT REQUIREMENTS

There appears to be a natural mechanism by which spawning is initiated when temperature exceeds an approximate threshold. While other factors may have a secondary influence on spawn timing (e.g., flow and photoperiod – see Liebe *et al.* 2004) temperature appears to have a dominant effect. A threshold temperature of 13 ºC has been reported for Nechako River White Sturgeon (Sykes 2010); however, daily mean temperatures as low as 10.5ºC have been recorded during assumed spawning dates (Sykes 2010).

3.4. SPATIAL EXTENT OF AREAS LIKELY TO HAVE STURGEON HABITAT PROPERTIES

The Upper Fraser White Sturgeon DU range extends upstream from Hells Gate and includes the Nechako River and tributaries (COSEWIC 2012, DFO 2014). Knowledge of distribution varies between each of the three separate groups that comprise the Upper Fraser DU. There are twelve suspected spawning sites identified in the Upper Fraser DU range, with only one further site confirmed in the vicinity of Vanderhoof on the Nechako River (COSEWIC 2012). Critical habitats for the Upper Fraser River and Nechako River groups have been identified by DFO (2014).

Sampling conducted during the FRWSMP within the range of the Mid-Fraser group (Hells Gate upstream to Prince George) showed that White Sturgeon were commonly recorded near the confluences of tributaries (e.g., Nahatlach, Stein, Seton, Cottonwood and Chilcotin Rivers) and in the French Bar Canyon (rkm 409) and Powerline Rapids (rkm 359 to 365) areas. White Sturgeon distribution was more sporadic upstream of the Chilcotin River confluence, with areas of higher use noted in the vicinity of confluences. Fish have been observed in the mainstem of the Fraser River, as well as in several large lakes including Kamloops Lake (DFO 2014).

Sampling during the FRWSMP conducted within the range of the Upper Fraser group (upstream of Prince George) showed that White Sturgeon were most commonly found near the confluence areas of major tributaries. These included the McGregor, Bowron and Torpy Rivers, with fish also sampled in the lowermost reaches of these tributaries. Fish sampled in the vicinity of the Torpy River were at ~rkm 1,040, and were the furthest upstream of all fish caught in the program. Very limited sampling has been undertaken upstream of the confluence with the Morkill River (~rkm 1,070) although White Sturgeon have been observed upstream of the Morkill River at approximately rkm 1,100 (Yarmish and Toth 2002). White Sturgeon are also commonly found in the Longworth (Grand Canyon) area (rkm 944 to 946; RL&L Environmental Services Ltd. 2000) and sampling in 2007 and 2008 showed that the Longworth and McGregor River confluence areas contained important rearing and overwintering areas (Lheidli T'enneh First Nation 2009). DFO (2014) defines these as critical overwintering areas for late juvenile and adult fish.

Of the three groups in the Upper Fraser DU, White Sturgeon distribution is best characterized for the Nechako River group. Sampling during the FRWSMP showed that high-use areas included the section between Isle Pierre and the Stuart River (rkm 67 to 79), the Sinkut area (rkm 115 to 117), and downstream of Vanderhoof (rKm 122 to 127). White Sturgeon were also sampled in the Stuart River, downstream of rkm 50 (RL&L Environmental Services Ltd. 2000). Subsequent extensive sampling targeted the Stuart River watershed in 2002 and 2004. Numerous sites (> 50) were sampled in Stuart River and Stuart Lake in 2002, resulting in capture of a total of six fish from both waterbodies (Toth and Yarmish 2003). Sampling in 2004 was extended to also include Tachie River, Trembleur Lake, Middle River and Takla Lake, resulting in capture of 22 fish from Stuart River, Stuart Lake and Trembleur Lake (Yarmish and Toth 2005). Migration through the Nautley River and the use of Fraser Lake are common, and adults have been observed in the lower Stellako River where they follow spawning Sockeye Salmon in August and September. Overwintering areas have been identified in the Nechako River in pools at rkm 116.2 and 124.6 (RL&L Environmental Services Ltd. 2000).

3.5. HABITAT ACCESSIBILITY CONSTRAINTS

The use of currently available habitat for the Upper Fraser DU is not constrained by physical barriers to large areas of suitable mainstem habitat. There are no physical barriers separating the three groups, although there is only limited movement between individual groups (COSEWIC 2012). The Fraser River mainstem does not have any hydroelectric developments and therefore the middle and upper Fraser River has a relatively natural hydrologic regime, and is not constrained by dams. Habitat in the Nechako River has been affected by regulation/diversion and the Kenney Dam has regulated flow in the Nechako River since the 1950s (COSEWIC 2012). Diversion has reduced flows overall, and freshet flows have been particularly affected by storage. Flow regulation was hypothesised to be a direct or indirect cause of the majority of the threats to the Nechako River group (Korman and Walters 2001); however, additional information suggests that alteration to the mainstem riverbed substrate may have been the cause of the recruitment failure in the Nechako River (McAdam *et al.* 2005). The effect of riverbed substrate alteration is considered further in Section 4.

3.6. WHITE STURGEON RESIDENCY

SARA defines a residence 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" (Statutes of Canada 2002).

The residence must support a life cycle function, there must be an element of investment in the creation or modification of the structure, and it must be occupied by one or more individuals. White Sturgeon are broadcast spawners and they do not modify their environment for the purpose of "breeding, rearing, staging, wintering, feeding or hibernating;" the concept of residence therefore does not apply.

4. THREATS AND LIMITING FACTORS TO THE SURVIVAL AND RECOVERY OF WHITE STURGEON

Twelve threats to White Sturgeon in the Fraser River are discussed in detail in Hatfield *et al.* (2004) and DFO (2014); readers are referred to those documents for a detailed description and evaluation of each threat. For completeness, the full suite of threats discussed in those documents is summarized here, although several threats are not strongly linked to the population status of the Upper Fraser DU. The level of risk posed by each threat to individual groups are summarized in Table 3, based on the results of assessments presented in DFO (2014). Additional information is provided in COSEWIC (2012), while Korman and Walters (2001) present a detailed evaluation of the potential causes of recruitment failure in the Nechako River group. Information in these documents is integrated into the threat summaries below.

This section addresses elements 8, 9, and 10 of the National Framework for Recovery Potential Assessments.

4.1. ABIOTIC THREATS TO WHITE STURGEON SURVIVAL AND RECOVERY

4.1.1. Loss of Habitat Quality and Quantity

The large rivers occupied by White Sturgeon have a variety of interlinked habitats, including main channel, tributary confluence, foreshore, seasonally-inundated, and tidal and estuarine areas. Both habitat quality and quantity have declined throughout the species' range. Changes to White Sturgeon habitat or to the habitats of prey species are believed to be directly related to impacts on recruitment and overall carrying capacity. Spawning habitat is vulnerable, particularly in the Nechako, as substantial changes to spawning habitat availability have occurred and there is limited spawning habitat remaining (McAdam *et al.* 2005). This loss and alteration of spawning habitat has been the primary cause of recruitment failure in the Nechako (McAdam *et al.* 2005). This is underscored by other evidence that early survival has a substantial effect on recruitment and total abundance (Gross *et al.* 2002). DFO (2014) assessed risk associated with habitat loss to be moderate for both the Mid-Fraser and Upper Fraser groups, and high for the Nechako River group (Table 3). This is discussed further in Section 4.3.

4.1.2. Habitat Fragmentation

Dam and reservoir construction has had a large influence on the distribution of aquatic habitat within the natural range of White Sturgeon. Such impacts do not apply to the Mid-Fraser and Upper Fraser groups as the mainstem of the Fraser River is not impounded. The Kenney Dam regulates the Nechako River but it does not fragment historic White Sturgeon habitat (DFO 2014). DFO (2014) assessed risks to be low in relation to this threat for all three groups (Table 3).

4.1.3. Altered Hydrograph Components

The life history of White Sturgeon is closely linked to river hydrology. The precise mechanisms responsible for population decline and recruitment failure are still unproven, but river regulation is heavily implicated. DFO (2014) assessed risk associated with this threat to be low for both the Mid-Fraser and Upper Fraser groups (unregulated systems), but high for the Nechako River group (Table 3), reflecting the effects of Kenney Dam.

4.1.4. Pollution

The large rivers that support White Sturgeon are the receiving waters for a wide variety of point and non-point source pollutant discharges. These discharges are introduced over a very broad geographic scale, especially in the more urbanized or industrialized areas. This concern is important because White Sturgeon are more sensitive to contaminants than other species (Bennett and Farrell 1998, Vardy *et al.* 2011). Existing and proposed oil pipeline crossings in the upper Fraser River watershed pose a potential threat to the Upper Fraser DU. Numerous mines are also present in the Upper Fraser DU and pollution from mining operations poses a potential threat to White Sturgeon.

DFO (2014) assessed risks associated with pollution to be moderate for the Mid-Fraser group, which is downstream of pulp mill effluent discharge locations in Prince George (COSEWIC 2012).

DFO (2014) assessed risks to be low for the Upper Fraser group, and low for the Nechako River group, although a proposed oil pipeline crossing of the Stuart River poses a potential threat to the Nechako River group (COSEWIC 2012). There is also potential for spills at railway crossings of the Nechako River, which is not fully captured in the low risk rating for the Nechako River group.

4.1.5. Reduced Turbidity

Drift by White Sturgeon larvae may expose them to predation, which may decrease when water is turbid (e.g., during freshet). Regulated systems tend to have reduced turbidity due to sediment settlement in reservoirs and the diminished erosive potential of lower peak flows. Since predators of sturgeon larvae are primarily visual hunters, increased water clarity in regulated systems may allow for a higher predation rate on early juveniles (i.e., less than 1 year old).

DFO (2014) assessed risks associated with this threat to be low for all three groups (Table 3). Reduced turbidity due to lower flows was assessed to be a moderately plausible explanation for recruitment failure in the Nechako River (Korman and Walters 2001). Such an effect could reduce spawning success or increase predation on juvenile fish by visual predators.

4.1.6. Fishing Effects

White Sturgeon (adults and late juveniles) are caught both intentionally and incidentally by fisheries that use a range of capture methods and gear, with effects varying by timing and gear type. Although direct harvest of White Sturgeon is prohibited in British Columbia, mortality can occur due to angling-related injuries, illegal harvest or as by-catch in aboriginal or commercial fisheries (Hatfield *et al*. 2004, COSEWIC 2012, DFO 2014). The extent of mortality related to angling is unknown, although it is likely to be low given that catch and release angling for White Sturgeon is only permitted in part of the Mid-Fraser group's range, and research in the lower Fraser River has shown that direct mortality of angled fish is extremely low (<0.012%, Robichaud *et al*. 2006). Prior to 2009, the extent of mortality associated with by-catch in the Upper Fraser DU was unknown. However, since then, annual by-catch monitoring of the First Nation food, social and ceremonial salmon fishery has been underway in the Nechako River watershed, which provides some indication of the magnitude of mortality associated with by-catch (described below).

For the Mid-Fraser group, DFO (2014) assessed risks associated with fishing to be moderate (Table 3). A catch and release recreational fishery is present in the lower reaches of the middle Fraser River, downstream of Williams Lake River (COSEWIC 2012). All fishing for White Sturgeon is prohibited upstream of this point. For the Upper Fraser group, DFO (2014) assessed risks associated with fishing to be low (Table 3); however, the amount of illegal harvest is unknown.

For the Nechako River group, DFO (2014) assessed risks associated with fishing to be moderate (Table 3). The most recent annual by-catch monitoring data correspond to 2013; these show that 14 White Sturgeon were released alive, while three mortalities were reported (Nechako White Sturgeon Recovery Initiative 2014). Mortality due to illegal harvest is unknown.

4.1.7. Altered Thermal Regime

White Sturgeon metabolic rates are directly related to water temperature, so changes to temperature may affect multiple aspects of sturgeon biology. Temperature has also been implicated in terminating pre-spawning behaviour at certain locations (e.g., Paragamian *et al.* 2001). Increased winter temperatures along with higher flows may impact winter survival, although this has not been investigated yet. Recently, it has been hypothesized that high summer water temperatures in the middle and upper Fraser River and the Nechako River are causing indirect effects on White Sturgeon by impeding the upstream migration of Sockeye Salmon. Sockeye Salmon are an important food source for White Sturgeon and the majority of Sockeye Salmon Conservation Units in the Upper Fraser DU have been designated as being in poor (red) biological status (DFO 2012).

DFO (2014) assessed risks associated with this threat to be low for all three groups (Table 3). The potential for changes to the natural thermal regime is most limited for the Mid-Fraser and Upper Fraser groups as the Fraser River is unregulated. However, localized changes may still occur in relation to effluent discharge or, more generally, due to climate change, as described above in relation to Sockeye Salmon.

For the Nechako River group, Korman and Walters (2001) deemed it moderately plausible that alterations to the thermal regime in relation to river regulation are the cause of the recruitment failure due to impacts to spawning cues or the bioenergetic requirements of juvenile White Sturgeon. However, more recent data collected as part of the Nechako White Sturgeon Recovery Initiative show that spawning appears to be occurring regularly (i.e., spawning cues exist) and gametes are viable (Nechako White Sturgeon Recovery Initiative 2014).

