



ECOLOGICAL RISK ASSESSMENT FOR PROPOSED WHITE STURGEON STOCKING OF KINBASKET RESERVOIR, B.C.

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Abstract

In January of 2004, an ecological risk assessment was commissioned by the Upper Columbia White Sturgeon Recovery Initiative to consider the hazards of stocking white sturgeon into Kinbasket Reservoir. The intent of the program is to evaluate the risks associated with stocking sturgeon to develop a recovery area upstream of Mica Dam.

In this paper, we followed a practical approach developed by fishery managers for assessing ecological risks associated with fish stocking programs. The objective was to prepare a qualitative prediction of the ecological impact of establishing a self-sustaining population of 2500 adult white sturgeon (including those associated those juveniles and sub-adults) on the existing Upper Columbia River aquatic community. Information regarding the risk of disease and parasites are presented in a separate report. While the input of policy makers and stakeholders is needed to determine acceptable impact levels, this program identified all non-target taxa (NTT) in areas of presumed overlap, species that are highly valued, and the status of valued non-target taxa.

The study area encompassed the Columbia River upstream of Mica Dam and its major tributaries (i.e., Bush, Wood and Sullivan rivers), Kinbasket Reservoir, and Windermere and Columbia lakes. Ecological risks to the Upper Columbia River aquatic community associated with the proposed white sturgeon stocking program were assessed by reviewing scientific literature on target and non-target taxa in general and, where available, with reference to the Kinbasket Reservoir-upper Columbia River aquatic community.

The preliminary list of valued non-target taxa in the study area included kokanee, mountain whitefish, bull trout, burbot, and Westslope cutthroat trout. Identifying species that are highly valued involved consideration of economical, social, religious, recreational, and scientific factors. Thus, the list of valued non-target taxa was refined following review by policy makers, stakeholders, and other scientists to include suckers, peamouth chub and northern pikeminnow. Current population status was determined to be healthy for kokanee, mountain whitefish, and bull trout; however, status of burbot and Westslope cutthroat trout is depressed within the study area. Suckers, peamouth chub and northern pikeminnow are considered healthy, though data are limited for these species. Since the magnitude of ecological risk is strongly dependent on the degree of spatial and temporal overlap (sympatry) between sturgeon and NTT, habitat use by each species was reviewed to identify overlap for stocked sturgeon, any offspring that they may produce, and the NTT. Sympatry was determined to be greatest between introduced sturgeon and burbot.

Information regarding the ecological interactions of sturgeon was limited. Thus, potential interactions were determined by examining the available literature on common resources, diet and behaviour. Deleterious interactions included: competition for food or space, predation, pathogen transfer, and nutrient mining. Beneficial interactions included an increase in prey available for piscivorous NTT.

Given the dominance of benthic-oriented prey in the adult sturgeon's diet and their exploitation of aggregating fish species, aggregating or benthic fishes and invertebrates are most likely to be consumed by stocked sturgeon. Because, burbot, mountain whitefish, and sculpins are sympatric bottom feeders, they are expected to be encountered

and consumed at a greater frequency by white sturgeon than are pelagic rainbow and bull trout. Consumption of kokanee is expected to be considerable. Though predominantly a fish of the weedy shallows in lakes, predation on peamouth is expected to occur mainly in the winter months when they occupy depths > 20 m near the bottom. In Kinbasket Reservoir, northern pikeminnow, redbside shiners, and sucker spp. are expected to be consumed less frequently by stocked white sturgeon since these species and white sturgeon are largely allopatric (exhibit very little spatial and temporal habitat overlap).

Sturgeon are expected to compete with burbot for food as well as rearing and overwintering habitat since both are bottom oriented, deep water, piscivores. Mudflats appear important to both species. It is not known if burbot or sturgeon will exhibit interspecific territorial behaviour, or if fine sediment (sand and mud) habitats are limiting in Kinbasket. However, if fish densities become high enough, and common food and/or habitats are limiting, resource and habitat competition could become strong.

In the absence of established management intent to serve as the benchmark against which ecological risk will be assessed, preliminary NTT objectives of 10% were proposed as conservative impact levels for all taxa. This impact level may be refined upward for healthy and increasing taxa. Strong ecological interactions were identified as: (1) predation on kokanee, mountain whitefish, burbot, and sculpin and (2) competition with burbot. Kokanee and burbot were identified at highest risk (i.e., probability of exceeding acceptable impact levels) from sturgeon introductions.

Technical representatives reviewed a summary of the risks and uncertainties presented in this report. With limited scientific information on the majority of the aquatic community in study area, the magnitude of impact levels for many species were uncertain. However, white sturgeon likely were present in the area historically and are part of the natural species composition in large natural lakes throughout the Columbia Basin (e.g., Kootenay, Arrow and Slokan lakes). White sturgeon have evolved, and coexist, with similar species to those reported in the Kinbasket – Upper Columbia in other parts of the Columbia Basin.

To reduce uncertainty in the risk assessment, it is recommended that index sites be established and sampled to estimate population parameters of abundance and size for indicator species. Kokanee, burbot, bull trout and mountain whitefish were recommended as indicator species because: (1) they are highly valued taxa (2) the ecological risk was considerable for these species and (3) information regarding the current distribution, abundance, and size structure (i.e., kokanee) is available in the study area. Information on bull trout, burbot, mountain whitefish and non-sport species is limited. Such information is needed to track future ecological and biological changes in the reservoir, so that managers can compensate for undesirable outcomes of sturgeon introduction or other changes.

Employing strategies that minimize negative and maximize positive interactions between hatchery fish and NTT can also reduce ecological risks. For example, stocking limited numbers, in stages, and disease-free combined with monitoring of sturgeon and NTT may allow negative interactions to be minimized. Ultimately, the potential ecological costs will be balanced with the anticipated benefits of stock restoration.

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1. Introduction

The upper Columbia River white sturgeon (*Acipenser transmontanus*) population has declined due to lack of recruitment. Multiple changes to the system contribute to this decline, including habitat alteration and fragmentation. A recovery plan for this population has been prepared that includes restoration of habitat and connectivity as measures for the initiative. Short and medium term measures include hatchery supplementation of existing populations in two to three areas.

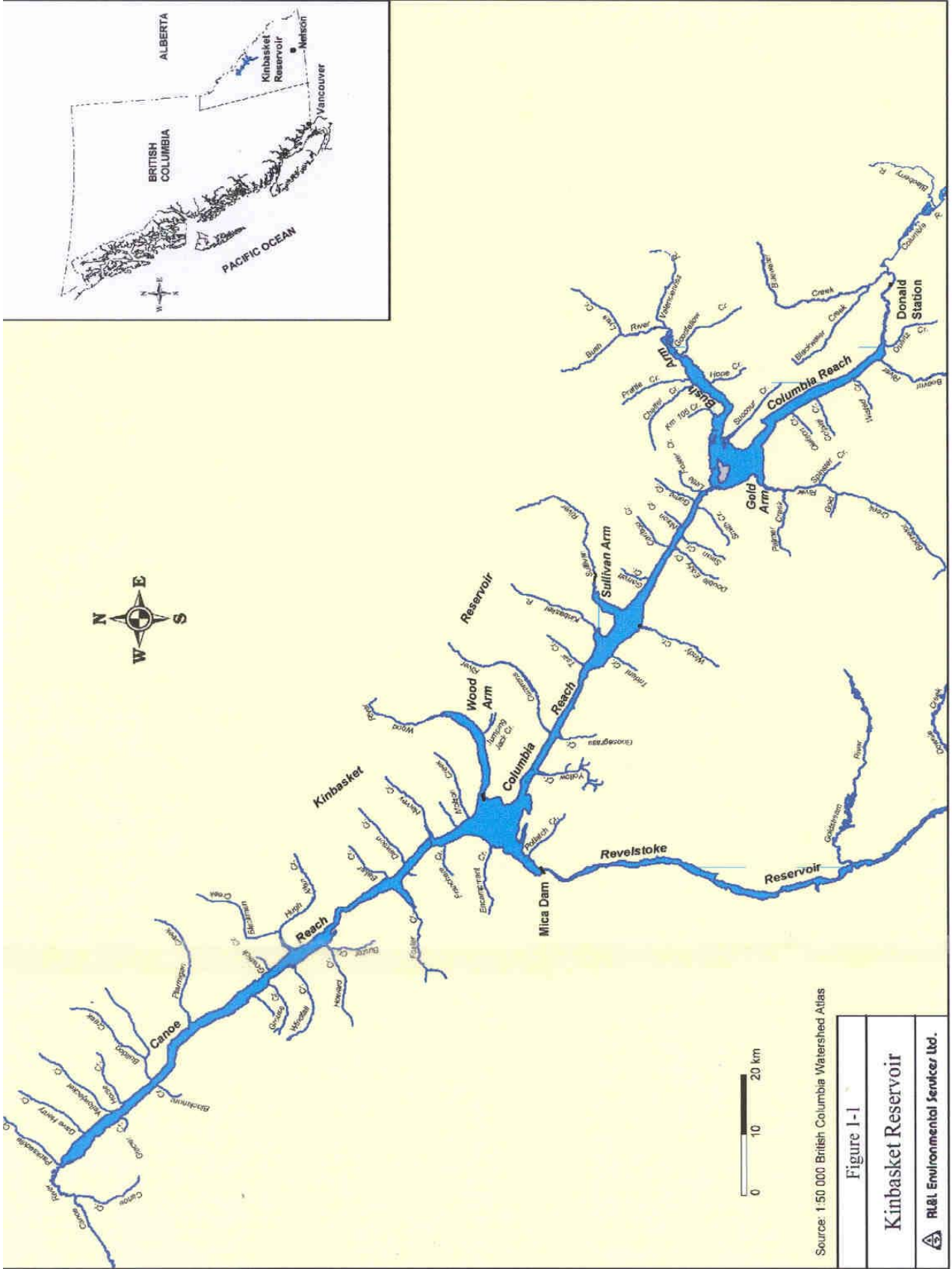
There are two reasons for establishing multiple population recovery areas: (1) in case efforts to restore natural production in other areas are unsuccessful and (2) as insurance against catastrophic events that might decimate populations in other areas. One region recommended for establishing a recovery area is the Columbia River upstream of Mica Dam. Anecdotal reports indicate that sturgeon used this area historically, though possibly only seasonally. However, present numbers are likely very low, as researchers have failed to capture sturgeon in this area and anecdotal reports are infrequent. Re-establishing a sturgeon population within this area has raised public and First Nation concerns, as past stocking (e.g., brook trout) has had detrimental effects on native species. To address these concerns, the Recovery Team has recommended a risk assessment be prepared.

