Volume III, Chapter 1
White Sturgeon

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1.0 White Sturgeon (*Acipenser transmontanus*)

Distribution of the world's Acipenseriformes has been classified according to nine biogeographic provinces identified by Bemis and Kynard (1997). All extant taxa within Acipenseriformes exist in biogeographic provinces within the Holoarctic region (Bemis *et al.* 1997a). All known fossil Acipenseriformes were also found exclusively in north temperate localities (Grande and Bemis 1991; Jin 1995; Bemis *et al.* 1997b; Grande and Bemis 1997; in Bemis and Kynard 1997). With the exception of the Pearl River in China, all spawning within Acipenseriformes occurs in rivers located entirely within the north temperate zone of Asia, Europe, and North America (Bemis and Kynard 1997). The absence of Acipenseriformes from waters south of the north temperate zone is likely explained by geographic distribution of empirical thermal maxima (~68°F [20°C]) for successful maturation and early development of many sturgeon species (Artyukhin 1988; Conte *et al.* 1988; Detlaff *et al.* 1993; Anders and Beckman 1995; Bemis and Kynard 1997).

Sturgeons *(Acipensaeridae)* have become the subject of intense worldwide conservation efforts in response to increasing numbers of imperiled and extirpated sturgeon populations (Rochard 1990; Birstein 1993; Waldman 1995; Bemis *et al.* 1997; Birstein *et al.* 1997, 1997a, 1997c; Secor *et al.* 2002). In North America, sturgeons were second only to marine *Sebastes* (Scorpaenidae) in terms of numbers of threatened and endangered species (Musick *et al.* 2000; Secor *et al.* 2002). Being predominantly associated with the world's large river systems, sturgeons have collectively exhibited declining population trajectories due to severe large-scale habitat alterations and the effects of harnessing the world's large rivers for human purposes. Overharvest and habitat loss, degradation, and alteration are the causes most commonly cited of sturgeon population declines (Birstein 1993; Bemis and Kynard 1997; Waldman 1995; *et al.* 1997c; Anders *et al.* 2002; Secor *et al.* 2002).

Sturgeons are evolutionarily unique, ancient fish in need of modern protection (Birstein 1993; Waldman 1995; Anders 2000). Ironically, the very life history traits and behaviors responsible for sturgeons' long successful evolutionary history now serve as obstacles to their conservation, management, and recovery (Secor *et al.* 2002). Sturgeons worldwide share a predominantly threatened status (Birstein 1993; Findeis 1997; Birstein *et al.* 1997), as do many populations of North American taxa (Birstein 1993; Waldman 1995; Beamesderfer and Farr 1997; Birstein *et al.* 1997c; Secor *et al.* 2002). Despite valuable recently published collections of peer-reviewed research on various aspects of sturgeons (Birstein *et al.* 1997c; Bruch *et al.* 2001; Van Winkle *et al.* 2002), much remains unknown or poorly understood about many sturgeon taxa, including the white sturgeon, *(Acipenser transmontanus).*

White sturgeon are endemic to the Pacific coast of North America and its major river systems west of the Rocky Mountain Continental Divide, from central California to the Gulf of Alaska and the Aleutian Islands (Scott and Crossman 1973) (Figure 1-1). Sturgeon have been reported in other rivers of Yukon and Alaska, including the Taku, Skeena, Nass, and Yukon Rivers (Perrin *et al.* 1999). However, Lane (1991) suggested that these observations in the extreme northern extent of the species' range may have been of green sturgeon (*A. medirostris*) rather than white sturgeon.

Although white sturgeon occupy marine and estuarine habitats, marine residence is not required (Perrin *et al.* 1999). Thus, white sturgeon can be referred to as facultatively anadromous where dams have not blocked or restricted their access to marine and estuarine habitats. Although white sturgeon are found along the Pacific Coast from central California to the Gulf of Alaska, spawning populations have been confirmed in only three large river drainages: Columbia, Sacramento-San Joaquin, and Fraser (PSMFC 1992) as illustrated by the following map. Individuals have been observed as far south as Ensenada, Mexico, but did not appear to represent spawning populations (Moyle 1976).

Unlike salmonid fishes, white sturgeon do not require specific physiological changes (e.g. smoltification) prior to entering salt water, and can freely migrate between fresh and salt water environments or remain in estuarine habitat for prolonged periods (DeVore *et al.* 1999). Empirical tag-recapture data have confirmed their ability to migrate in excess of 1,550 miles (2,500 km) within, between, and among major river systems of western North America (DeVore *et al.* 1999; ODFW 1996). However, all sturgeons spawn exclusively in fresh water (Bemis and Kynard 1997).