4.2. BIOTIC THREATS TO WHITE STURGEON SURVIVAL AND RECOVERY

4.2.1. Effects of Small Population Size

There are significant risks to long-term viability when populations are small, even when habitat and food resources are not limiting. For example, small populations are more susceptible to random demographic and environmental variability, and mortality can begin to increase as the population declines below a specific abundance threshold (Allee effect), due to changes in predation or mating success. DFO (2014) assessed risks associated with this threat to be high for the Upper Fraser group, moderate for the Mid-Fraser group and high for the Nechako River group (Table 3), reflecting the relative sizes of these groups.

4.2.2. Hatchery and Aquaculture Effects

Hatchery effects are well-known for salmon and other species with captive breeding programs (Rand *et al*. 2012). There are specific risks to naturally-reproducing White Sturgeon from conservation and commercial aquaculture programs, including population effects, genetic effects, and disease transfer. There is also concern regarding imprinting behaviour and whether hatchery-reared fish will be able to find or select suitable spawning locations at maturity.

DFO (2014) assessed risks associated with this threat to be moderate for all three groups (Table 3). There are no White Sturgeon hatchery operations within the ranges of the Mid-Fraser and Upper Fraser groups. However, a conservation aquaculture program is underway on the Nechako River and there is some concern that cultured fish could mix with downstream groups, causing adverse effects due to genetic introgression (Hatfield *et al*. 2004). The likelihood of this is considered low, primarily due to the limited movement that has been observed between groups (Nechako White Sturgeon Recovery Initiative 2005). The Nechako Technical Working Group has specifically taken steps to monitor and adaptively manage risks associated with this threat; these include: locating the fish culture facility near the spawning reach, using local river water to aid imprinting, and monitoring movements of released hatchery fish. Participants at the RPA workshop indicated that the stated risk of this threat is overestimated due to the adaptive program of hatchery releases and the explicit aim to avoid swamping the other groups within the metapopulation with large numbers of hatchery fish (McAdam, pers. comm. 2016[1]). In addition, habitat restoration in the Nechako could yield some benefit by improving wild recruitment and thereby reducing the necessity for hatchery fish.

4.2.3. Reduced or Altered Food Supply

The elimination, reduction, or alteration of White Sturgeon prey base may have important effects on White Sturgeon abundance and distribution. Potential causes of a decline in food supply are numerous and include: climate change, overharvesting, and habitat loss. Historically, significant reductions in important food sources for White Sturgeon in the Upper Fraser DU are known to have occurred, most notably of spawning salmon (DFO 2012) and Pacific Lamprey (see Section 3.2 for overview of main food sources). DFO (2014) assessed risks associated with this threat to be high for all three groups (Table 3).

4.2.4. Change in Ecological Community

Increased predator and/or competitor abundance may be an important threat to White Sturgeon. This could include shifts in native fauna and/or introduction of non-native species. Risks associated with this threat have been assessed as low for all three groups DFO (2014) (Table 3).

For the Nechako River group, predation due to increased Cyprinid abundance was initially deemed to be a highly plausible cause of the recruitment failure (Korman and Walters 2001). Results from subsequent research indicate a reduced likelihood that this is an important factor (DFO 2014), although initial results from unpublished juvenile monitoring show that increased predation cannot yet be ruled out as a causal factor of the recruitment failure in the Nechako River.

4.2.5. Disease

Several parasites and diseases of White Sturgeon are known to be present in British Columbia, and additional pathogens may be introduced. Diseased juvenile sturgeon are regularly encountered in the lower Fraser, and some testing has been conducted, but the causes of disease have not been isolated. (Erin Stoddard, pers. comm. 2015[4]). In the Upper Fraser DU, this threat is deemed relatively low risk to all three groups (DFO 2014, Table 3).

Table 3. Summary of threats to White Sturgeon in the Upper Fraser DU, with associated risks to individual groups. Risk levels reflect assessed severity of impacts; categories are: negligible, low, moderate, high, unknown. Reproduced from DFO (2014).

Threat		**Level of Relative Risk**		
Stressor	**Activity**	**Middle Fraser**	**Upper Fraser**	**Nechako**
Abiotic				
Habitat loss	Flow regulation, sand/gravel extraction, land use change, flood risk management works	Moderate	Moderate	High
Habitat fragmentation	River impoundment, dyke construction	Low	Low	Low
Altered hydrograph components	Flow regulation, climate change	Low	Low	High
Pollution	Point sources (e.g., pulp mill effluents) and non-point sources (e.g., agricultural runoff)	Moderate	Low	Low

[4] Erin Stoddard, Ecosystem Biologist, BC Ministry of Forests, Lands and Natural Resource Operations, Vancouver, BC

Threat		Level of Relative Risk		
Stressor	**Activity**	**Middle Fraser**	**Upper Fraser**	**Nechako**
Fishing and industrial effects	Fishing: poaching, by-catch Industrial effects: interactions with industrial facilities	Moderate	Low	Moderate
Reduced turbidity	Flow regulation	Low	Low	Low
Altered thermal regime	Flow regulation, climate change	Low	Low	Low
Biotic				
Effects of small population size	Anthropogenic factors causing recruitment failure	Moderate	High	High
Hatchery and aquaculture effects	Conservation or commercial aquaculture	Moderate	Moderate	Moderate
Reduced or altered food supply	Multiple: e.g., fishing, climate change, land use change	High	High	High
Change in ecological community	Multiple: e.g., fishing, species introductions, climate change	Low	Low	Low
Disease	Multiple: e.g., aquaculture, climate change, pollutant stressors	Low	Low	Low

4.3. ACTIVITIES LIKELY TO THREATEN STURGEON HABITAT PROPERTIES

The large rivers occupied by White Sturgeon have a variety of interlinked habitats, including main channel, tributary confluence, and seasonally-inundated areas. Both habitat quality and quantity have declined throughout the Upper Fraser DU and, as described in Section 4.1.1 above, there is a range of threats to habitats within the Upper Fraser DU that vary in extent and potential consequence between the three groups.

Human development poses a threat to White Sturgeon habitats; this includes developments associated with: residential and commercial developments; agriculture; energy production and mining; transportation and service corridors, and; recreational activities (Salafsky *et al*. 2008). Generally, development pressures are relatively low in the Upper Fraser DU, e.g., compared with the Lower Fraser DU. However, this is not always the case, and the threat posed by specific developments is higher for some groups, e.g., energy production for the Nechako River group. The partial network of dykes in the Prince George region potentially impacts habitat for all three groups, although dykes are less extensive there than in the floodplain of the lower Fraser River (COSEWIC 2012).

Pollution poses a threat and the upper Fraser River watershed receives a wide variety of point and non-point source pollutant discharges over a broad geographic scale. These include point source discharges from pulp mills, industrial plants, treated and untreated municipal and private sewage, and various other industrial, agricultural and urban discharges, as well as non-point sources of pollution from agriculture, forestry, and urban areas. Aquatic species are at risk when water conditions degrade beyond specific thresholds for oxygen, temperature, pH, or pollutants. The main pollutant point sources in the upper Fraser River are effluent discharges from pulp mills in Prince George and Quesnel (Hatfield *et al*. 2004).

Natural factors also pose a threat to White Sturgeon habitats; these include climate change, severe weather and geological events (Salafsky *et al*. 2008). The risk posed by these threats to White Sturgeon in the upper Fraser DU has received relatively little attention, although one example is disruption of adult Pacific salmon migration due to high summer water temperatures, as discussed in Section 4.1.7.

Threats to White Sturgeon habitats that are specific to the Mid-Fraser group include effluent from pulp mills near Prince George (COSEWIC 2012). In addition, there are numerous major mining operations in the middle Fraser River (e.g., Gibraltar and Mt. Polley mines). There are general concerns regarding the potential for such operations to adversely affect fish populations in the middle Fraser River (Komori 1997), and pollution associated with mining is a potential threat to White Sturgeon habitats.

White Sturgeon habitats used by the Upper Fraser group are the most pristine of all those in either the Upper Fraser or Lower Fraser DUs (COSEWIC 2012).

Unlike the Fraser River, flow in the Nechako River is regulated by the Kenney Dam. There is strong evidence that flow regulation has affected habitats for the Nechako River group, although the impact pathways involved are uncertain (Korman and Walters 2001).

Recent work has shown that increased substrate degradation is likely to be an important cause of the recruitment failure in the Nechako River group. McAdam (2011) examined drift rates, hiding behaviour and predation rates for White Sturgeon (yolksac larvae) in the Nechako River, and showed that substrate degradation due to deposition of fine sediments on porous substrates can have a significant adverse effect on larval survival. Fine sediment deposition is known to be an issue at the spawning reach on the Nechako River near Vanderhoof and therefore this process likely poses an important threat to spawning and early juvenile habitats. Substrate degradation is potentially related to flow regulation (Korman and Walters 2001); however, analysis of the chronologies of the recruitment failure and flow regulation show that any link between flow regulation and sediment degradation is indirect (McAdam *et al*. 2005). Instead, reworking of local bedload sediment sources and upstream avulsions (i.e., major sediment erosion events) have been shown to be more direct causes of adverse geomorphological changes to main channel habitats (McAdam *et al*. 2005, Northwest Hydraulic Consultants 2013). This has been followed up with lab studies that demonstrated that substrate porosity influences larval drift behaviour and may influence survival of larvae (McAdam *et al.* 2011). This result was validated with field studies that demonstrated higher larval survival in gravel substrate sites than in embedded substrate sites (McAdam 2012). This work led to the addition of two gravel spawning pads in the Nechako River near Vanderhoof to improve habitat conditions within the Nechako River for White Sturgeon (Nechako White Sturgeon Recovery Initiative 2012).

There is a proposed oil pipeline crossing on the Stuart River, which is known to be an important habitat for the Nechako River group COSEWIC (2012). Pipelines pose a potential threat due to construction impacts and potential spills (COSEWIC 2012). Pollution from mining operations poses a potential threat to White Sturgeon in the Nechako River and there are two active metal mines in the Nechako River watershed (Fraser Basin Council 2015).

4.4. NATURAL LIMITING FACTORS

The intrinsic biological factors most limiting to White Sturgeon population growth are very low early survival and delayed maturation. Gross *et al.* (2002) undertook an elasticity analysis on White Sturgeon life history parameters, which indicated that population growth is most sensitive to changes in early survival rates. Changes in survival of older fish and changes in fecundity had considerably less effect on population growth. The late maturity of White Sturgeon can result in long time lags between changing physical or biological parameters and population response, especially when the number of mature fish is limited (Wood *et al.* 2007). A wide variety of natural factors (e.g., temperature, habitat availability, hydrology, etc.) cause variable recruitment, which can lead to variable population growth. Although human factors have caused a general decline in food availability for White Sturgeon (e.g., Pacific Lamprey; COSEWIC 2012), it is likely that food availability has greater potential to be a natural limiting factor in the Upper Fraser DU, compared to the Lower Fraser DU where sturgeon have access to a greater range of food sources.

4.5. POTENTIAL ECOLOGICAL IMPACTS OF IDENTIFIED THREATS

The ecological implications of threats identified as "high risk" (DFO 2014) include habitat loss, and in particular the continued (or worsening) impairment of habitats believed to be causing recruitment failure in the Nechako. The benefits of restoring habitat function would include the restoration of natural recruitment of the Nechako White Sturgeon group. It is assumed that restoring White Sturgeon habitat and recruitment would benefit the overall ecological health of the Nechako River.

Any habitat alteration, disturbance or destruction that adversely affects recruitment within the Upper and Mid-Fraser and Nechako groups would be detrimental to achieving the targets identified in the recovery strategy (DFO 2014). Maintenance of habitat function and productivity would support the maintenance of many other aquatic species within the distribution of the Upper Fraser DU.

Similarly, any increase in human-induced mortality to the Upper and Mid-Fraser groups would adversely affect recruitment, and would be detrimental to achieving the recovery targets (DFO 2014). Maintaining White Sturgeon abundance targets in the Upper and Mid-Fraser is assumed to support the ecological health of the aquatic community as a whole.

Any increase in human-induced mortality to the Nechako group would be detrimental to achieving the abundance and recruitment targets identified in the recovery strategy (DFO 2014). Any decrease in the remaining number of adults within the Nechako decreases the potential availability of brood stock to support conservation fish culture objectives and decreases the number of potential contributors to wild spawning and juvenile recruitment.

5. MITIGATION MEASURES AND ALTERNATIVES TO ADDRESS THREATS TO UPPER FRASER WHITE STURGEON DU

This section addresses elements 15, 16, and 21 of the National Framework for Recovery Potential Assessments.

DFO (2014) describes a number of research and management activities needed to meet recovery targets for White Sturgeon across their range in Canada; we reduced the list to those of immediate relevance to the Upper Fraser DU (Table 4). The actions fall into broad categories of protecting critical habitats, clarifying and mitigating threats, increasing public awareness, and maintaining ecosystem functions. The actions will undoubtedly address some of the ongoing threats to this DU (Table 3); however, it is likely that fully mitigating the threats would require substantial investment, such that implementation of all measures may not be feasible.