The Kinbasket Reservoir - upper Columbia sturgeon stocking risk assessment aims to consider the hazards, individually and collectively in relation to the proposed stocking of white sturgeon upstream of the Mica Dam. Potential introduction risks include: disease, parasites, and species and community level ecological changes. This document focuses on the third risk category by summarizing existing information regarding sturgeon biology and the upper Columbia River aquatic community to identify potential ecological interactions (e.g., predation and competition). Information regarding the risk of disease and parasites are presented in a separate report (CCRIFC 2005).

This paper follows a practical approach developed by fishery managers for assessing ecological risks associated with fish stocking programs (Pearsons and Hopely 1999). The objective is to prepare a qualitative prediction of the ecological impact to the existing Kinbasket Reservoir - upper Columbia River aquatic community of establishing a potentially self-sustaining population of 2,500 adult white sturgeon with initial stocking of hatchery produced juveniles.

1.1. Study Area

The assessed area is Kinbasket Reservoir and the Columbia River upstream from Mica Dam (i.e., Canoe and Columbia reaches), its major tributaries (Bush, Wood and Sullivan rivers), and Windermere and Columbia lakes (Figure 1). The mainstem of the Columbia River upstream of Kinbasket Reservoir is a wetland complex flowing over 180 km through the Columbia Trench and encompassing over 20,000 hectares. It is the only section of the Columbia River to retain a natural hydrograph and the turbid water that may be important to white sturgeon.



Kinbasket Reservoir is a deep, cold and nutrient poor reservoir formed after the completion of the Mica Dam in 1976. At full pool, the reservoir has a total length of about 216 km, covers approximately 410 km², and has a mean depth of 57 m (RL&L 1991). Temperatures in Kinbasket are above 8°C from May to October for depths less than 60 m (RL&L 2001). During spring and summer, the surface waters of Kinbasket Reservoir gradually warm, reaching maximum temperatures of up to 24°C (RL&L 2001). There is no well-defined epilimnion in summer due in part to the hypolimnetic water withdrawal at the dam.

Kinbasket is a large storage reservoir with normal surface elevation fluctuations of 19m, although it is licensed to fluctuate up to 47 m (RL&L 2001). These fluctuations in water levels severely limit benthic productivity in the varial zone, and directly limit fish production in the reservoir. Primary producers are dominated by diatoms (primarily *Asterionella formosa*), cladocerans the dominant zooplankton, and chironomids the dominant benthos, although the latter are scarce in the littoral zone due to water level fluctuations. Zooplankton biomass is low in June (13 mg/L, likely a reflection of the cold glacial inflow), but by October, biomass increases (up to 1080 mg/L) to twice the levels measured in other upper Columbia River reservoirs (RL&L 2001).

2. Ecological Risk Assessment

Risk assessment is the process of estimating the potential impact of a hazard on a specified environment under a specific set of conditions (Barnthouse 1995). It is the process of determining as accurately as possible both the actual likelihood and the consequences (should that risk occur) of the risks presented by exposure to identified hazards. It should be noted that risk assessment is a scientific process that does not take political or other non-scientific aspects into account.

Ecological risks to the Upper Columbia River aquatic community associated with the proposed stocking program were addressed by reviewing scientific literature on target (i.e., white sturgeon) and non-target taxa (i.e., other fish species) both in general and with respect to the study area. Little published information exists on the aquatic community in this area. The majority of fisheries research to date has focused on salmonids in Kinbasket Reservoir and its tributaries and has stemmed from monitoring activities associated with Mica Dam. Other than two adult burbot studies in Columbia Lake, there was limited information (primarily fish presence-absence studies) on fish communities of the Columbia River upstream from Kinbasket Reservoir.

2.1. Non-target taxa of concern (NTT)

The first step in assessing the ecological risks associated with a fish stocking program is to select non-target taxa of concern and express NTT objectives as acceptable impact levels. Selecting valued NTT involves identifying: (1) all sympatric non-target taxa, (2) all highly valued species, and (3) status of the NTT (e.g., healthy, depressed, critical). An extensive literature review of fisheries information on Kinbasket Reservoir was recently completed in preparation for the basins' water use plan (RL&L 2001). The following summary is based on this literature review with additions from recent bull trout and kokanee investigations in the reservoir and studies from the Columbia Wetlands (including Windermere and Columbia lakes).

2.1.1. Non-target Taxa

Sampling within the study area has indicated use by 20 species of fish (Table 1, RL&L 2001). Prior to impoundment by Mica Dam, the sportfish fauna in the Columbia River system included: bull trout (*Salvelinus confluentus*), brook trout (*S. fontinalis*), rainbow trout (*Oncorhynchus mykiss*), Westslope cutthroat trout (*O. clarki*) mountain whitefish (*Prosopium williamsoni*), pygmy whitefish (*P. coulteri*), and burbot (*Lota lota*) (RL&L 2001). In addition, there have been several anecdotal accounts of white sturgeon upstream from Mica Creek (Prince 2001, CCRIFC 2005).

Table 1. Fish species reported from Kinbasket Reservoir and tributaries following impoundment by Mica Dam (Source RL&L 2001). Species are listed in order of abundance as determined by five years of gillnet sampling in Kinbasket Reservoir (RL&L 2001).

Species	Scientific Name
Sportfish	
Kokanee * ¹	<i>Oncorhynchus nerka</i>
Mountain whitefish* ¹	<i>Prosopium williamsoni</i>
Bull trout* ¹	<i>Salvelinus confluentus</i>
Rainbow trout* ¹	<i>Oncorhynchus mykiss</i>
Burbot* ¹	<i>Lota lota</i>
Cutthroat trout	<i>Oncorhynchus clarki</i>
Brook trout ¹	<i>Salvelinus fontinalis</i>
Non-sportfish	
Peamouth* ¹	<i>Mylocheilus caurinus</i>
Northern pikeminnow* ¹	<i>Ptychocheilus oregonensis</i>
Longnose sucker* ¹	<i>Catostomus catostomus</i>
Largescale sucker* ¹	<i>Catostomus macrochelius</i>
Redside shiner* ¹	<i>Richardsonius balteatus</i>
Pygmy whitefish	<i>Prosopium coulteri</i>
Longnose dace ¹	<i>Rhinichthys cataractae</i>
Slimy sculpin*	<i>Cottus cognatus</i>
Prickly sculpin	<i>Cottus asper</i>
Torrent sculpin ¹	<i>Cottus rhotheus</i>
Mottled sculpin	<i>Cottus bairdi</i>

* Species confirmed in Kinbasket Reservoir

¹ Species reported in Columbia Wetlands, Lake Windermere or Columbia Lake

In addition, largemouth bass (*Micropterus salmoides*), sunfish (*Lepomis spp.*) and pumpkinseed (*L. gibbosus*) have been identified in Windermere Lake (Urban Systems 2001) and pumpkinseed have been reported in the Columbia Wetlands (Jamieson and Hennan 1998).

During pre-impoundment studies (i.e., pre 1973), kokanee (*O. nerka*) were not reported in the Kinbasket area. Between 1982 and 1985, B.C. Environment stocked the upper Columbia system with kokanee. Since then, the kokanee population has rapidly increased in size, and is currently the dominant sportfish species in the reservoir comprising anywhere from 26 to 86% of the total catch in fish monitoring studies (RL&L 2001). Mountain whitefish is the second most dominant species followed by rainbow trout and bull trout. All studies conducted to date have shown that sport fish comprise at least two-thirds of the gill net catches from Kinbasket Reservoir (RL&L 2001).

Non-sport fish species including longnose sucker (*Catostomus catostomus*), largescale sucker (*C. macrocheilus*) and northern pikeminnow (*Ptchocheilus oregonensis*) appeared in samples for the first time in 1987 (RL&L 2001). Peamouth chub are the most abundant non-sport fish species in the reservoir, having been collected four of the five years of gill net sampling where they represented up to 37% of the catch. In comparison, northern pikeminnow only represented 2% of the total annual catch.

2.1.2. Highly valued species

Identifying highly valued species involves consideration of economical, social, religious, recreational, and scientific factors. In the Upper Columbia River study area, highly valued species for sport fishing include kokanee, mountain whitefish, bull trout, rainbow trout, Westslope cutthroat trout and burbot. Perhaps the most valued species is kokanee as they are a sportfish, a food source for piscivorous fish, and a nutrient source for spawning tributaries. Bull trout, burbot, rainbow trout, and mountain whitefish are also highly valued by anglers in Kinbasket Reservoir (Prince 2001). In addition, mountain whitefish have ecological value as a food source for piscivorous fish both in riverine and reservoir habitats. Non-sport fishes that were identified as important for ecological health or historic sustenance were northern pikeminnow, suckers and peamouth chub (CCRIFC Board Meeting, February 8, 2005).

Currently, the study area hosts no rare or endangered fish species (i.e., red listed) identified by the B.C. Conservation Data Center. Though white sturgeon (an endangered species) were encountered during the building of Mica Dam, their presence in the reservoir remains unconfirmed (Prince 2001). Similarly, the presence of mottled sculpin (red listed) has yet to be confirmed; misidentification is suspected for the one existing record of this species in the study area (RL&L 2001). Bull trout and Westslope cutthroat trout are indigenous species that are listed as species of special concern (blue listed) by the B.C. Conservation Data Center. Conservation status listings acknowledge their sensitivity to human activities, and listed species or populations are considered at risk. Their listing, combined with their importance as sportfish make them highly valued taxa in the study area.

2.1.3. Status of Non-target Taxa (i.e., healthy, depressed, or critical)

The status of NTT as outlined below was determined by reviewing available data within the study area and Conservation Data Center designations.

2.1.3.1. Kokanee (healthy)

Between 1982 and 1985, BC Environment introduced 654 000 kokanee fry and 504 200 kokanee eggs into Succour Creek, Blackwater Creek, and the upper Columbia System (i.e., Windermere Lake, Windermere Creek, and Dutch Creek). The brood sources for these introductions were from the Kootenay River basin, specifically Meadow, Kikomun, and

Norbury Creeks. Kokanee were stocked to take advantage of the extensive pelagic habitats in Kinbasket Reservoir. Since then, the kokanee population has increased rapidly in size and is currently the dominant sportfish in the reservoir (RL&L 2001).

Adult kokanee in Kinbasket spawn in the lower reaches of tributaries to Kinbasket Reservoir and the upstream Columbia River. In 1995, an extensive survey of kokanee spawning escapement was completed to identify potential index streams for long-term monitoring (Oliver 1995). The total spawning escapement was estimated to be between 700,000 and 1 million kokanee with the mainstem Columbia River at Fairmont and the Wood River being the two areas with greatest concentrations. Since that time, estimated numbers of spawning kokanee in selected tributary streams to the upper Columbia River basin increased annually, doubling by 2001. Counts for 2002 and 2003 have returned to 1996 levels (Westover 2003).