The following paragraph from Parsley *et al.* (2002) summarizes challenges to restoring natural recruitment of white sturgeon populations in altered large river systems:

> *Recovery or maintenance of sturgeon populations through natural production in perturbed rivers requires adequate knowledge of the abiotic and biotic factors that influence spawning and cause mortality of embryonic, larval, and juvenile life stages. Although year-class strength of white sturgeon is determined within 2-3 months after spawning, little is known about specific causes of mortality to early life stages during this period. Initial spawning success is critical in the development of a strong year-class, and maximized recruitment may be dependent upon water temperature and the availability of optimal in-river habitat. Analyses have shown that increased river discharge combined with suitable water temperatures during spawning, egg incubation, yolk-sac larvae dispersal, and first exogenous feeding result in greater recruitment. However, little is known about the importance of other variables, such as food availability or losses due to predation that influence year class strength*

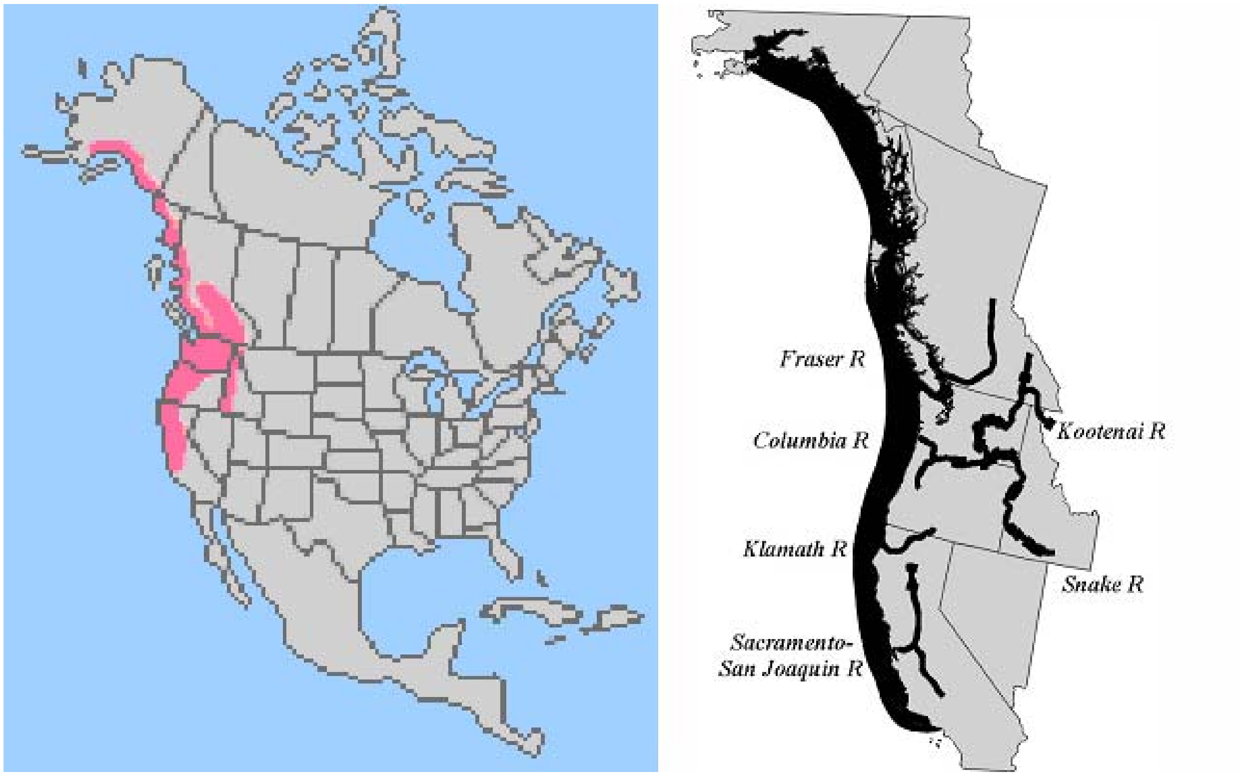

Figure 1-1. Range of white sturgeon (*Acipenser transmontanus*) along the Pacific Coast of North America. White sturgeon inhabit large Pacific coastal river systems and adjacent marine environments.