The activities listed in Table 4, particularly those in the categories of protecting critical habitats, and clarifying and mitigating threats, have the potential to maintain or increase habitat productivity and to improve survivorship. Survivorship may be improved with additional limits to direct effects (e.g., poaching) and indirect effects (e.g., by-catch, latent mortality) of fishing. However, regulations are already in place to limit these effects on White Sturgeon. Other positive effects on survivorship may accrue through improvements to effluent discharges, but the effects of pollutants on survivorship and the potential for improvement to survival have not been quantified.

The potential for productivity increases through habitat improvements is likely limited by urban, agricultural and flood control development throughout the upper Fraser River. Undoubtedly, opportunities exist for habitat restoration or enhancement, but the scope is likely limited. Habitat improvements as considered to be a key mitigation measure and habitat improvements will be considered at a group level rather than at the DU scale.

Management actions to address threats to White Sturgeon (Table 4) are likely to have benefits to a broad range of aquatic species in the Upper Fraser River DU. At this time there are no obvious trade-offs with other ecological values, although potential for trade-offs may need to be explored when detailed plans are being developed for specific actions.

Table 4. Actions intended to mitigate threats to, and encourage conservation of, the Upper Fraser White Sturgeon DU. Actions from DFO (2014).

Strategy	**Actions**
Protect critical habitats	1. Protect, maintain, and enhance critical habitat for White Sturgeon. 2. Ensure habitat diversity, connectivity & productivity. 3. Work cooperatively to develop plans to protect habitat
Natural recruitment[1]	1. Examine potential mechanism of recruitment effect. 2. Undertake meso-scale and large scale field trials. 3. Determine habitat requirements for dam-affected population enhancement or recovery. 4. Initiate, within 5 years, pilot studies towards restoration of natural recruitment for each population that is affected by dams. 5. Within 10 years, identify methods for each population, that if and when implemented, can restore recruitment to a level sufficient to achieve the other recovery measures.
Clarify and mitigate threats	1. Clarify the follow threats and their relative risks: a. fishing; b. pollution; c. predation; d. food supply; and e. habitat. 2. Undertake specific actions to manage risks: a. protect, maintain, and enhance critical habitat; b. manage illegal harvest; c. minimize bycatch and mitigate impacts from fisheries through regulation and best practices; d. limit and manage pollutant discharges and contaminant loading, especially adjacent to important or critical habitats; e. protect, maintain and enhance water quality; and f. better understand, maintain and enhance food availability for all life stages of each population. 3. Monitor threat indicators and population trends. 4. Work cooperatively to develop plans to mitigate threats to White Sturgeon
Increase stakeholder and general public awareness of White Sturgeon and its conservation needs.	1. Maintain and where possible increases awareness and stewardship of White Sturgeon throughout its natural range. 2. Engage in effective public education of the species and its conservation needs.

Strategy	Actions
Maintain and where necessary restore ecosystem functions relevant to White Sturgeon	1. Incorporate the needs of health White Sturgeon populations into the management of White Sturgeon prey species, especially salmon and resident sportfish. 2. Closely manage non-native predatory fish species.

[1] Strategy applicable for Upper Fraser and Nechako groups.

6. RECOVERY TARGETS FOR WHITE STURGEON

This section addresses element 11 of the National Framework for Recovery Potential Assessments.

The National Recovery Strategy for White Sturgeon (DFO 2014) cites McElhany *et al.*'s (2000) definition of a viable population as one "that has a negligible risk of extinction due to threats from demographic variation (random or directional), local environmental variation, and genetic diversity changes (random or directional) over a 100-year time frame." The Recovery Strategy set a range of population targets for other populations that are consistent with this definition of a viable population. The aim is to reach these targets within 50 years. Consistent with this, we considered a time frame of 50 and 100 years for modelling purposes. Such a time frame is relevant to the perspectives of managers, yet is still biologically relevant to White Sturgeon as it would encompass at least two full generations of this long-lived species. Considerably longer time frames would be required for populations to reach equilibrium abundances in response to management actions.

Viability reflects abundance, population growth rate, population structure and population diversity (McElhany *et al.* 2000). We propose only abundance and distribution targets here, but provide a brief description of these other considerations. It is important to note that although these recovery targets may be assessed independently, a loss in any one recovery component is deemed an overall failure.

It is important to recognize that these targets will focus on recovery or population survival for the different groups in the Upper Fraser DU. Since both the Mid-Fraser and Upper Fraser groups are believed to be near their historical abundances (DFO 2014) and stable, targets provided in this section are for population survival, since the focus of management effort is maintaining these groups.

The Nechako River group is different in that it has experienced a decline in abundance due to recruitment failure. The primary interest for this group is therefore recovery rather than population survival. The current estimate of the Nechako adult population is 630 (based on a median of model predictions; Carruthers *et al*. in preparation[2]); however, this estimate does not reflect a healthy population since younger adult cohorts are absent due to recruitment failure (RL&L Environmental Services Ltd 2000, Korman and Walters 2001, French *et al*. 2004). Using the age structure from historical samples, which is assumed to be natural or close to natural, the Nechako adult population was estimated to be approximately 1,600 in 1967.

6.1. ABUNDANCE

The minimum population abundance required to maintain moderate to long-term viability of vertebrate species in general has been estimated as 7,000 adults based on a review of modelling results for a range of species (Reed *et al*. 2003). Estimates in this study were relatively consistent between taxa, although they were substantially larger for species with slower growth rates. For White Sturgeon populations, the National Recovery Strategy presents a target of ~10,000 mature reproductive individuals as an estimated abundance for medium to long-term persistence (DFO 2014). This value was used as an abundance target in the lower Fraser in the Fraser River White Sturgeon Conservation Plan (Fraser River White Sturgeon Working Group 2005) and the draft Lower/Mid-Fraser White Sturgeon Provincial Conservation and Management Five-Year Strategic Action Plan (Sue Pollard, pers. comm. 2015[5]). Since the Upper Fraser DU is composed of three groups with some exchange between them, an abundance target of 10,000 adults would be inappropriate for each of the three separate groups. This is because declines in abundance in one group can be compensated by migration from other groups that experience increases, thus reducing the likelihood of extinction of a single group. In this DU, the extinction of a single group is considered a failure; therefore a grouped abundance target would be inappropriate for the Upper Fraser DU. In addition, groups in the Upper Fraser DU have naturally low abundance (i.e., carrying capacity) relative to other populations. For example, although the Mid-Fraser and Upper Fraser groups have relatively low abundances (749 and 185 mature fish, respectively), these populations are considered to be within their historical abundance ranges, which are likely naturally limited by suitable habitat (DFO 2014). The abundance targets listed for the Mid-Fraser and Upper Fraser groups are to maintain the current abundance of mature fish (DFO 2014). Therefore, abundance targets for these two groups should reflect their current abundances.

As noted above, the Nechako River group has experienced a decline in abundance that reflects recruitment failure. The current estimate of the Nechako adult population is 630 (based on a median of model predictions; Carruthers *et al*. in preparation[2]); however, this estimate does not reflect a healthy population as younger adult cohorts are absent from the population due to recruitment failure (RL&L Environmental Services Ltd 2000, Korman and Walters 2001, French *et al*. 2004). Assuming that age cohorts that were historically sampled reflected the natural population structure prior to the recruitment failure, the total abundance was back-calculated to estimate the abundance of adult White Sturgeon prior to the recruitment failure approximately 50 years ago. Based on this calculation, the Nechako adult population was approximately 1,600 in 1967; which is close to the recovery target of 1,000 mature individuals as outlined in the recovery strategy (DFO 2014). To be consistent with the recovery strategy, we have identified 1,000 mature individuals as our recovery target.

6.2. DISTRIBUTION

As noted in Section 2.2, the Upper Fraser DU occurs in the mainstem Fraser River upstream of Hells Gate, as well as the Nechako River and Stuart River. Within the Upper Fraser DU, the three groups are: the Mid-Fraser group downstream of the Nechako River confluence; the Upper Fraser group upstream of the Nechako River confluence, and; the Nechako River group. The distribution target for this RPA is to maintain the current geographical distribution of these three groups.

In addition to abundance, our population modelling considered the following three factors, which the national Recovery Strategy (DFO 2014) specifies should be considered when assessing viability:

> **Population Growth**: ongoing natural recruitment, and increasing trend in abundance when a population is below the abundance target.
>
> **Population Structure**: natural sex ratio (currently defined as 1:1), and natural age structure.

[5] Sue Pollard, Rivers Management Specialist, BC Ministry of Forests, Lands, and Natural Resource Operations, Victoria, BC

Population Diversity: to be maintained by ensuring a sufficient spatial and temporal array of habitat types, that dispersal among them is not altered, and general processes that give rise to diversity are maintained over the natural range of White Sturgeon.

Although these targets are identified within the Recovery Strategy (DFO 2014), we focused on abundance targets in the modelling exercise.

7. METAPOPULATION WHITE STURGEON MODELS

This section addresses elements 3, 12, 13, 14, 18, 19, 20, and 22 of the National Framework for Recovery Potential Assessments.

7.1. MODEL STRUCTURE

For the RPA, we used the White Sturgeon model presented in Appendix 2 of Wood *et al.* (2007) but added a metapopulation structure, which allows for exchange between the three groups in the Upper Fraser DU. A diagram of the model structure is shown in Figure 4 while parameter values for our model are discussed further below. Our model represents each group as having the potential to be self-sustaining, based on a stock recruitment formula represented by the blue curved arrow.

A key component of the metapopulation model structure is adult exchange between groups (represented by black arrows with Mxx-yy, where xx represents the source group and the yy represents the destination group). The metapopulation dynamic of the DU is unknown as some studies within the Upper Fraser and surrounding DUs have shown the presence of resident groups (Nelson and McAdam 2012), while other studies show a split between resident and non-resident movement types in the Lower Fraser DU (Beardsall and McAdam 2016[6]). Genetic analysis from Schreiers (2012) suggests that there may be some modest genetic distinctions between the Mid-Fraser group and the Nechako River group; however, the Upper Fraser group comprised a “mixing” zone of fish from the Nechako and Mid-Fraser groups. This information suggests that there is some level of gene flow among the three groups; however, the extent of exchange is still unknown. Movement through Hell’s Gate has also been observed, suggesting genetic mixing between the Lower Fraser River DU and the Mid-Fraser group (RL&L Environmental Services Ltd 2000); however, immigration or emigration from the Upper Fraser DU was not considered in this model structure.

Movement between groups could conceivably result in fish moving between groups for feeding or non-spawning habitat (demographic exchange), moving between groups for spawning only (genetic exchange), and moving between groups for spawning and remaining within the group (immigration). In the model structure used here, we considered only immigration and therefore only mature fish are assumed to move from one group to another and join the group permanently. All migrant individuals were included in the carrying capacity and fecundity calculations for subsequent years. It is important to recognize that this assumption may not represent all movement that occurs between groups.

The groups are subject to population alteration processes that include stocking hatchery fish (Hatch), adjustments to human-induced mortality (HM), and adjustments to the larval/juvenile habitat productivity (Habt) which are also included in Figure 4. Stocking can increase production in the group and is represented by the green arrows labelled Hatchx where x represents the

[6] Beardsall, J. and D.S.O. McAdam. 2016. Spatial distribution of lower Fraser River White Sturgeon (*Acipenser transmontanus*): recapture database spatial analysis technical report. Prepared for the BC Ministry of Environment. 88pp.

group. Currently, stocking is only applied to the Nechako group. Adjustments to human-induced mortality can alter survival in the group through altering the extent of harvest or bycatch; this is represented by the red arrow labelled HMx, where x represents the group. Human-induced mortality was applied to all three sturgeon groups. Finally, adjustments to larval/juvenile habitat productivity (Habt) can alter productivity of the group through destruction or restoration of sturgeon spawning habitat within the DU; this is represented by the green arrows labelled Habtx, where x represents the group. As with HM, habitat productivity is applied to all three sturgeon groups.

The majority of formulas from Wood *et al.* (2007) were left intact to calculate the abundance of White Sturgeon under different management scenarios. To calculate the number of fish at age *a* alive at year *t*, the following formula was used:

$$N_{a,t} = N_{a-1,t-1}S(1 - V_a HM)$$

Where *S* is the annual age-independent survival rate, V_a is the age-specific vulnerability to human-induced mortality, and *HM* is the human-induced mortality rate. The formula to calculate the age-specific vulnerability to human-induced mortality was:

$$V_a = \frac{\alpha^{\tau_v}}{\mu_V{}^{\tau_V} + \alpha^{\tau_v}}$$

Where μ_v is the age at which vulnerability is 0.5, and τ_v is the slope of the relationship.

Equation 3 from Wood *et al.* (2007) was adjusted to remove input of hatchery fish and is now represented as:

$$N_{1,t} = Hab_t \frac{\alpha E_t}{1 + \beta E_t} e^v$$

Where $N_{1,t}$ is the number of age-1 recruits, Hab_t is a recruitment multiplier used to simulate improvements from larval/juvenile habitat supplementation, E_t is the relative egg deposition in year *t*, α and β are the slope and density-dependent terms of the stock recruitment relationship, and *v* is an annual random deviate drawn from a normal distribution with mean 0 and a standard deviation of σ_r.