Preliminary estimates for 2001 - 2003 indicate that kokanee abundance (all ages) in Kinbasket Reservoir has ranged between 8.0 and 10.8 million (Table 2)(Dale Sebastian, Ministry of Water, Land, and Air Protection, pers. comm.). The relatively small proportion of ages 1+-3+ fish indicates that most of the mortality occurs during the first winter, which is typical of other kokanee populations. Survival between ages 1 and 3+ is believed to be fairly good based on trawl catches (50-65% of non-fry are 1+) and 5% of the total population reaching spawning. Thus, it would appear that the component of age 2 and 3+ (during August) in Kinbasket Reservoir would be at least 0.5 to 1.2 million for the last 3 years (Table 2). This is probably an underestimate as few 3+ fish are captured in August as they have initiated spawning migrations by this time.

Table 2. Estimated kokanee abundance (all age classes) in Kinbasket Reservoir. Estimates do not include depths < 20m or limited amounts of deeper habitat in Bush Pool at the south end of Kinbasket Reservoir (Dale Sebastian, MWLAP, pers. comm.).

Year	Population Estimate	+/- 95% Confidence limits	Age class component of total population (%)		
			Fry (0+)	(1-3+)	(2-3+)
2001	10.1 million	(9.0-10.9)	7.6 million (76%)	2.4 million (24%)	0.8-1.2 million (35-50%)
2002	8.0 million	(7.1-8.8)	6.5 million (81%)	1.5 million (19%)	0.5-0.8 million (35-50%)
2003	10.8 million	(9.9-12.1)	8.9 million (82%)	1.9 million (18%)	0.7-1.0 million (35-50%)

Kokanee in Kinbasket Reservoir grow rapidly during their first year compared to other populations in south-central B.C. (Sebastian et al. 1995). However, growth rates appear to decline considerably during the second and third year of life averaging 3 to 4 cm annual increases. The mean size of each age class for 0+ to 3+ kokanee captured in trawl and gill net samples in August 1993 was 60 +/- 2 mm, 182 +/- 2 mm, 203 +/- 5 mm, and 225 +/- 26 mm respectively. The mean length of kokanee measured during a creel survey on Kinbasket reservoir in 1994 was 233 mm, and mean weight was 162g ((n = 35); Pole 1995). Periodic monitoring of spawners in Kinbasket tributaries determined size of spawning

kokanee (the 3+ age class) has averaged 270 mm in length and 223 g in weight for the last two years (Westover 2003).

2.1.3.2. Mountain Whitefish (healthy)

Mountain whitefish represent a substantial component of the Kinbasket Reservoir sportfish catch accounting for up to 25% of the gillnet catch (RL&L 2001). Studies indicate that whitefish utilize riverine habitats for rearing and adult feeding and reservoir/ large river habitats for overwintering (Columbia, Canoe, and Wood Rivers). In tributary habitats, mountain whitefish densities ranged from 153 to 438 fish per 1000 m² (Aquatic Resources Ltd. 1992). Information on the size and numbers of the adult population in the reservoir is currently lacking for this species.

2.1.3.3. Bull trout (healthy)

A substantial bull trout population has developed in Kinbasket Reservoir, with individuals reportedly reaching 10 kg. This population forms a major component of the sport fishery in Kinbasket Reservoir (RL&L 2001), where bull trout are considered abundant. During a 1995 creel survey (Pole 1996), the total catch was composed of 62.3% bull trout. The largest sample size of bull trout from Kinbasket was collected during the 1995 creel survey ($n = 28$); fish lengths averaged 550 mm and weights averaged 3.5 kg (Pole 1996). No population abundance estimates or habitat use studies have been conducted for bull trout in Kinbasket Reservoir.

2.1.3.4. Rainbow trout (healthy)

Prior to inundation, large-bodied piscivorous rainbow trout (locally known as “yellow-fins”) spawned in Camp Creek (a tributary of the Canoe River). Although no longer observed in the fishery, descendants of these indigenous trout may still exist in the reservoir. Genetic analysis revealed that upper Arrow Lake and Kinbasket Reservoir rainbow trout are more similar to modern day Camp Creek trout than to those spawning in tributaries of the Columbia River at Revelstoke. This suggests some affinity to the ancestral adfluvial Camp Creek population (Taylor and McLean 1999). However, it is unlikely this population is composed of modern day descendants of ancestral piscivores because their reported maximum size is only 2 kg (RL&L 2001).

Since the formation of Kinbasket Reservoir in 1973, a substantial rainbow trout population has developed (RL&L 2001). Rainbow trout accounted for 22.4% and 20.4% of the sportfish catch in 1994 and 1995 respectively (Pole 1996, 1995). The largest sample size of rainbow trout from Kinbasket Reservoir was collected during the 1994 creel survey ($n = 56$); fish lengths averaged 300 mm (range: 194 – 414 mm) and weights averaged 350 g (range: 90 – 750 g) (Pole 1995). Rainbow trout population abundance or habitat use studies have not been conducted for Kinbasket Reservoir.

2.1.3.5. Burbot (reservoir unknown, riverine depressed)

Little information is available on the current status of burbot in Kinbasket Reservoir. The only reported catch was at Sullivan Arm where the mean length of the sampled burbot was 67.5 cm ($n = 9$, RL&L 1996b). Angler reports suggest that the current burbot fishery of Kinbasket Reservoir remains abundant with large catches reported at the mouths of Sullivan and Bush rivers (Prince 2001).

In areas from Kinbasket Lake to the headwaters, Columbia River burbot were historically abundant and large. Specific areas of abundance included the mouth of the Sullivan, Bush, Beaver, Kicking Horse, Spillimacheen rivers, Quartz and Bugaboo creeks (Prince 2001). Catches of fish weighing 15-20 lbs. were common at Bugaboo Creek, Spillimacheen and Beaver Rivers during spawning in February and supported a commercial cod fishery in the early 1960's. Today, there has been a drastic reduction in the size and numbers of burbot upstream from Kinbasket Reservoir attributable to overfishing and habitat degradation (Prince 2001).

A four-year study examining characteristics of the burbot spawning population in the Columbia River headwaters (i.e., Columbia Lake) documented decreasing numbers of spawners: 1500 in 1996 and 1997, 745 in 1998, and 86 in 1999 (Arndt and Hutchinson 2000). Average size of spawners ranged from 545 to 500 mm, which is significantly less than the historical range. The largest known burbot in British Columbia was captured in Windermere Lake in 1923 and weighed 15.44 kg (34 lbs), (McPhail and Paragamian 2000).

2.1.3.6. Westslope Cutthroat trout (depressed)

Local anglers historically captured this species in the tributaries of the Columbia River from Spillimacheen to Columbia Lake (e.g. Quartz, Beaver, Isaac, Frances, and Goldstream Creeks). However, these populations currently are reported as depressed (Prince 2001). Cutthroat trout have been reported only in tributary inventories (RL&L 2001).

2.1.3.7. Brook trout (unknown)

Brook trout only have been reported in tributary inventories (RL&L 2001).

2.1.3.8. Non-sport Species

Pygmy whitefish were present (1965) in tributaries of Kinbasket Lake prior to inundation; however, their presence in the reservoir or lower sections of the tributary streams has not been documented (RL&L 2001). Similarly, longnose dace and torrent sculpin species have not been documented in the reservoir, and are known only in tributaries and the upstream Columbia River. Prickly sculpin, in particular smaller (40 – 80 mm) individuals, were captured in nearshore habitats (Aquatic Resources 2002).

Peamouth chub are the most abundant non-sport fish species in the reservoir having been collected in four of the five years of gill net sampling where they represented up to 37% of the catch (RL&L 2001). Longnose sucker, largescale sucker and northern pikeminnow appeared in the catch for the first time in 1987, but together, only comprised 11% of the catch (RL&L 2001). Three redbside shiners were captured for the first time in gill net sampling conducted in 1993, representing 1.4% of the total catch (RL&L 2001). All of these suckers, minnows and sculpins have been recorded in the upstream Columbia River and although relative abundance was not reported, it is likely the status of these species is healthy. Status of pygmy whitefish is unknown.

2.2. Acceptable Impact Levels

Policy makers must establish acceptable impact levels based on scientific hypotheses regarding how the impact will affect a NTT. Concrete management objectives should be the starting point for the assessment. Otherwise consensus on risk assessment issues will be difficult because people will be assessing risks against different standards (Pearsons and

Hopely 1999). Risk assessments should also include the weighing of benefits to evaluate the net value of proposed management actions.

Impacts to NTT are expressed relative to baseline abundance, distribution, and size structure (Pearsons and Hopely 1999). For example, an acceptable impact level for the status of an endangered species may be zero, but for a healthy population with moderate utilization value, it may be 40%. This task poses the greatest challenge to complete because of the high diversity of values associated with certain species of fish.

Preliminary NTT objectives of 10% were proposed as a conservative impact level and were set for all taxa. The impact level may be refined upward for many species (e.g., kokanee) due to their status in Kinbasket Reservoir as a healthy and increasing taxa. It is doubtful that this magnitude of variation (i.e., 10%) is detectable; however, as empirical data become available, statistical analysis that can define the magnitude of variation, and partition it into spatial and temporal components, can determine detection and statistical power levels.

2.3. Spatial-temporal overlap of sturgeon with NTT

The stocking of hatchery-reared sturgeon may pose ecological risks to wild fish species in areas where both occur. Sturgeon may reduce the growth and/or prey on wild fish. Although the magnitude of ecological risk is strongly dependent on the degree of sympatry (McMichael and Pearsons 2001), additional relevant ecological data are needed to better estimate net effects of interaction between populations. In other words, sympatry alone does not confirm risk. While closely related species that naturally do not exist in sympatry but occupy similar environments have the greatest potential for interference competition, naturally sympatric species are more likely to have evolved mechanisms for partitioning limited resources (Gunckel *et al.* 2002).

Interactions can occur at two distinct times: 1) as a result of direct releases of introduced fish, and 2) through an increase in naturally produced offspring from introduced fish. Knowledge of the movement patterns of the stocked species and the distribution of NTT is essential in predicting the degree and importance of sympatry. Since little information is available on habitat use by NTT in Kinbasket Reservoir or the upper Columbia River, the information presented in the following section has been supplemented first with knowledge of habitat use from studies within the Columbia drainage followed by data from elsewhere within their geographic range.

2.3.1. NTT overlap with adult white sturgeon

The bulk of information collected on white sturgeon habitat use stems from studies on wild populations. Since transplanted wild sub-adult white sturgeon (30-92 cm fork length) from the lower Columbia River have shown a similar distribution to resident wild fish when stocked in a reservoir (Rien and North 2002), and in the Transboundary reach of the Columbia River, hatchery reared juveniles have been relocated with aggregations of wild sturgeon (Larry Hildebrand, Golder and Associates, pers. comm.), it is hypothesized that sturgeon stocked in the study area will exhibit similar habitat use patterns as determined from studies on wild fish. However, it should be noted that hatchery-reared fish often behave differently in the wild than naturally reared fish and information addressing those differences in white sturgeon currently is not available.

2.3.1.1. Adult white sturgeon habitat use

Upper Columbia River adult sturgeon (upstream from Lake Roosevelt) often occupy riverine and lacustrine habitats at depths of 15-30 m (RL&L 1994). Thus, sturgeon are expected to have more overlap with non-target taxa that occupy depths greater than 15 m. However, sturgeon are opportunistic feeders and will exploit shallow water habitats when feeding on aggregating prey species such as spawning mountain whitefish and kokanee. Sturgeon will also occupy shallow water during spawning. In Columbia River reservoirs, sturgeon spawn in swift waters (0.8-2.1 m/s), over cobble substrate, with water temperatures of 12-18°C and depths of 4-24 m (Parsley et al. 1993). In winter (i.e., November-February), reservoir sturgeon move to deep water habitats (up to 500') where they exhibit very little movement and presumably limited feeding activity (Prince 2004).

The extent that stocked sturgeon will move between Kinbasket Reservoir and upstream tributaries (e.g., Columbia Wetlands) is unknown, as some sturgeon show limited movements, while others move extensively both within and between rivers, lakes and the ocean (Pacific States Marine Fisheries Commission 1992; Golder Associates Ltd. 2004). While very few fish below Hugh Keenleyside Dam (Castlegar, B.C.) have been observed moving distances greater than 40 km (the majority remaining within one kilometer of their original release location, RL&L 1994 and 1996), upper and lower Columbia sturgeon frequently travel the length of a reservoir, up to 155km (North et al. 1992; Prince 2004). Movement into alternate water bodies appears limited to overwintering, spawning and exploiting prey aggregations (Prince 2004). It is recommended that telemetry studies be performed to determine the extent of movements and to document important habitats (e.g., spawning, overwintering, feeding).

2.3.1.2. Kokanee

All free swimming life stages of kokanee live offshore in Kinbasket Reservoir (Sebastian et al. 1995) and thus are expected to be encountered by sturgeon. Hydroacoustic surveys to assess kokanee stocks in Kinbasket Reservoir have been conducted for the last decade though complete surveys have been conducted for only 1994, 2001, 2002, and 2003 (Dale Sebastian, MWLAP, pers. comm.). High numbers of kokanee were found in the Canoe Reach, Mica Pool, and the Columbia Reach. Vertical layering of kokanee was observed generally between 20-50 m depth, which overlaps with the expected distribution of adult sturgeon. In the fall, kokanee spawners migrate to the lower reaches of tributaries to the reservoir and the upper Columbia River.

2.3.1.3. Mountain whitefish

Sympatry of mountain whitefish and adult sturgeon is expected to be limited to the adult whitefish life stage. Adult mountain whitefish are captured at depths <20m in Kinbasket Reservoir (Sebastian et al. 1995). In lakes, adult mountain whitefish usually occur at depths of less than 20 m but exhibit seasonal changes in habitat use that are associated with temperature changes (Scott and Crossman 1973). In Koochanusa Reservoir, adults are found in shallow water in the spring but as summer progresses they move to deeper water and then return to the littoral zone in the fall (Chisholm et al 1989). After spawning in February/March, they again move to deep water to over-winter.

Juvenile mountain whitefish in lentic habitats tend to remain in shallow (<2m), inshore areas throughout the spring and summer where they are associated with sand and coarse gravel

substrates. This habitat preference is expected to limit overlap with adult sturgeon. Similarly, young-of-the-year whitefish are found in shallow water (<50 cm) over fine gravel or sand substrates in both lakes and rivers. In rivers, adult and juvenile mountain whitefish prefer depths <3 m, with moderate to fast velocities and gravel/cobble substrates; therefore only would be encountered by sturgeon during spawning (Ford et al 1995).

2.3.1.4. Bull trout

Bull trout in Kinbasket Reservoir are adfluvial, spending most of their life as adults in the lacustrine environment of the reservoir and moving into tributaries to spawn. Bull trout spawn in cold streams with coarse substrates. Spawning occurs in most accessible tributaries entering Kinbasket Reservoir. Several tributaries ($n = 18$) were accessed by radio tagged Kinbasket Reservoir bull trout, though no tagged fish were relocated in the Columbia River upstream of the reservoir (2001).

Since juveniles normally rear in their natal tributaries for several years (2-4 yrs at a fork length >200 mm) prior to returning to the lake environment (Ford et al. 1995), sympatry of bull trout and adult sturgeon is expected to be limited to the adult/subadult bull trout life stage. Young bull trout are seldom found in the littoral zone and immediately move to deep water upon entering the lake environment. In Kinbasket Reservoir, bull trout are most frequently captured at depths <20 m, although they have also been captured in pelagic and deep-water habitats (>20 m)(Sebastian et al. 1995, RL&L 2001). In spring and fall, adult bull trout forage in littoral areas at night but move to deep, open water in the summer once water temperatures in the littoral zone exceed 15°C (Ford et al. 1995).

2.3.1.5. Rainbow Trout

Rainbow trout will use most areas of a lake provided there is no competition from other species and maximum temperatures are <20-25 °C (Ford et al. 1995). Generally adults will stay at depths below the 18°C isotherm, whereas juveniles prefer margins of lakes at depths of 3-6 m. Therefore, overlap with adult sturgeon is expected to be restricted to the adult life stage.

Adults spawn in small streams with gravel substrate in spring. Once hatched, outmigration to lakes usually does not occur until late summer/early fall, and may not occur until the second year. All life stages of rainbow trout occur in Kinbasket Reservoir and are most frequently captured at depths <20 m though they have also been reported in pelagic and deep-water habitats >20 m (Sebastian et al. 1995, RL&L 2001).

2.3.1.6. Burbot

Adult burbot typically inhabit deep lakes and reservoirs occupying similar habitats to white sturgeon. Adult burbot are benthic and rarely enter water less than 2 m deep or water temperatures above 13°C (McPhail and Paragamian 2000). Burbot are most frequently associated with deep-water habitats (20-100 m) and have been captured at the mouth of the Sullivan River (RL&L 1996b) in Kinbasket Reservoir. Like sturgeon, burbot may move into shallow areas or rivers in late fall as part of a feeding migration. The habitat used by burbot in rivers is unclear, though they are known to occupy the Columbia River upstream of Kinbasket Reservoir (Prince 2001). Sub-adult burbot and sturgeon have been captured on the same set-lines in Arrow Reservoir (L. Hildebrand, Golder and Associates, pers. comm.), indicating they occupy the same habitats and are attracted to similar food sources.

Juvenile burbot (<40mm) school and are diurnal, but as they grow, they become nocturnal and adopt the adult solitary, benthic life (McPhail and Paragamian 2000). Juvenile burbot inhabit the littoral zone (0.5 to 3.0 m depth); their presence is strongly correlated with cover (rocks, weeds or debris) (McPhail and Paragamian 2000). Therefore, they are expected to have infrequent encounters with adult sturgeon.

2.3.1.7. Westslope Cutthroat Trout

Westslope cutthroat trout have not been captured in Kinbasket Reservoir or the upper Columbia River mainstem (RL&L 2001) and only have been reported in tributaries to the study area (Prince 2001). Therefore, overlap with sturgeon is not expected.

2.3.1.8. Brook trout

Brook trout have not been captured in Kinbasket Reservoir and only have been reported in tributaries to the study area (RL&L 2001). Therefore, overlap with sturgeon is not expected.

2.3.1.9. Peamouth

Sympatry of peamouth with adult sturgeon is expected to be limited to the adult peamouth life stage. Adults of this species were captured throughout Kinbasket Reservoir and were most frequent in pelagic and deep-water habitats (>20 m) (Sebastian et al. 1995). During winter, adults are closely associated with the bottom, often at depths of over 20 m (Northcote et al. 1964). In summer, adults exhibit a diel migration to inshore areas (Northcote et al 1964).

Adult peamouth move inshore to spawn during the spring (Scott and Crossman 1973). In lakes, juvenile peamouth school in littoral areas and therefore are not expected to be sympatric with adult sturgeon. In large rivers, peamouth congregate near the mouths of tributary streams and often ascend these creeks.

2.3.1.10. Northern pikeminnow

Overlap of northern pikeminnow with adult sturgeon is expected to be limited to the adult life stage. Northern pikeminnow appeared in the Kinbasket Reservoir catch for the first time in 1987 and since then have comprised less than 2% of the total catch. Adults of this species were captured throughout Kinbasket Reservoir including pelagic and deep-water habitats (> 20 m) (Sebastian et al. 1995). Northern pikeminnow are present throughout the Columbia River and in a variety of habitats including riverine, reservoir and tailrace (Gadomski et al 2001). Thus, the degree of overlap with sturgeon in the reservoir is unknown. In summer, adults are bottom oriented and use the littoral zone and the off shore side of weed beds; though they also are known to move offshore eating limnetic planktivores during the fall-winter (Beauchamp et al. 1995). Juveniles typically occur in shallower water (<1.0 m) and are more surface oriented than adults moving offshore only to overwinter in deep water.

2.3.1.11. Longnose sucker

Although this species has been detected only in shallow water (<20 m) during sampling of Mica Dam forebay (RL&L 2001), longnose suckers are often associated with great depths in lakes (up to 600 ft, Scott and Crossman 1973). Lake dwelling adults and juveniles are bottom feeders and fall prey to a wide variety of predaceous fish, birds, and mammals.

Therefore, overlap of longnose suckers with adult sturgeon is expected to include both the adult and juvenile life stages. Little is known about the habitat use of adult longnose suckers in rivers.

2.3.1.12. Largescale sucker

Sympatry of largescale suckers and adult sturgeon is expected to be minimal and limited to the adult sucker life stage. This species has been detected only in shallow water sampling of Mica Dam forebay (RL&L 2001). All stages of largescale suckers usually are found at depths <3 m (Scott and Crossman 1973).

2.3.1.13. Redside shiner

The overlap of redside shiners with adult sturgeon is expected to be minimal and limited to the adult life stage. This species only has been captured in pelagic and deep-water habitats (>20 m) of Kinbasket Reservoir (Sebastian et al. 1995). In lakes adults generally occupy the littoral zone during the day at depths <4m, though at night they move offshore to the limnetic zone (Scott and Crossman 1973). Juveniles occur in loose schools around lake margins in association with vegetation.

2.3.1.14. Pygmy whitefish

Pygmy whitefish were present in tributaries of Kinbasket Lake prior to inundation; however, their presence in the reservoir or tributary streams has not been documented since the construction of Mica Dam (RL&L 2001). Therefore, overlap with adult sturgeon is not expected.