Stocking in the Upper Fraser DU is only planned for the Nechako group, so this population supplementation parameter is only required for the Nechako group. The stocking program is planned to be optimally executed, where releases of juveniles will reach but not exceed historical adult production. This is further described in Section 7.2.2.

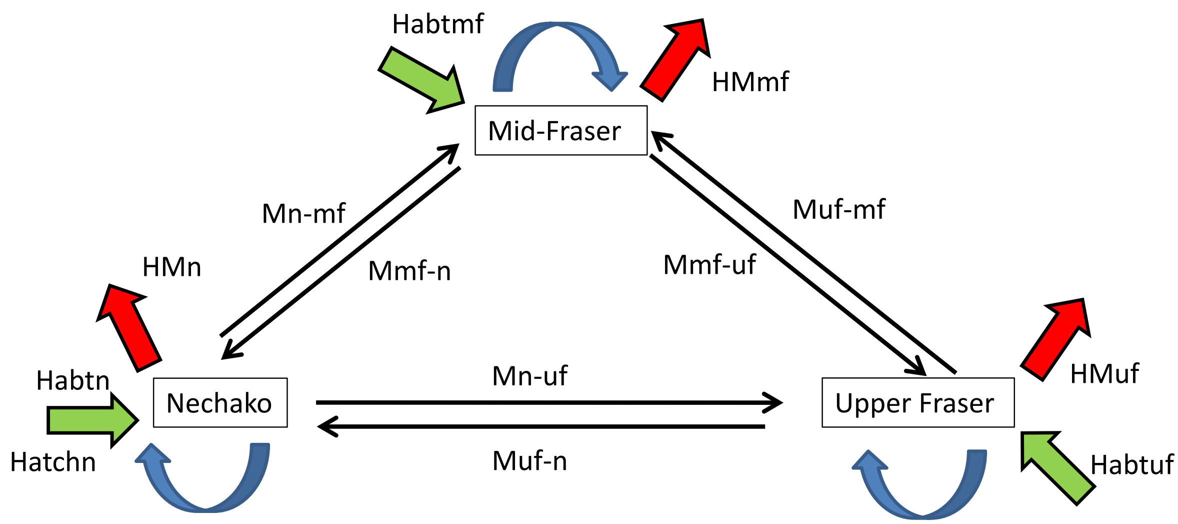

Figure 4. Metapopulation model for Upper Fraser DU.

7.2. MODEL PARAMETERS

Two classes of parameters are incorporated in the model structure: life history parameters that are based on sturgeon life history and allow the population to remain self-sustaining, and population alteration parameters that are based on management actions and can increase or decrease the abundance. These classes of parameters and their corresponding values are discussed further below.

7.2.1. Life History Parameters

The key life history parameter values used in the model are presented in Table 5. For some parameters, there are group-specific values, while a single value is used for other parameters to represent all groups. The values from the Wood *et al*. (2007) RPA are used, but group-specific values are provided where appropriate. Group-specific values were collected from the literature or were based on expert opinion as indicated in the table. The survival and the fish growth values differ among groups and the values from Wood *et al*. (2007). These differences in individual fish growth directly affect size at age (Figure 5) which, in turn, affects age at 50% vulnerability but also weight at age (Figure 6), which affects the maximum number of eggs deposited by each individual fish.

The only life history parameter not included in Table 5 is exchange rate between groups. Due to the high uncertainty of the magnitude and extent of exchange between groups in the Upper Fraser DU, this parameter is not a single fixed value in the model structure and is explored further in multiple model scenarios. This is described further in Section 7.3.

The values in Table 5 highlight the variation between parameter values among the group-specific values as well as among these group-specific values and the values from Wood *et al*. (2007). Although the life history values differ slightly between the group-specific values and the values from Wood *et al*. (2007), this difference has little to no effect on the population trends. Based on this result, we only used the group-specific values in the current analysis. If new or better estimates are available, the models should be re-run.

Table 5. Parameter values for the Upper Fraser DU model.

Parameter Description	All - Wood *et al.* (2007)	Middle Fraser	Upper Fraser	Nechako
Annual Survival	0.923	0.96[a]	0.96[a]	0.96[a]
Adult carrying capacity based on current Hab_t	-	749[b]	185[b]	0[c]
Goodyear compensation ratio	5	-	-	-
Standard deviation of age-1 recruitment	0.6	-	-	-
Brody growth (length-at-age) coefficient	0.0231	0.034[d]	0.027[e]	0.034[d]
Asymptotic length	412.8	300[f]	237[e]	300[g]
Weight at 100 cm (kg)	7	9.3[e]	6.8[h]	7.0[h]
Length at first maturity (cm)	165	153[e]	165[i]	165[i]
Age at 50% senescence	80	-	-	-
Slope of age-senescence relationship	5	-	-	-
Age at 50% vulnerability	7.7	7.7[j]	14.9[j]	7.7[j]
Slope of age-vulnerability relationship	5.1	-	-	-
Current Adult Abundance	-	749	185	630

[a] Range of values has been shown to be 0.92-0.98 from Carruthers in prep[2]; however, recommendations have been provided that suggest adult survival should be closer to 0.96-0.98 (Steve McAdam, pers. comm. 2016[1]; Lee Williston, pers. comm. 2016[7]). Since this incorporates survival of all fish >1+, we will use 0.96.

[b] DFO 2014

[c] Value is based on complete recruitment failure. Although there is some natural production observed in the Nechako, it is sporadic, and overall, is unable to maintain the population. Therefore, the natural production is considered to be effectively 0 (Cory Williamson, pers. comm. 2016[8]).

[d] Value is generated by back-calculating von Bertalanffy formula to determine the K value for a 100 yr old fish to reach 290 mm.

[e] RL&L 2000

[f] Value is based on observations in mid-Fraser that largest fish found was 290 mm (Lee Williston, pers. comm. 2016[7]). To achieve this value, asymptotic length was estimated at 300 mm.

[g] Value is based on observations in Nechako that largest fish found was 290 mm (Cory Williamson, pers. comm. 2016[8]). To achieve this value, asymptotic length was estimated at 300 mm.

[h] Value based on length-weight relationships from unpublished Nechako database which includes Nechako and upper Fraser fish.

[I] Value was assumed to be similar to values reported in Wood *et al.* (2007).

[j] Based on reaching the 67 cm length as per Wood *et al.* (2007)'s value.

[7] Lee Williston, Fisheries Biologist, BC Ministry of Forests, Lands, and Natural Resource Operations, Williams Lake, BC

[8] Cory Williamson, Hatchery Manager, Freshwater Fisheries Society of BC, Prince George, BC

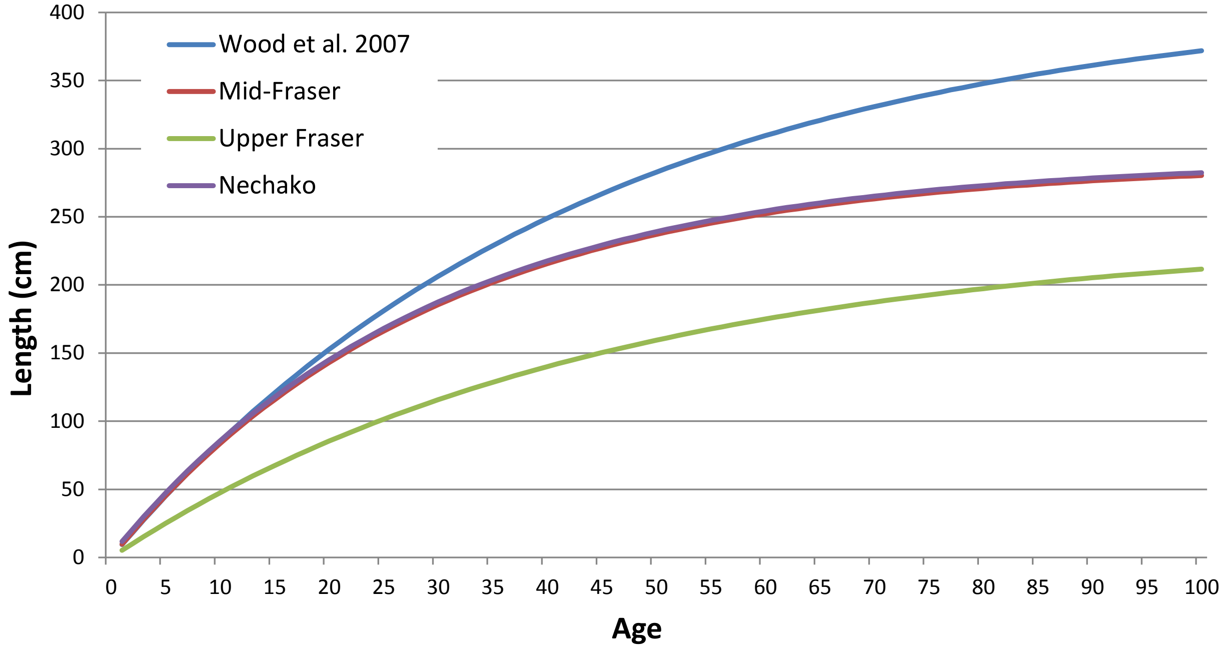

Figure 5. Length at age plots for the trends used for the Mid-Fraser, Upper Fraser, and Nechako groups. For comparison the values generated from the Wood et al. (2007) parameter values are also shown.

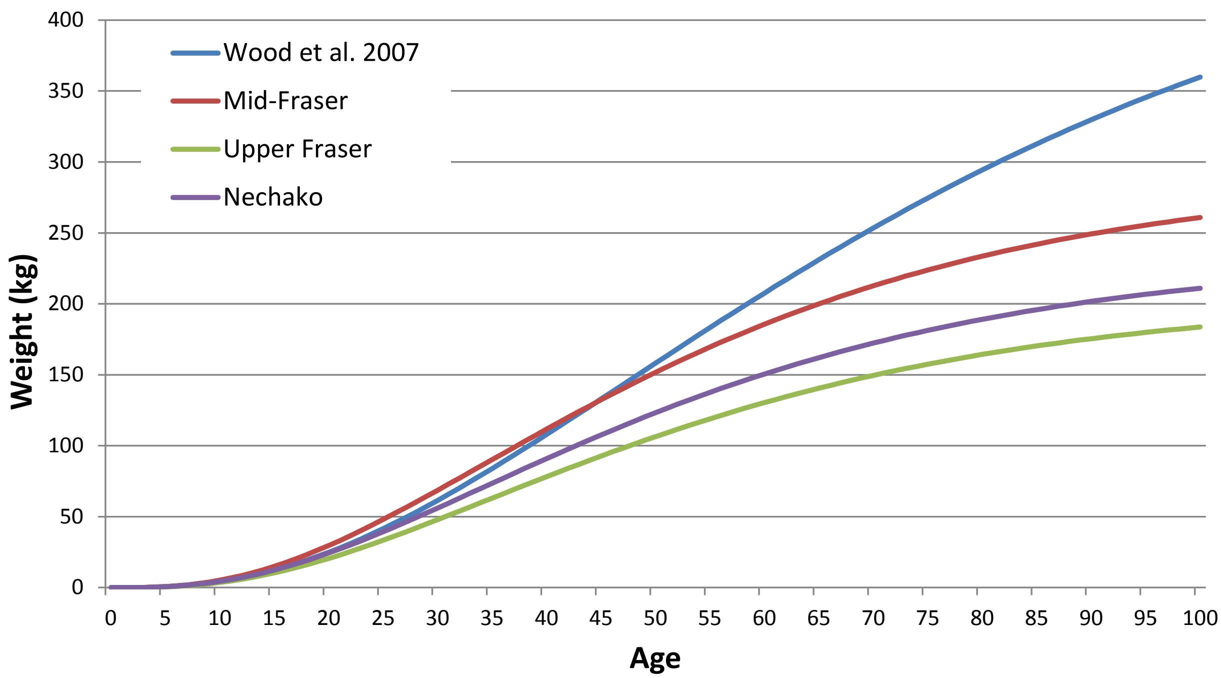

Figure 6. Weight at age plots for the trends used for the Mid-Fraser, Upper Fraser, and Nechako groups. For comparison the values generated from the Wood et al. (2007) parameter values are also shown.

7.2.2. Population Alteration Parameters

The population adjustment parameters include changes in stocking releases (S), larval/juvenile habitat productivity (Hab_t) and human-induced mortality (HM). These parameter values are based on adjustments to the sturgeon population from management actions.