2.3.1.15. Longnose dace

Longnose dace have not been reported in Kinbasket Reservoir (RL&L 2001) but have been captured in the Columbia River mainstem between Windermere and Columbia Lakes (Radridge 1998). In other areas of the Columbia River, adults and juveniles prefer riverine habitats with the fastest available velocity, large substrate and depths <3.0 m (RL&L 1995). In lakes they are associated with wave-swept cobble beaches. Young-of-the-year are found in quiet water close to shore and in areas with cover (RL&L 1995). Longnose dace are a benthic oriented species (Scott and Crossman 1973) and their lack of detection in Kinbasket Reservoir may be attributed to sampling methods. Cyprinids are consumed by white sturgeon in the Fraser River (D. Lane pers. comm.) and the benthic orientation of longnose dace will make them vulnerable to foraging white sturgeon.

2.3.1.16. Prickly sculpin

Prickly sculpin have been reported in Kinbasket Reservoir (Aquatic Resources Ltd. 2003) and in small tributaries to the study area (RL&L 2001). In the Columbia River at Castlegar BC, adult and juvenile prickly sculpin occur over boulder substrates in relatively shallow (< 1m) and quiet water (<40 cm/s) (RL&L 1995). However, in lakes, adults have been known to occupy depths up to 100m and juveniles use open water habitats at night, frequently appearing in juvenile sockeye salmon surface trawls (Mueller and Enzenhofer 1991). Therefore, overlap of prickly sculpin with adult sturgeon is expected to be limited to the adult life stage.

2.3.1.17. Torrent sculpin

Torrent sculpin have not been reported in Kinbasket Reservoir and only have been reported in small tributaries to the study area (RL&L 2001), the Columbia Wetlands (Radridge 1998) and Columbia Lake (Taylor 1998). In lakes, adults typically occur in shallow water <1m deep with cobble substrates (Northcote 1954; Taylor 1998). Therefore, overlap with adult sturgeon is not expected.

2.3.1.18. Slimy sculpin

Slimy sculpin were captured in nearshore areas of Kinbasket Reservoir (Aquatic Resources Ltd. 2003) and in small tributaries to the study area (Radridge 1998). In lakes, slimy sculpin are bottom dwellers found in cool water, using a variety of depths (5 – 90 m) throughout the year (Scott and Crossman 1973). The benthic orientation and use of deeper water is expected to make slimy sculpin vulnerable to predation by sturgeon.

2.3.2. NTT overlap with stocked juvenile white sturgeon

There are no recent records of juvenile white sturgeon from the upper Columbia River; however, information is available on several lower Columbia River reservoir populations in the U.S. (Parsley et al. 1993). In these lower Columbia reservoirs, yolk-sac white sturgeon larvae are transported by river currents from spawning areas to deeper habitats with low velocities and finer substrates. Young-of-the-year white sturgeon (20-321 mm total length) are found at depths of 9-57 m (mean 30 m), at mean water column velocities of 0.6 m/s and less, and over substrates of hard clay, mud, silt, and sand (majority of captures were over sand). Juvenile sturgeon (150-1030 mm fork length) are found at depths of 6-58 m (mean 19 m), at mean water column velocities of 1.2 m/s and less, and over substrates of hard clay, mud, silt, and sand (99.7% captures).

In the lower Fraser River, where wetland habitat is available, juvenile sturgeon (<1m) use sloughs, backwaters, side channels and the lower reaches of tributaries (Ptolemy and Vennesland 2002). Water depth (> 5 m), low velocities, variable current direction, high turbidity and relatively warm water were cited as important for determining rearing habitat quality in the lower Fraser River (Ptolemy and Vennesland 2002). In the middle Fraser, larger juveniles have been found in the same areas as adults (Ptolemy and Vennesland 2002). Aggregations of a range of sizes, from hatchery released juveniles to adults, have been recorded together at the Columbia River - Pend d'Oreille confluence (Golder video footage).

Juvenile sturgeon released below Keenleyside Dam have been relocated in riverine habitat with aggregations of adults, as well as in Lake Roosevelt, near the river lake interface (Lee and Pavlik 2003). Therefore, some stocked juvenile sturgeon likely will utilize warm, deep accessible habitats within the Columbia Wetlands for several years and others may disperse downstream to Kinbasket Reservoir immediately.

Estimates of juvenile survival established for Kootenay River stocked juveniles is 60% for the first year and 90% afterwards (Ireland et al. 2002). Based on these estimates, approximately 35,000 1 yr old sturgeon would have to be stocked to produce the 2500 adults, assuming it would take an average of 20 years for these 1 yr fish to mature.

Additional stocking would be required only if natural recruitment did not occur and would be at a level that compensates for adult mortality.

Table 3 summarizes the expected NTT overlap with stocked juvenile white sturgeon. Information on habitat use for each of the NTT is presented in Section 2.3.1. Thus, the reader should refer to the previous section for a description of habitat use by species and age class.

Table 3. NTT overlap with stocked juvenile white sturgeon.

Species	Life stage overlap with juvenile sturgeon
Kokanee	All
Mountain whitefish	Adult
Bull trout	Adult/subadult
Rainbow trout	Adult/subadult
Burbot	Adult and juvenile
Cutthroat trout	None
Brook trout	None
Peamouth	Adult and juvenile
Northern pikeminnow	Adult and juvenile
Longnose sucker	Adult and juvenile
Largescale sucker	Adult and juvenile
Redside shiner	Adult and juveniles
Pygmy whitefish	None
Longnose dace	Adult and juveniles
Slimy sculpin	Adult and juveniles
Prickly sculpin	Adult
Torrent sculpin	Adult and juveniles

2.3.3. Potential for recruitment of white sturgeon upstream of Mica Dam

The goal of recovery is to re-establish self sustaining populations of white sturgeon. Habitat upstream of Mica Dam includes attributes believed to be important in successful recruitment of white sturgeon in the lower Fraser River, such as natural hydrograph, turbid water and availability of side channels, sloughs and backwaters (Perrin et al. 2003). Factors that may limit successful recruitment include cold temperatures and lack of documented spawning sites.

The Columbia River upstream of Kinbasket Reservoir and major tributaries to Kinbasket Reservoir are glacial fed and remain cold throughout the year. Temperature sensors were installed in the Columbia River and several tributaries in 2002. Tributary temperatures were colder than Columbia River temperatures (CCRIFC, unpublished data) and may not be high enough for successful spawning and recruitment. Daily mean temperatures documented during spawning in other populations range from: the Kootenai River (7.5 – 14°C Paragamian and Wakkinen 2002), lower Fraser River (13 – 19°C Perrin et al. 2003), Columbia River downstream of McNary Dam (10 – 18°C Parsley et al. 1993), Pend D’Oreille

River – Columbia River confluence (14 – 21°C Hildebrand et al. 1999) and Columbia River at Revelstoke (10°C Tiley 2004). In the Kootenay River, most spawning events were recorded when daily mean temperatures were close to 10°C (9.5 – 9.9°C), but decreases of 0.8°C or more appeared to disrupt spawning (Paragamian and Wakkinen 2002).

Spawning areas described in the Canadian Columbia River are located in fast, turbulent water over large rocky substrate (Ptolemy and Vennesland 2002) and the same sites are used from year to year (Hildebrand et al. 1999). In contrast, in the Kootenay (Kootenai) River, spawning sites changed during the season over a 10 km reach and the substrate was primarily sand (Paragamian et al. 2002). In the lower Fraser River, sturgeon were found to spawn in side channels, in relatively shallow (<3 m) water, with a variety of substrates (Perrin et al. 2003).

Anecdotal information indicated sturgeon may have spawned in two areas of the Columbia River upstream of Kinbasket Reservoir – at “Surprise Rapids” (near Donald) and near the confluence of the Spillimacheen River. Daily mean temperatures at Donald were near 10°C in late July in 2002, but fluctuations of >1°C may disrupt spawning (Figure 2). The record at Athelmere, near the outlet of Windermere Lake, was for a shorter period, but generally mean daily temperatures were about 9°C higher than at Donald (Figures 2 & 3). It is expected that the site near Spillimacheen would have intermediate temperatures, thus suitable temperatures for spawning may be present in June. At Revelstoke, eggs developed to larval stages in temperatures near 10°C in 2003 (Tiley 2004). Juveniles reared in ambient temperatures at Revelstoke Dam in 2004 - 2005 continued to eat and show growth at temperatures below 5°C (Tiley 2005). Therefore it is unlikely that temperatures will preclude successful recruitment in the Columbia River upstream of Kinbasket Reservoir.

Perrin et al. (2003) hypothesized that in the lower Fraser River shallow waters were used because the high turbidity (average 42 NTU) provided cover or light attenuation in lieu of depth or velocity. Turbidity in the Columbia River at Donald, upstream of Kinbasket Reservoir, is high during summer (Figure 4). Near Radium, point measurements of turbidity have been 46 – 50 NTU (Nijman, 1985), similar to measurements in the lower Fraser River where successful spawning and recruitment was monitored (Perrin et al. 2003). Although habitat suitability has not been examined in the Columbia River near Spillimacheen, the area includes side channels and backwaters, thus may have similar attributes to those described in the lower Fraser River. While it is unknown how stocked sturgeon would locate spawning areas when mature, imprinting is often an important variable in fish species returning to spawning areas. In addition, the downstream migratory behaviour of young sturgeon and the probably lack of suitable habitats and food resources in Kinbasket Reservoir, the Spillimacheen confluence should be considered as a possible release site for juvenile sturgeon.

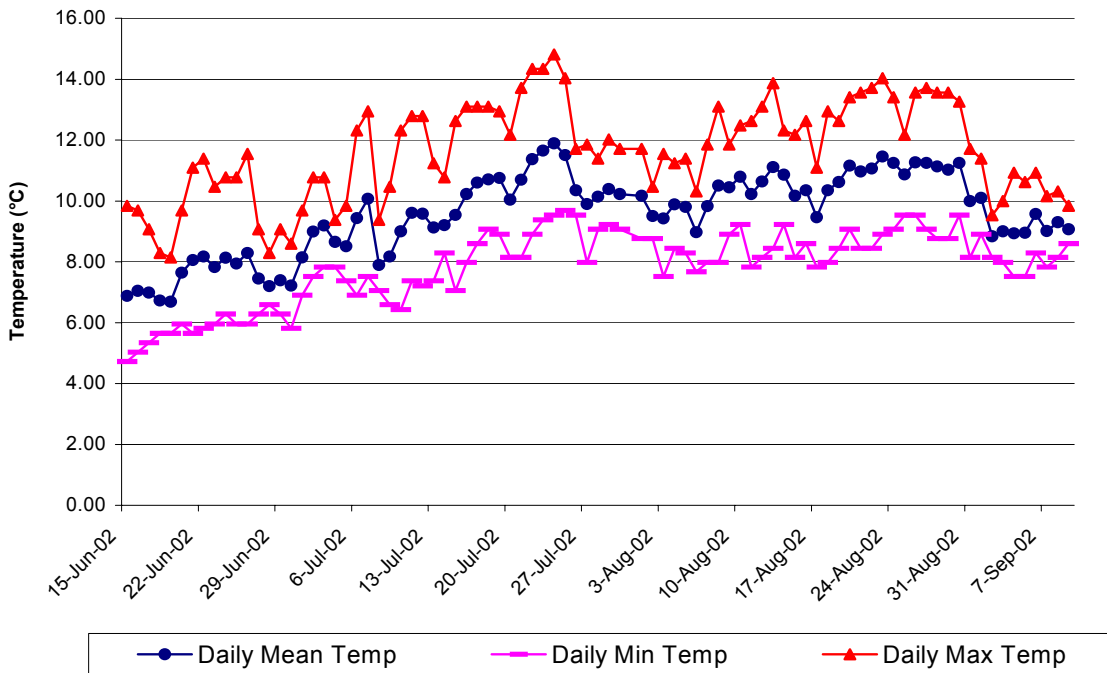


Figure 2. Water temperature at Columbia River at Donald in summer 2002 (source CCRIFC, unpublished data).

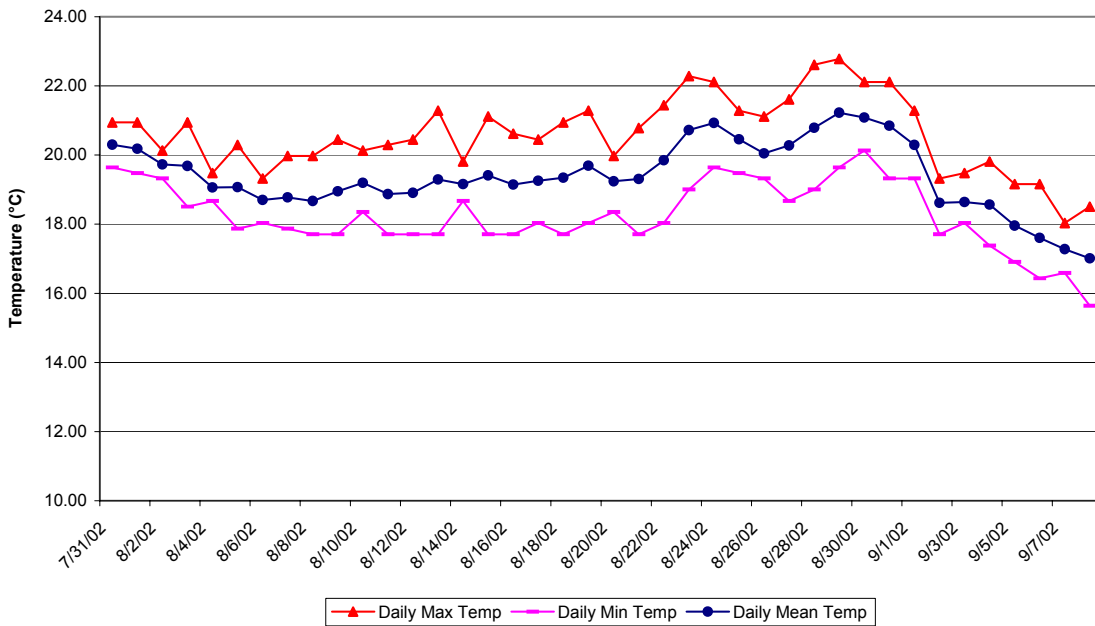


Figure 3. Water temperature at Columbia River at Athelmere in summer 2002 (source CCRIFC, unpublished data).

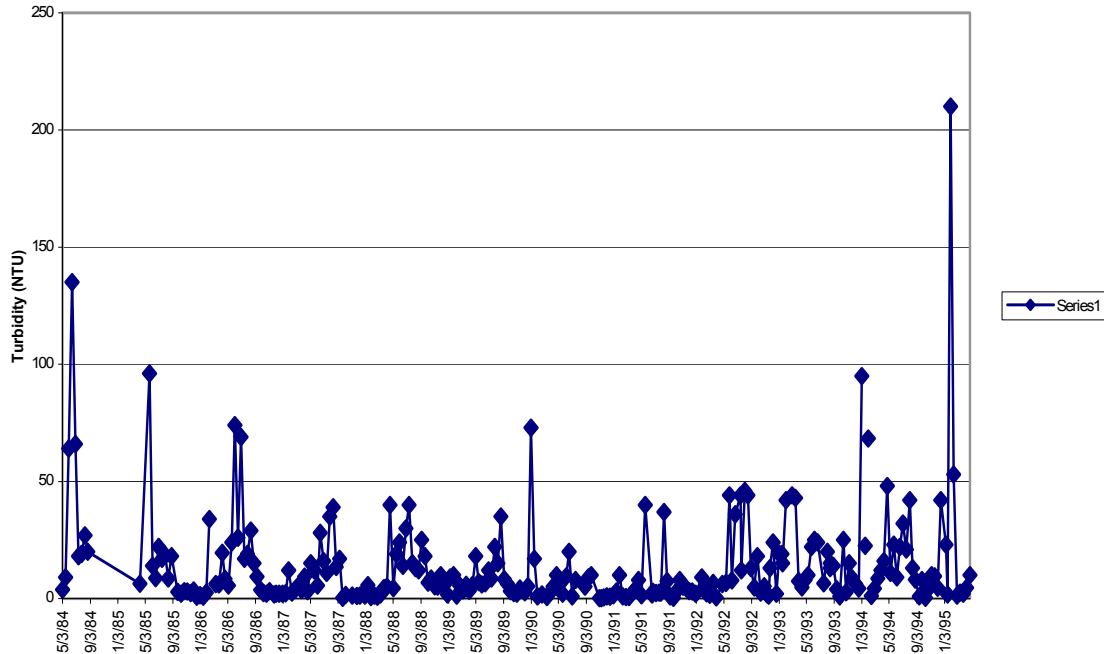


Figure 4. Turbidity in Columbia River at Donald 1984 – 1994. (Source: Environment Canada)

2.4. Ecological Interactions

The third task required in the ecological risk assessment of a fish stocking program is to postulate which ecological interactions may occur between NTT life stages that overlap with the target taxon and which interactions are potentially strongest (Pearsons and Hopely 1999). Interactions may be positive or negative and they may be weak, moderate, or strong. Strong interactions are defined as those with a high probability of causing an impact that exceeds an NTT objective in either a positive or negative direction. For example, if competition is thought to have a high potential to affect an NTT beyond an acceptable limit (e.g., negative 10%) then it would be a strong interaction.

Information regarding the ecological interactions of sturgeon is limited; thus, potential interactions were determined by examining the available literature on common resources, diet, and behavior. Deleterious interactions include competition for food or space, predation, decreased survival of NTT due to predator attraction or increased susceptibility to predation, pathogen transfer to NTT, nutrient mining, and behaviour alterations. Beneficial interactions include an increase in prey available for piscivorous NTT, an increase in available nutrients, and increasing survival of NTT due to satiating predators.

2.4.1. Feeding Ecology of White Sturgeon

In order to identify species that are competitors or at risk of predation, the ecology of the target and non-target taxa was reviewed. Sturgeon are bottom feeders and show special morphological adaptations including ventral barbels (“whiskers”), and a protrusible, sucker-like mouth. Their digestive system structure indicates they are carnivores, feeding on invertebrates and fish (Ford *et al.* 1995).

Sturgeon larvae forage on chironomid larvae, cyclopoid copepods, and amphipods (Muir *et al.* 2000). Juveniles consume amphipods, chironomids, freshwater clams, aquatic insect nymphs and small fish (McCabe *et al.* 1993). In the Transboundary Reach of the Columbia River, *Mysis spp* are the primary food source in summer and fall (Larry Hildebrand, Golder and Associates, pers. comm.).

Adult white sturgeon are more predaceous than any other North American sturgeon (Semakula and Larkin 1968). Fish dominate the adult sturgeon diet through most of the year (50%); in winter, benthic invertebrates become dominant with clams being the most important item (12-41%) (Semakula and Larkin 1968; McKechnie and Fenner 1971; Scott and Crossman 1973; Partridge 1980). Shallow mudflat areas appear important for the production of sturgeon food particularly in the winter.

Detailed information regarding adult white sturgeon diet is lacking for the upper Columbia region of BC. In the Fraser River, B.C. eulachons were the most abundant prey species followed by sculpins (*Cottus sp.*), sticklebacks (*Gasterosteus aculeatus*), lampreys (*Petromyzontidae*), and juvenile sturgeon (Semakula and Larkin 1968). Adult sturgeon have been located near the mouths of kokanee spawning tributaries in the late summer and fall in Arrow Lakes Reservoir (Prince 2004) and in the Transboundary reach of the Columbia River sturgeon feed on spawning aggregations of mountain whitefish (Larry Hildebrand, Golder and Associates, pers. comm.). Species that may be particularly vulnerable to sturgeon feeding behaviour in Kinbasket Reservoir include kokanee, prickly sculpins, and burbot. Invertebrates also are consumed: particularly chironomid larvae, crayfish, stonefly and mayfly larvae, mysids, *Daphnia spp.*, and freshwater copepods. Plant material is taken incidentally.

2.4.2. Competition

Given the high fish content in adult sturgeon diets, stocked sturgeon would compete for food with all overlapping piscivorous NTT. Piscivorous NTT in Kinbasket Reservoir include adult bull trout, burbot, northern pikeminnow, and prickly sculpin (Northcote 1954; Ford *et al.* 1995). The omnivorous diet of the prickly sculpin is most similar to the adult white sturgeon but due to the small size of the prey items (i.e., fish) consumed by sculpins, competition with sturgeon is expected to be weak. Similarly, the limited habitat overlap and abundance of northern pikeminnow in the reservoir should minimize competition with stocked sturgeon. Although bull trout, like adult sturgeon, are primarily piscivorous, competition is estimated to be moderate to weak because they target kokanee and rainbow trout. Kokanee are expected to be a major food source for sturgeon, however they are abundant and unlikely to become a limited resource. Burbot; however, with similar diets and habitat preferences, are hypothesized to have strong competitive interactions with adult sturgeon.

Sturgeon likely will compete with burbot for food as well as rearing and overwintering habitat since both are bottom oriented, deep water, piscivores. Mudflats appear important to

burbot, which are known to burrow in fine substrates, presumably for shelter, during periods of inactivity (Schram 2000) and in the Canadian Columbia River, sturgeon are known to target the shallow mudflats of Beaton Arm in the Arrow Lake Reservoir in the winter (RL&L 2001b). In addition, mudflats are important to sturgeon for the production of food particularly during winter. It is not known if burbot or sturgeon exhibit interspecific territoriality or if fine sediment (sand and mud) habitats are limiting in Kinbasket Reservoir. Thus, competition for these habitats could be strong if they were limited and optimal (strongly selected by) for both species while present in consistently high enough densities. Since white sturgeon do not construct nests like salmonids but are broadcast spawners, releasing their eggs and sperm in fast water during spring and summer, they would not compete for spawning habitat with any NTT.