Stocking in the Upper Fraser DU is only planned to occur for the Nechako group and therefore, this population supplementation parameter is only required for the Nechako group. Although numbers of released stocked fish in the Nechako has ranged from 46 individuals to 4,233 individuals in a year (Cory Williamson, pers. comm. 2016[8], Unpublished Data), the objective is to release up to 12,000 juvenile fish a year into the Nechako (Freshwater Fisheries Society of BC 2015). The stocking program is planned to be optimally executed with releases of juveniles to reach but not exceed historical adult production. The stocking program is planned to occur for 20 years, or less, if natural recruitment can be restored or limitations to hatchery operations occur. Using this information and assuming a stable age distribution for the Nechako group based on the historical adult abundance, we assumed that the annual maximum production of age-1 juveniles would be ~200 individuals. If natural production generated age-1 abundances less than 200 individuals, then it was assumed that stocking activities would supplement production to allow age-1 abundance to reach 200 individuals.

Hab_t is calibrated such that a value of 1.0 reflects the abundance at equilibrium. The Mid-Fraser and Upper Fraser groups are hypothesized to currently be at or near equilibrium, so their current Hab_t is equal to 1.0. The Nechako group has experienced near complete recruitment failure and the population is currently crashing. Based on this recruitment failure and current hypothesized carrying capacity due to the lack of viable spawning habitat (Table 5), the current Hab_t value for Nechako was assumed equal to 0.0. We used the estimated historical carrying capacity of 1,628 adults to represent the carrying capacity at Habt = 1.0 which is based on back-calculations of fish abundance. This estimate was based on the assumption that fish older than 46 years reflect the population structure and productivity prior to any substantial human productivity alteration. Using the population structure of these older fish from RL&L Environmental Services Ltd (2000) to validate this assumption, we used the abundance of fish 46 years old and older and the annual survival rate (Table 5) to calculate the estimated historical carrying capacity.

Similar to Hab_t, the current values of HM are required to calibrate the model. Although there is limited information on the current values of HM, estimates of HM for Mid-Fraser (0.006), Upper Fraser (0.004) and Nechako (0.005) were used based on discussions and comments from participants in the RPA workshop.

7.3. EXCHANGE UNCERTAINTY

Multiple exchange rates were evaluated in the model due the uncertainty and large potential effect of exchange rates on the abundance of each group. Two potential exchange rates were considered: 0% exchange and 0.1% exchange. Exchange rates could potentially be higher; however, the likelihood of this is thought to be low. These values represent the proportion of the adult population that moves from one group to another and span the plausible range in values based on current available information. As a fish moves to a group, it effectively joins the group and is included in the following carrying capacity and fecundity calculations for subsequent years. We assume that exchange rates are equal across all exchange directions. Individuals are able to move between these groups through the Upper Fraser group. Due to complexities of incorporating genetics into the population model, this model does not track individuals that move between groups and therefore all individuals that join a group adopt the survival and growth parameters of that group and therefore, have the same evolutionary fitness as the group's native individuals.

7.4. MODEL RUNS AND PARAMETER COMBINATIONS

In addition to the model scenarios described in Section 7.3, the effect of varying larval/juvenile habitat productivity (Hab_t) and human-induced mortality (HM) on White Sturgeon abundance in each group was tested using the metapopulation model. To evaluate the effect of varying Hab_t and HM values, 441 different parameter combinations of Hab_t and HM were used. The range of values and corresponding increments for the Hab_t and HM are provided in Table 6

Due to the complexities of allowing exchange between the different groups, when a single group's Hab_t or HM values were varied from the current conditions, the other groups' Hab_t or HM values remained at current conditions. This structure assumes that population alterations are group independent such that cumulative effects of multiple population alterations are not evaluated in this model structure.

Each parameter combination was examined by running Monte Carlo simulations with 750 iterations. To display these results, we present contour plots for each group at 50 and 100 years for each scenario combination. In addition to the median abundance contour plots, additional plots were generated to allow for further interpretation.

Table 6. Parameters that were varied for each parameter combination.

Parameter	Description	Value Range	Increments
Hab_t	Recruitment rate relative to equilibrium value. Hab_t is a recruitment multiplier used to simulate total habitat productivity changes from either habitat quantity or quality alterations.	0.0-2.0	0.1
HM	Human-induced mortality. HM is used to simulate varying mortality rates caused by increasing fishing pressure or alterations to harvest management practices. HM = 0.0 reflects a scenario with no human induced mortality.	0.0-0.05	0.0025

7.5. MODEL RESULTS

Based on current conditions, Mid-Fraser and Upper Fraser groups remained relatively constant with and without exchange (Figure 7); however, the Nechako group spiked prior to year 20 due to the multiple stocking events that had previously occurred. Once that pulse of stocked fish aged and began to die off, a steady population decline occured. Although a dynamic stocking program is still in operation during the modelled population decline, the number of fish that are expected to be released and contribute to the population may be fewer than were released previously, resulting in the Nechako abundance declining following the abundance pulse. Stocking operations do not allow the Nechako abundance to maintain the high abundance because the stocking program will be dynamic and explicitly avoid swamping the metapopulation with hatchery fish (McAdam, pers. comm. 2016[1]). The magnitude of the abundance pulse is due to the high number of stocked fish and the potentially high survival of stocked fish (Williamson, pers. comm. 2016). Since the stocking program will only last for 20 years, the population trajectory is ultimately expected to decline unless larval/juvenile habitat productivity improves. Although the Nechako abundance is able to reach the Nechako recovery target (1,000 adults), this abundance is not sustained in the absence of hatchery inputs, due to the low productivity of larval/juvenile habitat.

Across all sturgeon groups and exchange scenarios, abundance was influenced by habitat productivity and human-induced mortality; however, the magnitude of effect of each of these parameters varied for each sturgeon group and exchange scenario.

The contour plots display a broad range of combinations of human-induced mortality and habitat productivity and the corresponding abundances. The contour plots can be used to visualize the consequences of changes in human-induced mortality and habitat productivity. The results show that relatively small changes to human-induced mortality or habitat productivity can have substantial effects on the abundance of sturgeon in the Mid-Fraser and Upper Fraser, given our parameter and modeling assumptions. Although exchange is allowed between the groups, exchange rates of 1% would not mitigate the loss of sturgeon from increased human-induced mortality or loss of habitat productivity and is therefore expected to have a relatively small effect (assuming there is no fitness difference, like growth, survival and fecundity, between migrants and native fish).

For the Nechako group, stocking activities can substantially increase adult abundance; however, due to the relatively short length of the stocking program (i.e., 20 years), the abundance of the Nechako group cannot reach historical abundance levels with stocking alone. Further, abundances are not sustained. Habitat productivity will need to be improved and along with stocking, historical abundances could be reached within 100 years.

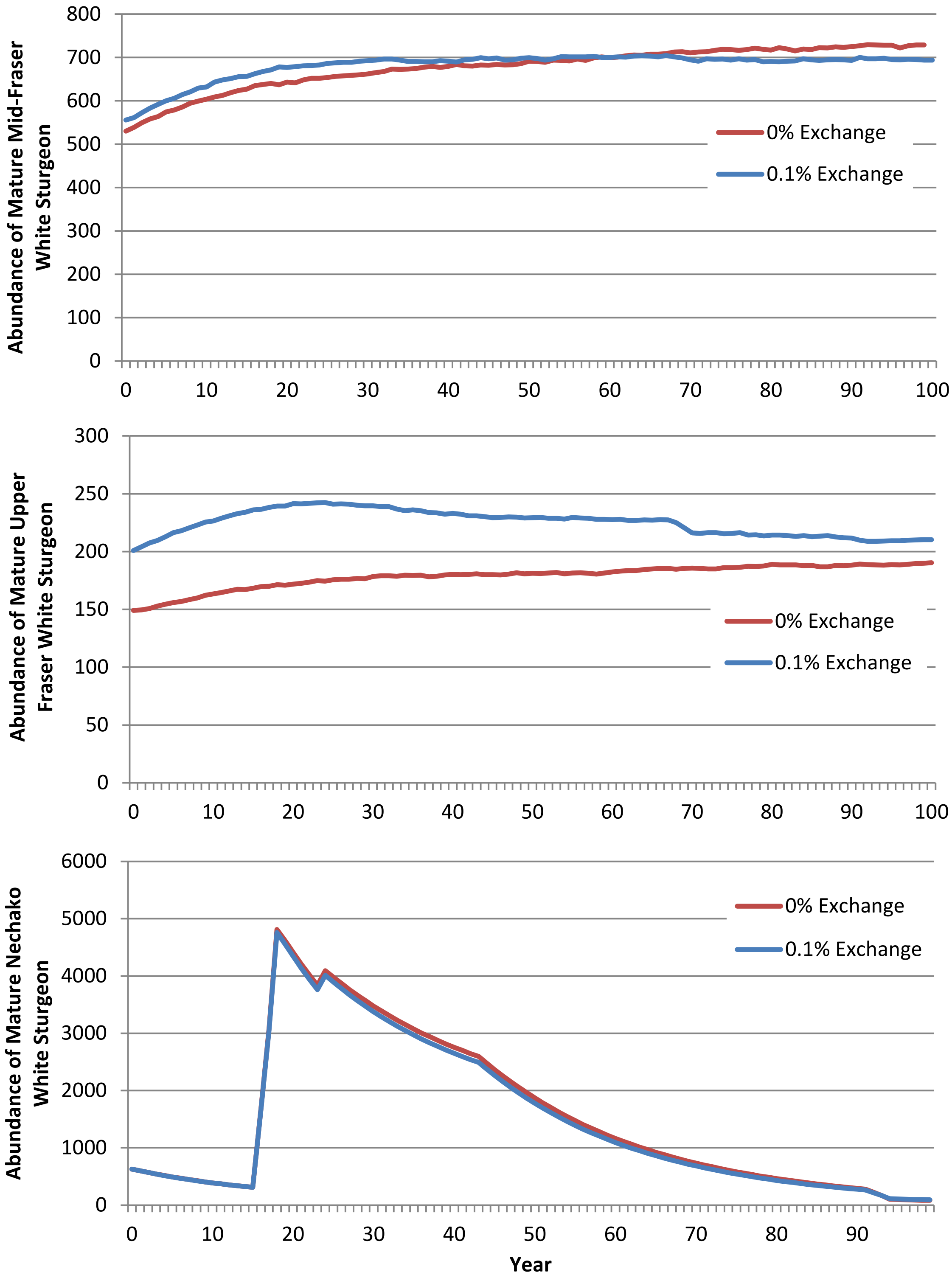

Figure 7. White Sturgeon median abundances 100 year time series for each exchange scenario at current Habt and HM conditions at the Mid-Fraser (top panel), b) Upper Fraser (mid panel), and c) Nechako group (lower panel).

7.5.1. Mid-Fraser Results

The abundance of the Mid-Fraser group was influenced by Hab_t and HM; however, the magnitude of effect from these two parameters was not equal. Small changes in HM had a substantial effect on the group's abundance. For example, an increase in HM to 0.05 relative to current values, would cause a change in the group's abundance equivalent to reducing habitat productivity in the middle Fraser to 20% of current productivity.

The model results suggest that exchange between groups could affect the Mid-Fraser group, given the current model structure and parameter values; however, the effect is minor. For the Mid-Fraser the effect of exchange was greatest when the group's abundance is low (i.e., low Hab_t or high HM values). Exchange between groups would result in a small increase in the Mid-Fraser group's abundance at these conditions. It is likely that greater exchange rates (e.g., 5% exchange) would have a much greater effect on the group's abundance. It is important to note that the model structure allows exchange between sturgeon groups but does not track individuals that have joined a new group and does not assign a different fitness to the native vs. immigrant individuals.

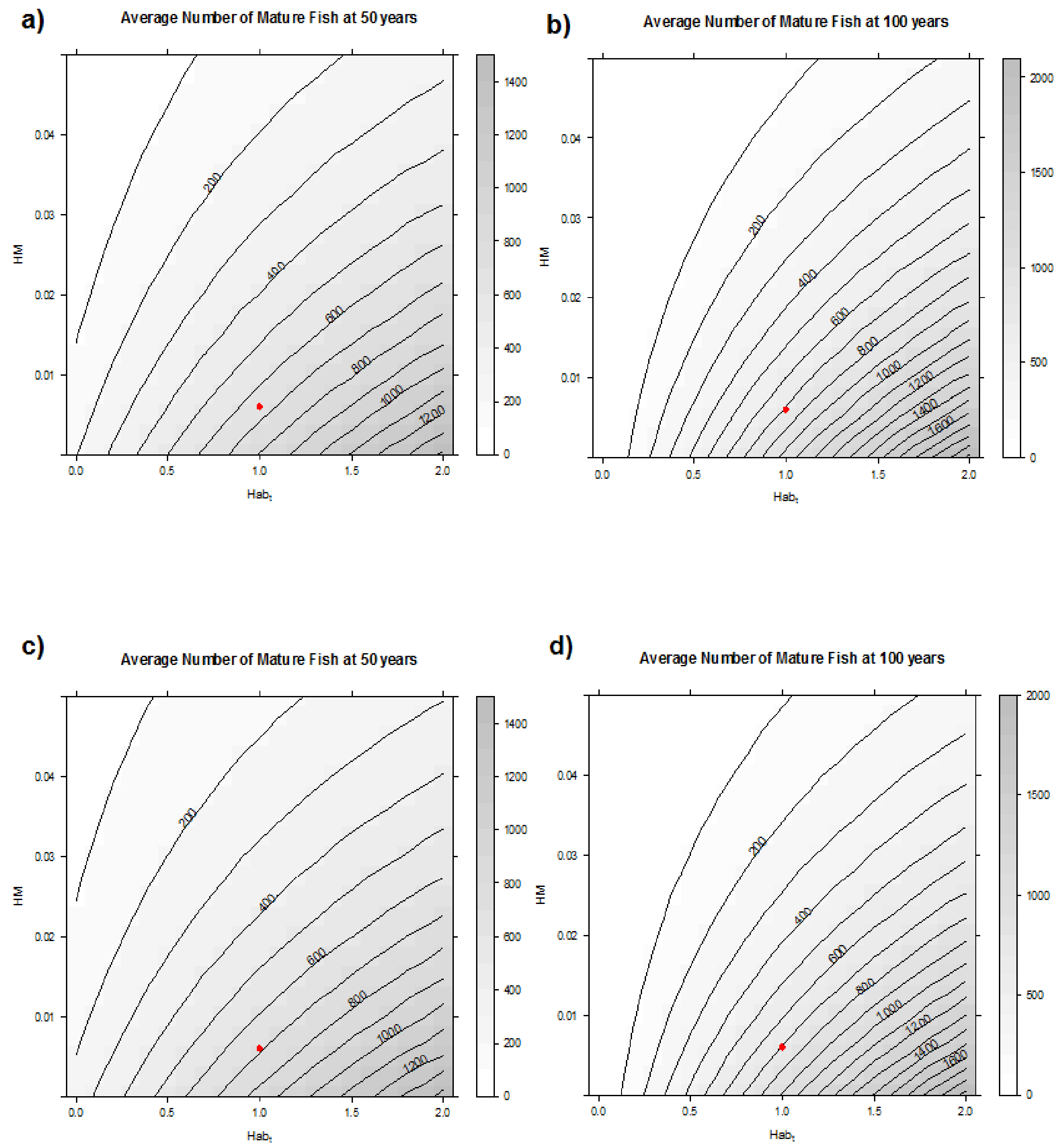

Figure 8. Contour plots of Mid-Fraser White Sturgeon abundance at 50 and 100 years, with an exchange rate of 0% (a and b) and 0.1% (c and d). The red icon illustrates current values of Hab_t and HM.

7.5.2. Nechako Results

The abundance of the Nechako group was influenced by Hab_t and HM; however, the magnitude of effect from these two parameters was not equal. Small changes in HM had a substantial effect on the group’s final abundance. Based on the model results, an increase in HM to 0.05 would have an effect on the group’s abundance equivalent to reducing habitat productivity to <10% of the historical productivity for Nechako.

The model results suggest that exchange between groups could affect the Nechako group based on the current model structure and parameter values. The model results suggest that exchange between groups can affect the abundance within the group; however, the effect is minor. For the Nechako, the effect of exchange was greatest when the group's abundances are low (i.e., low Hab_t or high HM values). Exchange between the groups would result in a small increase in the Nechako group's abundance under these conditions; however, the effect is not substantial. It is likely that greater exchange rates (5% exchange) will have a much greater effect on the Mid-Fraser group's abundance. It is important to note that the model structure allows exchange between sturgeon groups, but does not track individuals that have joined a new group, nor does it assume that newly joined individuals have a different evolutionary fitness than the native individuals.

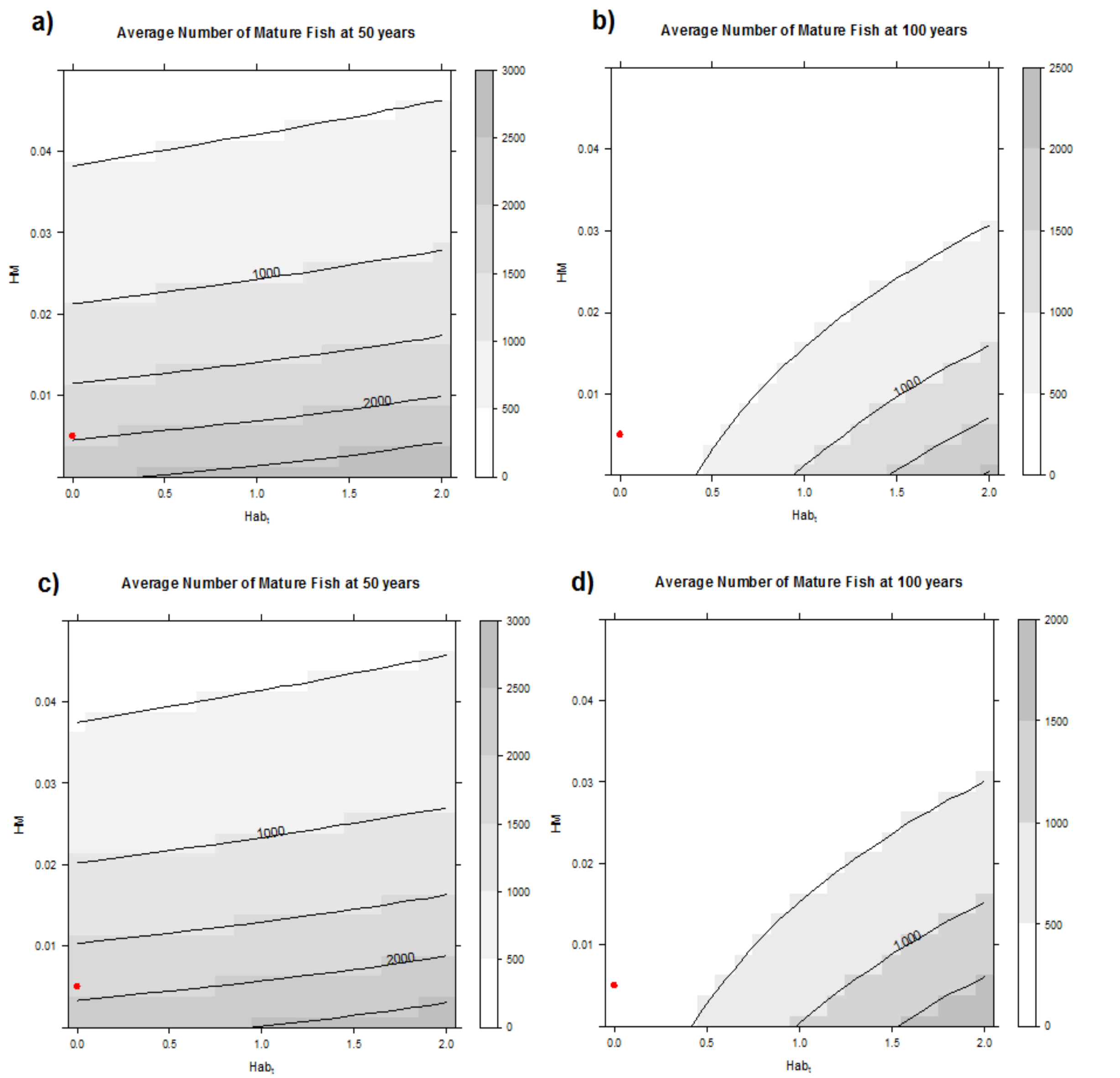

Figure 9. Contour plots of Nechako White Sturgeon abundance at 50 and 100 years, with an exchange rate of 0% (a and b) and 0.1% (c and d). The solid red icon illustrates the assumed current values of Hab_t and HM, but does not represent current abundance. Hab_t would increase if spawning habitat near Vanderhoof is improved.

7.5.3. Upper Fraser Results

The abundance of the Upper Fraser group was influenced by Hab_t and HM; however, the magnitude of effect from these two parameters was not equal. Small changes in HM had a substantial effect on the group's abundance. Based on the model results, an increase in HM to 0.05 would have an effect on the group's abundance, equivalent to reducing habitat productivity to 10% of the current productivity for upper Fraser.

The model results suggest that exchange between groups could affect the Upper Fraser group based on the current model structure and parameter values. Exchange does alter the slope of the contours, demonstrating an increase in abundance within Upper Fraser group when compared to the scenario with 0% exchange. The effect of exchange is likely more apparent in the Upper Fraser group due to the finer scale of the contour plot, and the higher net exchange that occurs due to the lower abundance of this group compared to the others. Since the exchange rate is fixed for all three groups, more fish will enter the Upper Fraser group than leave due to the greater abundances of the Mid-Fraser and Nechako groups.

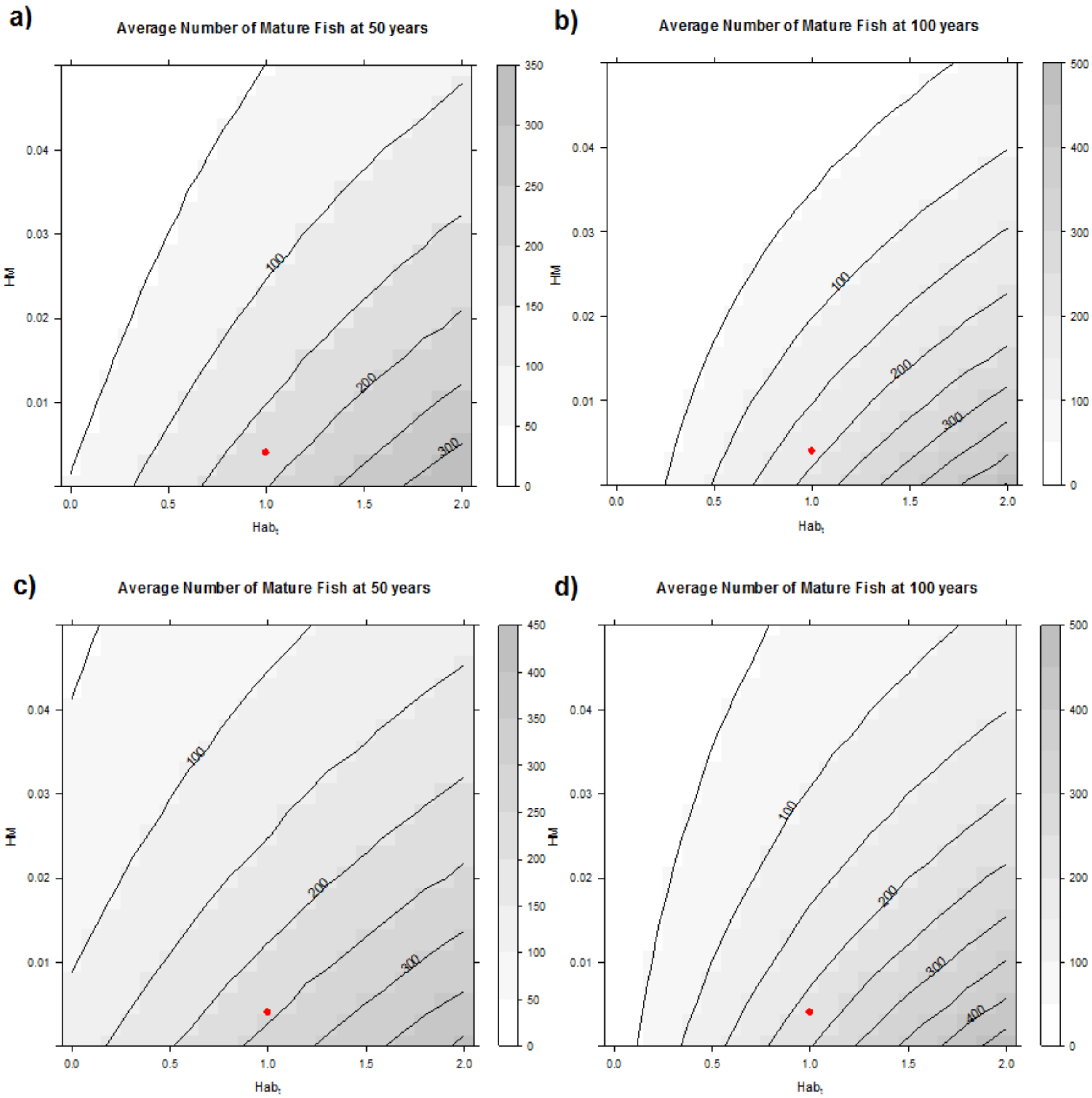

Figure 10. Contour plots of Upper Fraser White Sturgeon abundance at 50 and 100 years, with an exchange rate of 0% (a and b) and 0.1% (c and d). The red icon illustrates current values of Habt and HM.

7.5.4. Allowable Harm Assessment

Allowable harm was considered for White Sturgeon in the Upper and Mid-Fraser groups only, as they are currently at or near their population survival targets and therefore some harm to the population may be feasible. The Nechako group is currently well below its recovery target, so we assumed that allowable harm for this group is not feasible unless in support of conservation objectives.

Allowable harm can be evaluated through the potential loss of larval/juvenile habitat (Hab$_t$) or an increase in human induced mortality (HM). However, experts attending the RPA workshop stated that substantial losses of habitat in the DU are unlikely, so we considered only the effect of changes to HM while maintaining the current Hab_t values for Mid-Fraser and Upper Fraser groups.