Due to the predominance of invertebrates in their diet, juvenile sturgeon could compete with kokanee (adult and juvenile), mountain whitefish (adult), rainbow trout (adult and juvenile), burbot (juvenile), peamouth (adults and juveniles), pikeminnow (juvenile), longnose sucker (adults), largescale sucker (adults), redbreasted shiners (adults), and prickly sculpin (juveniles) (Ford et al. 1995; Scott and Crossman 1973). Juveniles remaining in the wetlands are likely to compete with sculpins, whitefish, cyprinids and suckers for drifting and benthic invertebrates. Larger juveniles likely will consume small fish, competing with northern pikeminnow and salmonids. If a high percentage of juveniles migrate into Kinbasket Reservoir, the limited productivity of zooplankton and benthos may result in strong competition for these food resources. In Lake Roosevelt, juvenile sturgeon were captured in the same nets as redbreasted shiner, largescale sucker, longnose sucker, lake whitefish, smallmouth bass and walleye (Lee and Pavlik 2003), indicating they are using similar areas.

2.4.3. Predation

Predation may be direct (i.e., consumption of NTT) or indirect (i.e., the increase in predation by other predator species resulting from the presence of hatchery reared sturgeon). Indirect predation can occur through the following mechanisms: (1) Hatchery reared sturgeon displace NTT from preferred habitat, making NTT more vulnerable to predators, or (2) the increased abundance of hatchery reared sturgeon attracts predators, causes predators to switch prey, or increases population densities of predators which can increase consumption of NTT, particularly if NTT are preferred (Pearsons and Hopely 1999). Stocked sturgeon are unlikely to displace NTT (other than burbot) or attract predators; thus interactions are expected to be limited to direct predation by sturgeon on sympatric taxa (Section 2.3.1).

Aggregating fish, bottom oriented fish and invertebrate species are most likely to be consumed by adult sturgeon. Therefore, burbot, mountain whitefish, kokanee and sculpins likely will be encountered and consumed at a greater frequency than pelagic rainbow and bull trout. Peamouth predation is expected to occur during the winter months when they occupy deep (>20 m) habitat. In Kinbasket Reservoir, limited consumption of northern pikeminnow, redbreasted shiners, and sucker spp. by sturgeon is expected since there is limited habitat overlap these species and they are apparently rare in the reservoir (RL&L 2001).

2.4.4. Behavioral Anomalies

The presence of white sturgeon is not expected to alter the natural behavior of NTT. The presence of white sturgeon in other parts of the Columbia drainage has not interrupted diel migrations (e.g., kokanee) or activity (e.g., spawning migrations) of other taxa. White

sturgeon are indigenous to the Columbia drainage and have evolved with all of the current native taxa of Kinbasket Reservoir.

2.4.5. Pathogenic Interactions

The transfer of a pathogen or the increased susceptibility of NTT to pathogens is being addressed in a separate document (CCRIFC 2005).

2.4.6. Nutrient Mining

Given the long-lived nature of white sturgeon (i.e., they may live 100+ years), combined with their preference for kokanee as a food source, some reduction in nutrients/food could be expected if sturgeon are stocked into the study area. Nutrients that would normally be made available to NTT through the carcasses of kokanee would be locked up in sturgeon biomass (i.e., those that consumed them) for a period of up to 100 years. This interaction is expected to be only weakly negative.

2.4.7. Prey Availability

Besides other sturgeon, there are no published accounts of predators of either young or adult sturgeon (Scott and Crossman 1973). However, stocked sturgeon may contribute additional resources to some NTT if they attempt to spawn following maturity. White sturgeon eggs have been found in the guts of three native species in the Columbia River: northern pikeminnow, large-scale sucker, and prickly sculpin (Miller and Beckman 1996).

In 1994 and 1995, 632 stomach content samples were collected from Kootenai River fishes: northern pikeminnow (formerly northern squawfish), peamouth chub, and suckers (Anders, 1994a, 1996). Of 428 naturally spawned white sturgeon eggs collected from the Kootenai River during 1994 and 1995, 12.2% (52) were recovered from these stomach content samples (Anders 1994a, 1994b, 1996). Although observed predation accounted for only 12% of all eggs collected during these 2 years, identification of eggs in stomach content samples was possible for only a short period of time, thus, likely represented an extremely conservative estimate of egg predation.

Since sturgeon spawn intermittently (i.e., every 2-11 years) with only a small portion of the population being reproductively active at any one time, the amount and duration of additional food supplied to egg predators by a population of only 2500 adults would be minimal and would not be expected to impact population densities.

2.4.8. Nutrient Enrichment

An increase in nutrients available to NTT is not expected due to the long-lived nature of sturgeon and the low numbers of stocked individuals.

2.4.9. Predator Swamping

The survival of NTT is not expected to be enhanced due to swamping of predators by hatchery fish because the number of stocked individuals will be low.

2.4.10. Hypothesized strong interactions

Strong interactions are defined as those causing an impact that exceeds an NTT objective in either a positive or negative direction. Interactions were identified as “strong” if the impact to abundance, distribution, and size structure of NTT was estimated to be 10% or greater. While a conservative impact level of 10% was proposed, this may be refined upward for many species (e.g., kokanee) due to their status as a healthy and increasing taxa. Thus, it is recommended that sampling to estimate distribution, abundance, and diet composition studies of potential predators and competitors should be conducted to confirm potential “strong interactions” in the Kinbasket aquatic community.

2.4.10.1. Predation on Kokanee, Mountain Whitefish, Sculpins and Burbot.

Kokanee, burbot, mountain whitefish, and sculpins are expected to be encountered and consumed more than pelagic rainbow and bull trout. Little information is available on the current status of burbot, mountain whitefish, and prickly sculpin in the study area. Thus, the degree of risk to these taxa is uncertain. At this time, a significant impact (>10%) appears unlikely because anecdotal angler reports and limited gill net sampling data suggest that the current whitefish and burbot populations of Kinbasket Reservoir are healthy. However, until studies are conducted to estimate their population abundance, distribution, and size structure in Kinbasket, whitefish, burbot, and sculpins should be considered taxa with potentially strong ecological interactions with sturgeon (predation).

The biomass of proposed stocked sturgeon at maturity and their predation rates are unknown. However, a hypothetical scenario was developed to estimate potential predation impacts of the stocked population on the existing kokanee population, as there are data for size and abundance of kokanee in Kinbasket Reservoir. Consumption rates specific to adult white sturgeon are not available (Cui and Hung 1995). However, bioenergetic models have been developed from experimentally determined food consumption rates of juvenile white sturgeon (Cui et al., 1996) and general knowledge of adult consumption rates relative to juvenile rates (Bevelhimer 2002). Since the optimum temperature for growth tends to decrease with increasing fish size, any discussion of consumption rate must address both components of size and temperature.

The following assumptions were used to estimate sturgeon consumption of kokanee:

1. The proportion of kokanee in the diet of sturgeon in Kinbasket Reservoir for 150-160 days in spring, summer and late fall was estimated as 50%, based on foraging behaviour described in other systems (Semakula and Larkin 1968; McKechnie and Fenner 1971; Scott and Crossman 1973; Partridge 1980) and 100% during the 20-30 day kokanee spawning run in August and September;
2. Average sturgeon size of 22.7 kg;
3. Consumption rate of 1% (wet weight natural food) of body weight per day for temperatures above 8°C (observed in Columbia River broodstock, Ron Ek, manager of sturgeon aquaculture, Kootenay Trout Hatchery, pers. comm.);
4. Water temperatures of 8°-15°C occur for 110 days;
5. At temperatures >15°C, food is increased to 2% body weight per day (wet weight)(Dr. Dave Lane, Lane Technical Services, pers. comm.);
6. Water temperatures of >15°C occur for 30-40 days exclusive of spawning run timing;

7. Mean weight of kokanee prey is 175 g (mean weight range 1-3+ yrs combined = 162-233g, Pole 1995, Westover 2003), resulting in 0.65 kokanee per day per sturgeon at 1% feeding rate; and
8. Kokanee in the spawning runs are 3+ (mean weight = 203-242.2 g, Westover 2003) and water temperatures >15° (use 2% feeding rate), resulting in a feeding rate of 2 kokanee per day per sturgeon.

Using these assumptions, a population of 2500 sturgeon would consume between 276,250 and 308,750 kokanee during the nonspawning time (110 days at 1% = 178,750 kokanee and 30-40 days at 2% = 97,500 and 130,000 kokanee). During the spawning run, adult sturgeon would consume 100,000 to 150,000 3+ kokanee for total annual consumption of 376,250 to 458,750 kokanee/yr. Based on the 2001-2003 kokanee population estimates (Table 2), this consumption rate represents 15-30 % of the 1-3+ population.

The above scenario assumes a constant population of 2500 adults, exclusive consumption of 1-3+ kokanee for 50% of their diet, and a continuous feeding rate, all of which likely overestimate the impact to the kokanee population. However, assuming a stable age distribution is attained, 22.7 kg is likely an underestimate of mean adult sturgeon weight.

An acceptable impact level of 10% was proposed for this taxon due to the high ecological importance of kokanee as a food base to reservoir fish populations but may be refined upward due to the status of kokanee in Kinbasket as a healthy and increasing taxa. Moreover, if the kokanee population biomass is limited by pelagic secondary productivity in Kinbasket reservoir, a reduction in kokanee population numerical abundance may result in an increase in average size, making them both more attractive to anglers (a benefit) and possibly more fecund. Predation on the remaining NTT of Kinbasket is expected to be less than 10% because white sturgeon and other NTT are allopatric for most of the year and our current understanding of adult sturgeon diets indicates that sturgeon are omnivorous and consume a variety of prey species; thus, no one species should be over-exploited.

2.4.10.2. Competition with Bull Trout

Where fluvial populations often are affected most by habitat alteration, adfluvial bull trout may be affected more by biotic interactions in lakes or reservoirs. Like sturgeon, bull trout become more piscivorous with increasing size, with bull trout > 450 mm exhibiting absolute piscivory. Kokanee, followed by mountain whitefish and other bull trout represent the largest fraction of fish in the diet, although cyprinids, cottids, and catostomids also are consumed (Fraley and Sheppard 1989; Beauchamp and Van Tassel 2001).

Model simulations indicate that 1,000 bull trout of at least 200 mm may consume 13,876 kokanee, 5,273 bull trout, 4,335 rainbow trout, and 3,172 mountain whitefish annually. In addition, an estimated 10,224 unidentifiable salmonids and 56,715 other fish (predominantly longnose dace) are consumed (Beauchamp and van Tassel 2001). In one 1,619 ha reservoir on the east side of the Cascade Mountains, a bull trout population of 3600-8400 (\geq 200 mm FL) was estimated to have removed 44% of age 0 bull trout and 59% of age 2-3 kokanee populations (Beauchamp and Van Tassel 2001). Thus, cannibalism and prey supply are potentially important factors limiting the abundance of bull trout.