7.5.4.1. Mid-Fraser Group

Allowable harm for the Mid-Fraser group was assessed at 1×, 1.5×, 2×, 2.5×, and 3× the current human-induced mortality value (i.e., HM = 0.006, 0.009, 0.012, 0.015, 0.018). As expected, group abundance decreased with increasing HM; however, none of the population trajectories result in a population crash and the median abundance stabilizes within 100 years following the change in HM (Figure 11). The effect of changes in HM was also evaluated using exceedance plots of abundances at 50 years (Figure 12). Based on the exceedance plots, 49% of the iterations at 50 years are equal to or greater than the current abundance (749 adults) at current HM values (0.006). When HM is increased to 0.009, 13% of the iterations at 50 years are equal to or greater than the current abundance. When HM is increased to 0.012, 3% of the iterations at 50 years are equal to or greater than the current abundance. When HM is 2.5× the current HM or greater, <1% of the iterations at 50 years are equal to or greater than the current abundance.

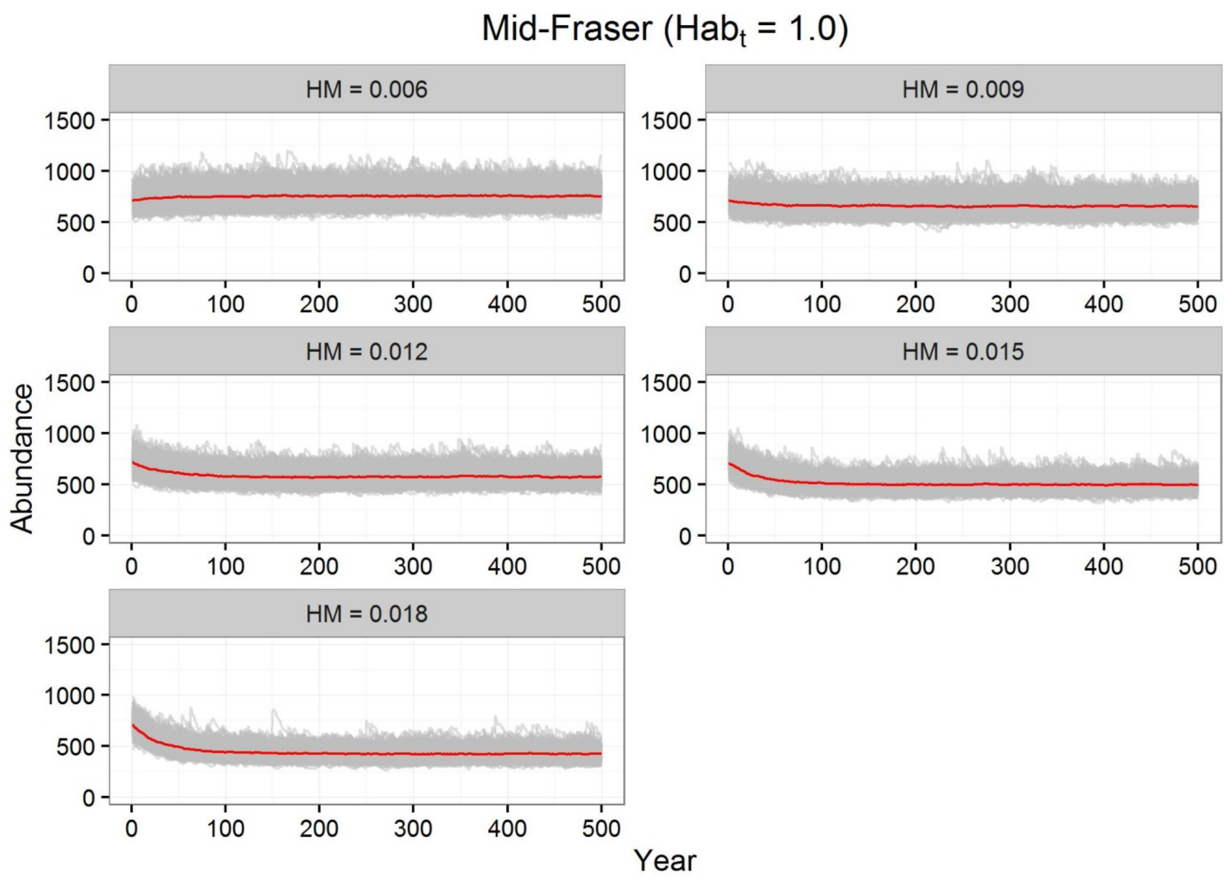

Figure 11. Population trajectories for the Mid-Fraser group at 1× (HM = 0.006), 1.5× (HM = 0.009), 2× (HM = 0.012), 2.5× (HM = 0.015), and 3× (HM = 0.018) current human-induced mortality (HM) conditions. The red line represents the median abundance value at each year.

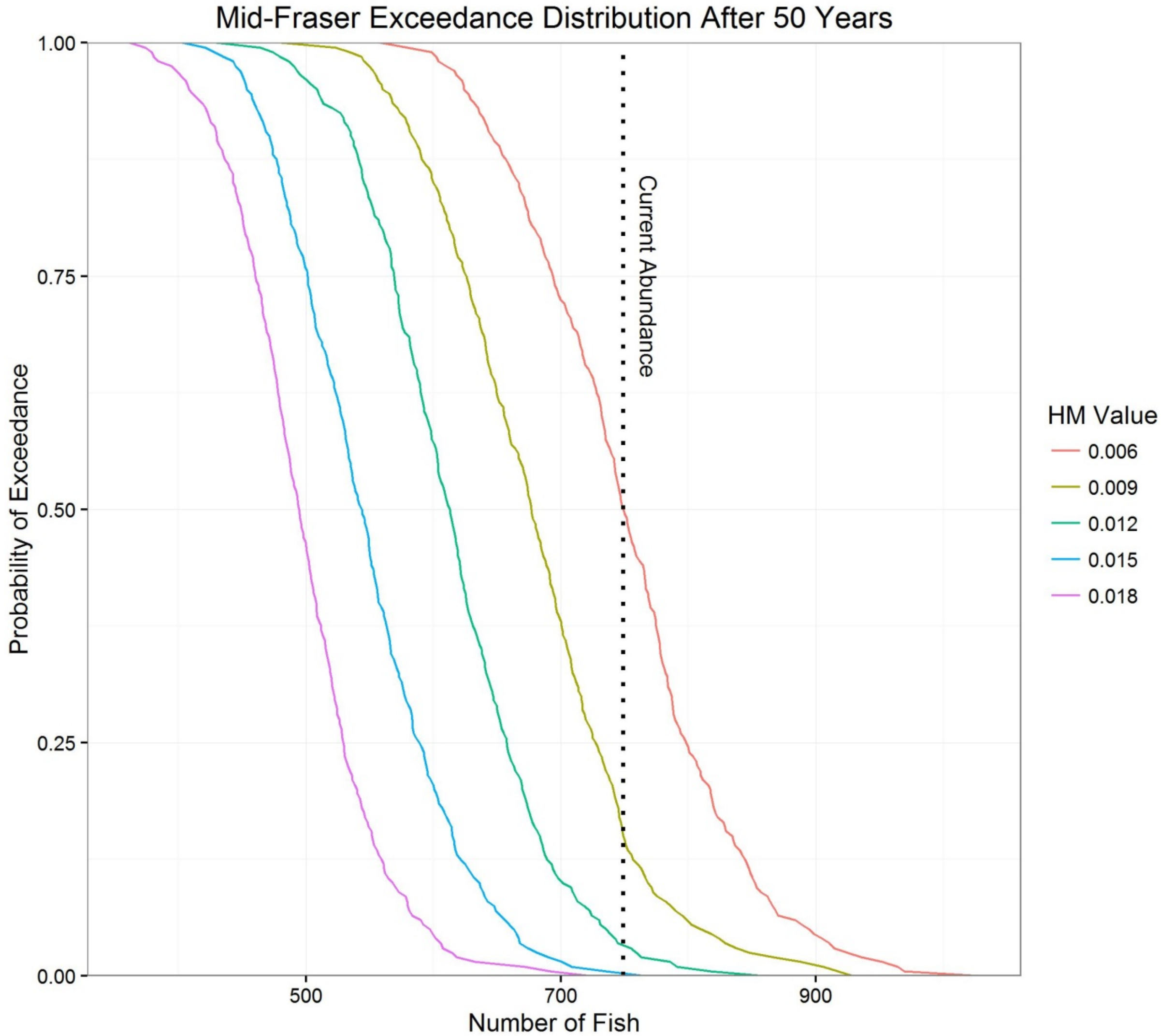

Figure 12. Exceedance plot of the Mid-Fraser group for 1× (HM = 0.006), 1.5× (HM – 0.009), 2× (HM = 0.012), 2.5× (HM = 0.015), and 3× (HM = 0.018) current human-induced mortality (HM) conditions.

7.5.4.2. Upper Fraser Group

Allowable harm for the Upper Fraser group was assessed at 1×, 1.5×, 2×, 2.5×, and 3× the current human-induced mortality value (i.e., HM = 0.004, 0.006, 0.008, 0.01, 0.012). As expected, group abundance decreased with increasing HM; however, none of the population trajectories result in a population crash and the median abundance stabilizes within 100 years following a change in HM (Figure 13). The effect of changes in HM was also evaluated using exceedance plots of abundances at 50 years (Figure 14). Based on the exceedance plots, 57% of the iterations at 50 years are equal to or greater than the current abundance (185 adults) at current HM values (0.004). When HM is increased to 0.006, 34% of the iterations at 50 years are equal to or greater than the current abundance. When HM is increased to 0.008, 17% of the iterations at 50 years are equal to or greater than the current abundance. When HM is 2.5× the current HM or greater, 3% of the iterations at 50 years are equal to or greater than the current abundance.

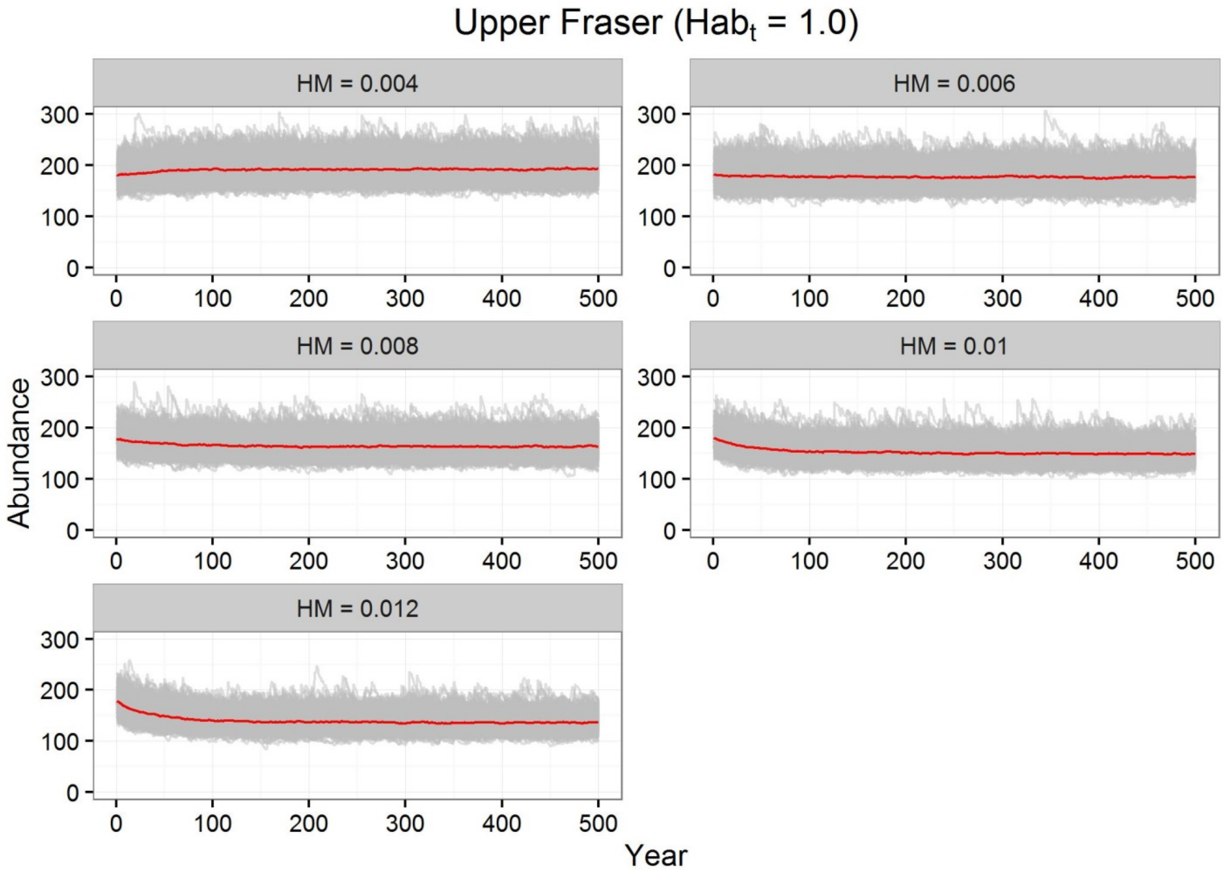

Figure 13. Population trajectories for the Upper Fraser group at for 1× (HM = 0.004), 1.5× (HM = 0.006), 2× (HM = 0.008), 2.5× (HM = 0.01), and 3× (HM = 0.012) current human-induced mortality (HM) conditions. The red line represents the median abundance value at each year.