Data on piscivore abundance are required to estimate predation rates in Kinbasket Reservoir. Unfortunately, bull trout population estimates (i.e., spawner counts) for Kinbasket Reservoir are unavailable. Data from creel surveys and gill net studies suggest that the

species is abundant in the reservoir (RL&L 2001). Information on Kootenay region bull trout redd densities and distributions may be used to generate a gross estimate of the current population density of bull trout in Kinbasket. Results of a radio telemetry study indicated that bull trout spawned in at least 18 tributaries to Kinbasket Reservoir (Oliver 2001). Redd counts of some of the most prolific East Kootenay bull trout streams over the last decade ranged from 66-189 in the Skookumchuck River, 153-166 in the middle fork of the White River, and 94-1916 in the Wigwam River (Bill Westover, MWLAP biologist, pers. comm.). Thus, a reasonable upper estimate might be 500 redds per known spawning bull trout tributary in Kinbasket yielding a total of 9000 redds. At 1.5 spawners per redd, that would put the Kinbasket adult bull trout population at 13 500 individuals. Given that not all adult bull trout spawn each year, the Kinbasket population of bull trout of 200 mm or greater FL may be estimated at a maximum of 20,000. At this population density, their annual kokanee consumption rate (i.e., 13.876 kokanee per bull trout per year) may be estimated at 277,520, or 11-14% of the 1-3+ Kinbasket kokanee population.

Bull trout are one of the piscivorous species of note in Kinbasket Reservoir and coexist with white sturgeon in other parts of their range (e.g., Arrow Lakes). Naturally sympatric species are more likely to have evolved mechanisms for partitioning limited resources (Gunckel *et al.* 2002) and the current kokanee population should be sufficient to support 2,500 sturgeon with minimal if any impact to the bull trout population. Therefore competitive interactions between bull trout and sturgeon are considered weak to moderate.

2.4.10.3. Competition with Burbot

Little information is available on the current status of burbot in Kinbasket Reservoir. Thus, the degree of risk to burbot is uncertain. Introduced sturgeon may have a significant impact (>10%) on the current burbot population due to their similar diet and habitat preferences; however, competitive exclusion, or temporal/spatial resource and habitat partitioning could reduce the magnitude of negative effects expected from introducing sturgeon to the reservoir.

Adult burbot are primarily piscivores, and in our area, prey on a wide variety of fish including trout, suckers, minnows and sculpins. Thus, competition for food is expected to be weak to moderate, especially given the abundance of these species in the reservoir and the opportunistic omnivorous feeding strategies of burbot and sturgeon. Unlike many NTT in Kinbasket Reservoir, burbot are known to be bottom oriented. Therefore, burbot likely compete with sturgeon for rearing and overwintering habitat.

Until information regarding the current burbot population abundance, distribution, and size structure in Kinbasket is obtained, burbot should be considered a species with potentially strong ecological interactions with sturgeon, due to the expected direct predation on burbot by adult sturgeon and competition between the two species for food and space. However, burbot and sturgeon do coexist in other parts of their natural range (e.g., Arrow Lakes).

2.5. Ecological Risk

Ecological risk is defined as the probability of failing to meet NTT objectives, which need to be established collaboratively through a panel of scientists, managers, and policy makers. To complete the risk assessment, some assumptions should be made. These assumptions and sources of information used must be documented so conclusions can be supported and reviewed.

To determine the risk, interactions, particularly the strong ones, are qualitatively summed. This is accomplished by assigning a “+3” to strong positive, “+1” to weak positive, “-3” to strong negative and “-1” to weak negative interactions and then adding the values. The higher the negative number and the lower the acceptable impact, the higher the risk. Thus, the sign and strength of the interactions are compared to the acceptable impact to determine the probability of exceeding an objective. This qualitative comparison is the basis for assigning a percent risk. This approach avoids the need for consensus prior to assessing risks and helps diffuse disagreements.

The following table (Table 4) summarizes the ecological risk for all ecological interactions that could occur between stocked sturgeon and NTT in the absence of predetermined NTT objectives. The reader should refer to Section 2.3 for a rationale on each rating. Juvenile interactions may be strongest in the Columbia River upstream of Kinbasket Reservoir, where limited data preclude the ability to predict whether a 10% level of impact will be exceeded.

2.6. Scientific Uncertainty

The final task is to determine the scientific uncertainty of the risk assessment. Scientific uncertainty is calculated as the standard deviation of the risk scores that were produced during the risk assessment (Pearsons and Hopely 1999). If there is a lot of uncertainty about what kind and how strong ecological interactions are, then the uncertainty is high. For this assessment, the level of uncertainty was determined by the amount of scientific information available on the NTT; both in general and with respect to the study area. Without accurate scientific information on the majority of the aquatic community of study area or on many of the important life history characteristics of white sturgeon, estimates of impact levels are expected to be associated with a high degree of uncertainty (Table 4). Although there is high uncertainty about the risks of stocking sturgeon in the study area because of limited information, it is important to consider:

- 1) Sturgeon likely were present in the area historically,
- 2) Sturgeon are part of the natural species composition of large natural lakes throughout the Columbia Basin (e.g., Arrow Lakes, Kootenay Lakes, Slocan Lake); and
- 3) Sturgeon coexist with similar species in other portions of the Columbia River.

Thus these species appear to have partitioned resources adequately to coexist in other areas of the Columbia Basin. In addition, the stocking of juveniles likely would be undertaken over several years.

3. Conclusion

Ecological risks may extend to many classes of plants and animals. Every ecological risk assessment should explicitly specify (1) the assessment endpoint, (2) the measurement endpoint, and (3) the methods used to extrapolate from the measurement to the assessment endpoints (Suter et al. 1993). Assessment endpoints define the adverse effects to be avoided or the resources to be protected. Measurement endpoints are those variables measured in field studies. In this case, the assessment endpoint is the probability of a reduction in sportfish production (kokanee and bull trout). The measurement endpoints include changes in catch per unit effort (CPUE), size/age ratios by age class, and rates of decline in areas of use for indicator species.

Table 4. Qualitative ecological risk assessment to Upper Columbia River fish communities relative to the proposed establishment of a population of 2500 adult white sturgeon in to Kinbasket Reservoir. Note: underlined letters represent hypothesized “strong” ecological interactions. (Template from Pearsons and Hopely 1999).

Non-target Taxa	Status ^a / Impact	Overlap ^b With adult sturgeon	Overlap ^b With juvenile sturgeon	Ecological Interaction ^c with Adult Sturgeon	Ecological Interaction ^c with juvenile sturgeon	Risk scores ^d	Overall risk	Probability ^e	Uncertainty ^f
Kokanee*	H/10%	All	All	P,M	P	-3,-1	-4	75%	25%
Mountain whitefish*	H/10%	Adults	All	<u>P</u> ,M	P	-3,-1	-4	50%	50%
Bull trout*	H/10%	Adults, subadults	Adults, subadults	C, <u>P</u> ,M	F	-1, -1,-1	-3	25%	75%
Rainbow trout*	H/10%	Adults	All	P,M	P	-1, -1	-2	25%	75%
Burbot*	U/10%	Adults	All	<u>C</u> , <u>P</u> ,M	P,F	-3,-3,-1	-7	75%	90%
Peamouth	H/10%	Adults	All	P,M	P	-1,-1	-2	10%	10%
Northern pikeminnow	R/10%	Adults	All	C,M	F	-1,-1	-2	10%	10%
Longnose sucker	R/10%	All	All	P,M	P	-1,-1	-2	10%	10%
Largescale sucker	R/10%	Adults	All	P,M	P	-1,-1	-2	10%	10%
Redside shiner	R/10%	Adults	All	P,M	P	-1,-1	-2	10%	10%
Prickly sculpin	U/10%	All	All	<u>C</u> , <u>P</u> ,M	P,F	-1,-3,-1	-5	50%	75%

* Highly valued non-target taxa

^a Reservoir Status: H = healthy, R = rare, U = Unknown. Impact – acceptable impact level to the NTT abundance, distribution, and size structure.

^b Overlap: spatial and temporal overlap

^c Ecological Interactions: *Competition (C)*, *Predation (P)*, *Behavioural anomalies (B)*, *Pathogenic interactions (V)*, *Nutrient mining (M)*, *Nutrient enrichment (N)*, *Prey (F)*, *Predator swamping (S)* (note: underlined letters indicate “strong interactions or interactions likely to exceed NTT objectives)

^d Risk: “-1” = weak negative
“-2” = moderate negative
“-3” = strong negative
“+1” = weak positive
“+2” = moderate positive
“+3” = strong positive
(Note: though prey abundance was identified as a potential positive interaction, the probability of juvenile production is unknown and therefore interactions with juveniles was not rated in the scoring summary).

^e Probability of failing to meet an objective for NTT; 0% corresponds to impossibility of failing, and 100% corresponds to surety that an objective will be exceeded.

^f Uncertainty: scientific uncertainty of risk assessment due to lack of information.

Ecological risk may be reduced by employing strategies that minimize negative and maximize positive interactions between hatchery fish and NTT (Pearsons and Hopely 1999). Managers can stock fish in minimum numbers, in stages, and disease-free. Finally, monitoring NTT for evidence of impacts can provide information that will allow for changes to minimize or eliminate undesirable impacts. The focus of risk containment monitoring is most appropriate if it is targeted at NTT status (i.e., distribution, abundance, size structure). In many instances, detection of small impacts to abundance (< 20%) will be impossible therefore, it is important to determine if monitoring will detect impacts at a level less than or equal to NTT objectives prior to hatchery stocking (Pearsons and Hopely 1999). Ultimately, the potential ecological costs will be balanced with the anticipated benefits of stock restoration.

In the Kinbasket Reservoir and upstream Columbia River, the highest risk identified was to burbot, which likely will be consumed by and compete with sturgeon. Limited information on burbot in the study area results in uncertainty of the potential impact to this burbot population. Kokanee, mountain whitefish and sculpins also are likely to be consumed by sturgeon. However, these species likely have healthy populations resulting in limited population level impacts. Bull trout are expected to compete with sturgeon for prey, however, it is expected that food sources are adequate to support both species in the study area. Although there is high uncertainty in the predictions, white sturgeon likely are native to the area and coexist with similar species assemblages in other parts of the Columbia Basin.

Several recommendations to improve the prediction of or manage risks associated with stocking sturgeon into the study area:

1. Develop index sites within Kinbasket Reservoir and the upstream Columbia River to monitor relative abundance of key species (burbot, bull trout, kokanee, mountain whitefish, prickly sculpin, northern pikeminnow, peamouth chub, suckers);
2. Conduct life history/habitat use study burbot;
3. Release radio or sonic tagged juveniles to determine the migration and important habitats; and
4. Stagger stocking across several years (likely required to maximize genetic diversity as well) and incorporate review of survival and target population sizes.

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