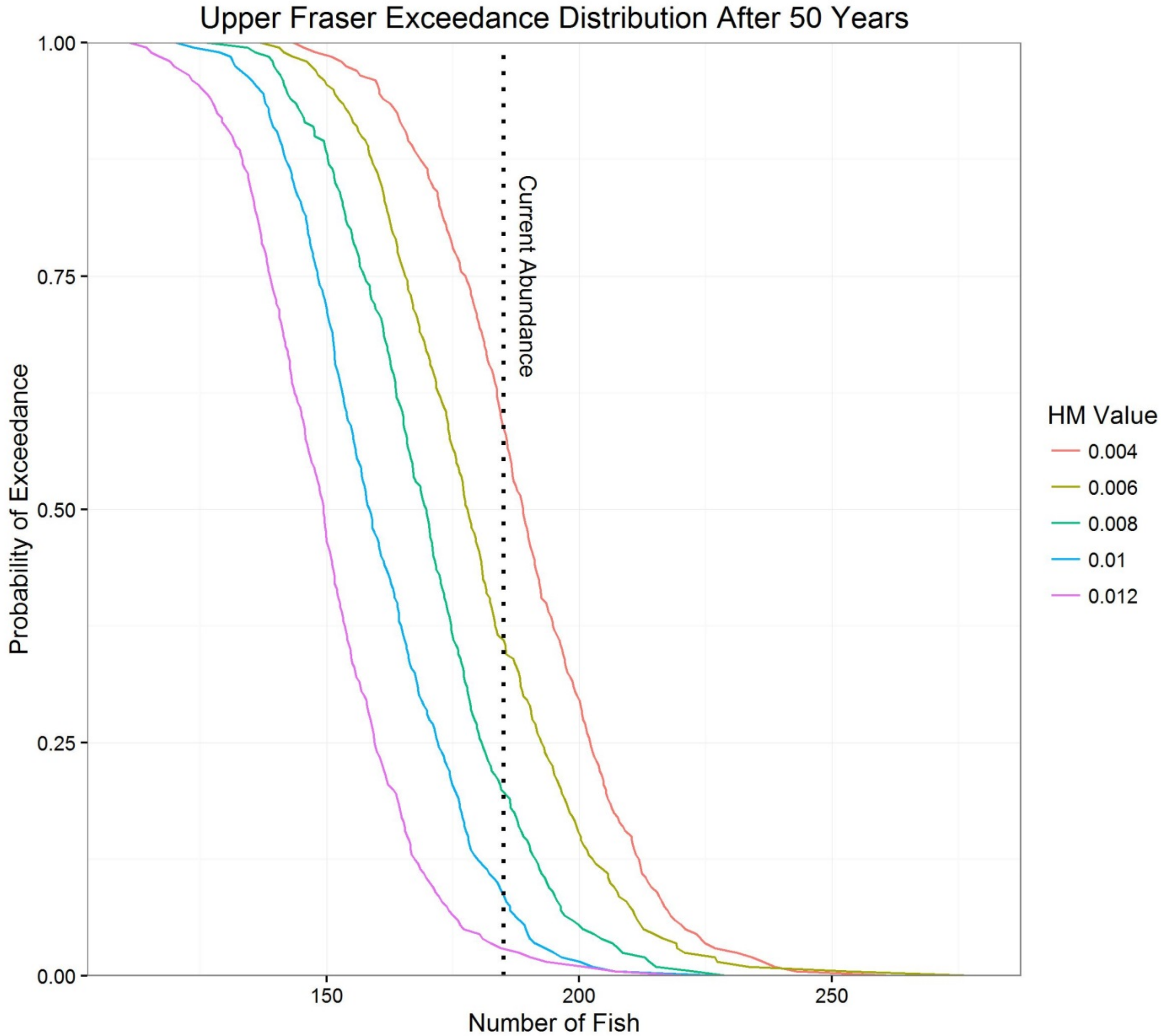

Figure 14. Exceedance plot of the Upper Fraser group for 1× (HM = 0.004), 1.5× (HM = 0.006), 2× (HM = 0.008), 2.5× (HM = 0.01), and 3× (HM = 0.012) current human-induced mortality (HM) conditions.

8. MODEL IMPLICATIONS AND RECOMMENDATIONS

This section addresses element 21 of the National Framework for Recovery Potential Assessments.

Although the contour plots display a broad range of combinations of human-induced mortality and habitat productivity, these combinations do not reflect the complete range for all possible management actions in the Upper Fraser DU. The range of these parameters could be extended to 0.0-1.0 for human-induced mortality and greater than 2.0 for habitat productivity; however, we limited the scope of our analysis to HM = 0.0-0.05 and Hab_t = 0.0-2.0, under the assumption that this represents a broad range of values for consideration of management actions. Current estimates of human-induced mortality for White Sturgeon populations throughout BC are substantially lower than 0.05 (Wood *et al.* 2007).

The activities listed in Table 4, particularly those in the categories of protecting critical habitats, and clarifying and mitigating threats, have the potential to maintain or increase habitat productivity and to improve survivorship, given our parameter and modeling assumptions.

However, at present there is insufficient information to quantify the effect of individual management actions on habitat productivity or survivorship. We have modelled the population response to combinations of mortality and productivity values, which allow an understanding of the necessary changes in these parameters to achieve a specific management target within 50 years or 100 years. As information becomes available that allows quantitative estimates for individual management actions, these actions can be “tested” through comparison to the modelled parameter ranges.

8.1. MODEL GAPS

There are several uncertainties that influence the model results which need to be assessed in future efforts to improve the accuracy of this model: the human-induced mortality rates, the exchange rates, and the evolutionary fitness differences between migrant and native fish.

In the Upper Fraser DU, there are multiple sources of mortality including bycatch, angling activities in the Mid-Fraser group, and poaching. There is very limited information available on the specifics of each of the potential sources of mortality; making it difficult to examine specific alterations to actions that cause human-induced mortality. Although direct and delayed mortality estimates for White Sturgeon are available in Robichaud *et al.* (2006); these rates cannot be directly applied to the model because they are not corrected for group specific encounter probability, which is the probability that an individual will be captured from the sampling gear type that is influenced by sampling effort. In addition, these rates do not apply to all potential human-induced mortality and rates of mortality from poaching would not be included in these estimates. In the absence of reliable encounter data, it would be speculative to translate these mortality estimates into HM rates for modelling purposes. Nevertheless, we acknowledge that threats discussed in Section 4 have worst-case potential that may add up to mortality rates greater than 0.05. In cases such as these, the HM parameter could be used to encapsulate all additional mortality from direct and indirect human-induced actions as well as other additional non-human related effects such as disease or competition.

Exchange rates within the Upper Fraser DU are another uncertainty. Analyses indicate that the groups in the Upper Fraser DU differ genetically, but are not distinct enough to be classified as separate DUs (COSEWIC 2012). Although exchange between the groups is occasionally observed and implicit in the genetic data, the magnitude and extent of this exchange is still quite unknown. Results in Section 7.5 demonstrate that exchange rates of 1% of adults per year have little effect on a group’s abundance; however, higher exchange rates can have a much greater and substantial effect on abundance. This potential effect and the remaining uncertainty for the true value of exchange illustrates the need for improved understanding of sturgeon exchange patterns and rates in the Upper Fraser DU.

The final uncertainty is fitness of migrant fish. Currently, the model does not account for differences in fitness between migrant and native individuals within a group; therefore the model results suggest that an increase in exchange rates could be beneficial to the Mid-Fraser and Upper Fraser groups due to the relatively larger Nechako abundance. If stocked fish have substantially different fitness than native fish, then competition between stocked and native fish may cause the productivity to be less than optimal compared to a group composed entirely of native fish. This issue would also affect the Mid-Fraser and Upper Fraser groups as migrant individuals could comprise the majority of these abundances.

8.2. CURRENT MONITORING EFFORTS

Past and ongoing White Sturgeon monitoring programs are unique to each group. Numerous knowledge gaps related to each White Sturgeon group are summarized within the Recovery Strategy (DFO 2014), and the monitoring programs are designed to address those knowledge gaps. The monitoring work continues to contribute to understanding of other species that are by-captured and/or encountered during these programs.

All sturgeon monitoring efforts outlined are periodic or temporary and contingent upon the availability of funding. It is important to note that there are a variety of other monitoring and research initiatives implemented by government agencies, academic researchers, industry, NGOs and First Nations; however, summarizing all of these is beyond the scope of this document.

Monitoring of adult White Sturgeon within the Mid-Fraser, Upper Fraser, and Nechako groups occurs through sampling and radio tagging/telemetry. This work has been ongoing over various time frames and has been the primary information source for current understanding of each group's abundance, movement patterns, range, biology and life history. Radio telemetry is conducted as part of the adult and juvenile monitoring programs in the Nechako, and adult monitoring programs in the upper Fraser and middle Fraser. Telemetry is conducted via stationary telemetry receivers, and via mobile (aerial and boat) surveys. Data are collected for other species possessing radio tags that are detected during monitoring.

Monitoring of the Mid-Fraser group has been combined with the Lower Fraser White Sturgeon monitoring efforts and is conducted, in part, by the Fraser River Conservation Society (FRSCS). The FRSCS was founded in 1997 to address the conservation and restoration needs of Sturgeon in the Fraser River. The monitoring work conducted by the FRSCS is volunteer-driven and although the FRSCS provides information on White Sturgeon in the lower and middle Fraser, the majority of its monitoring focus has been on the lower Fraser. There is ongoing radio tracking to provide information about the spatial and temporal habitat use patterns (DFO 2014).

There is limited monitoring work currently conducted for the Upper Fraser group. Lheidli T'enneh First Nation implements a monitoring program for the Upper Fraser group that includes population status investigations, movement studies, and bycatch assessments (DFO 2014). In addition, some of the monitoring work conducted by Nechako White Sturgeon Recovery Initiative (NWSRI) from 1999 to 2014 included sites within the upper Fraser, including the Fraser mainstem, Bowron River, and McGregor River (Cory Williamson, pers. comm. 2016[8], Unpublished Data).

Monitoring of other relevant species includes annual spawner escapement monitoring programs for Sockeye, Chinook and Coho salmon populations within the upper Fraser. This monitoring includes surveys specific to the spawning habitats of individual salmon stocks and does not generally overlap with sturgeon habitats. Nevertheless, understanding the status of these salmon stocks, an important prey species for White Sturgeon, is important for understanding the productivity of each sturgeon group.

Population monitoring of White Sturgeon in the Nechako River started in 1982 (Dixon 1986) and was followed by the extensive monitoring work from 1995 to 1999 described in RL&L (2000). The Nechako White Sturgeon Recovery Initiative (Nechako White Sturgeon Recovery Initiative) was started following the conclusions of the RL&L (2000) report. The NWSRI technical working group was formed in 2000 and is composed of members of the Province of British Columbia, Canadian Government, First Nations, and the private sector (Nechako White Sturgeon Recovery Initiative 2014). This initiative's actions include broodstock capture for hatchery purposes, juvenile indexing, spawning monitoring, spawning habitat manipulation, population indexing, juvenile stocking, and community outreach. Pilot stocking operations were completed in 2006 to 2009 with release of 14,298 juvenile White Sturgeon (Cory Williamson, pers. comm. 2016[8], Unpublished Data). The long-term Nechako White Sturgeon Conservation Facility began hatchery operations in 2014 with a target of 12,000 White Sturgeon releases per year (Freshwater Fisheries Society of BC 2015).

An annual juvenile-focused White Sturgeon monitoring program is undertaken in the Nechako River for the purposes of monitoring the status of wild juvenile recruitment, and the survival and distribution of hatchery White Sturgeon. This program is essential to understanding the results of habitat restoration efforts and adaptively managing operation of the conservation fish culture facility. A subset of the hatchery releases is being radio tagged prior to release, for the purposes of understanding movement and distribution. If hatchery juveniles are noted to be moving into the upper Fraser or middle Fraser, it is understood that monitoring and management of these fish will be a high priority.

Sediment transport/substrate monitoring is conducted in the Nechako White Sturgeon spawning reach. This is contributing to an understanding of bedload movement characteristics and potential effects on spawning habitat.

Water temperature of the Nechako River is monitored and actively managed through flow augmentation to meet objectives designed to maintain temperatures below an upper threshold for the period July 20 – August 20 to benefit migrating adult sockeye (Nechako Fisheries Conservation Program Technical Committee 2015). The direct implications of the program on White Sturgeon in the Nechako and Middle Fraser are unknown.

Although monitoring programs have been conducted for these groups, gaps addressed in Section 8.1 should be considered for incorporating into future monitoring plans to improve the accuracy of the model. When these gaps have been addressed and additional information has been collected, the model can be updated and new, more accurate results can be calculated.

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