The lower Columbia River downstream from Bonneville Dam has the most productive white sturgeon population in the species' range (DeVore *et al.* 1995). This high productivity supports healthy sport and commercial fisheries with mean annual harvests since 1992 ranging from 40,000 to 55,000 (Figure 1-2). The sturgeon fishery ranks as the largest sport fishery in the Columbia Basin in terms of effort, with 10-year annual angler trips exceeding 175,000; in some years, angler trips exceed 200,000. Factors most responsible for the favorable production potential of the population are access to marine areas, abundant food resources, and consistently favorable hydrologic conditions during the spawning timeframe, which enhances recruitment (Parsley and Beckman 1994; DeVore *et al.* 1995; Counihan *et al.* in press). This high productivity can be sustained in the long term only with careful scientifically-based management.

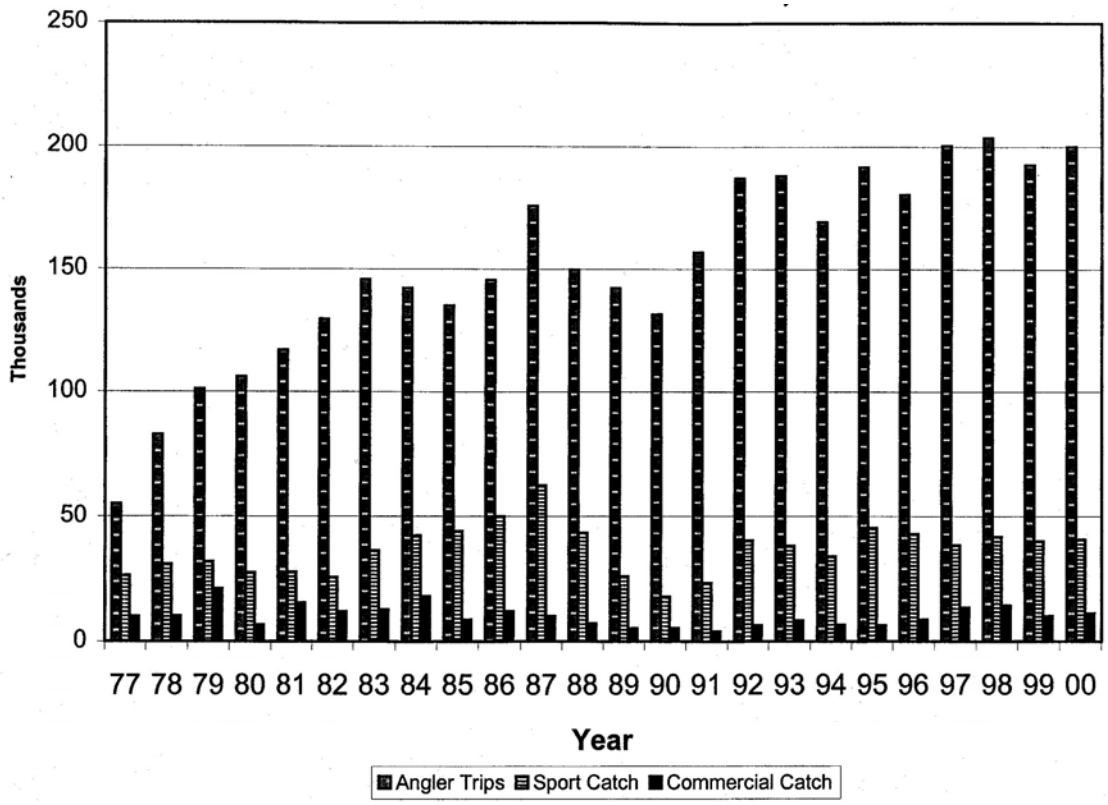

Figure 1-2. Sturgeon effort and catch on the lower Columbia River, 1977-2000

The longevity, slow growth, and delayed maturation of sturgeon make them vulnerable to overexploitation (Rieman and Beamesderfer 1990; Rochard *et al.* 1990; Birstein 1993). Excessive harvest during the 19th century resulted in the collapse of Columbia River sturgeon stocks. Intensive sturgeon fishing on the Columbia River began in 1889 and peaked in 1892 with about 2,500,000 kg (5.5 million pounds) of sturgeon landed. The stock was depleted by 1899 after a 10-year period of unregulated exploitation (Craig and Hacker 1940). Season, gear, and minimum size restrictions failed to bring about an increase in sturgeon production as evidenced by poor yields during the first half of this century.

The lower Columbia River sturgeon population rebounded after a maximum size regulation designed to protect sexually mature sturgeon was enacted in 1950. Annual harvests doubled by the 1970s and doubled again by the 1980s. Increased interest in the recreational sturgeon fishery was due to decreased salmon fishing opportunities, increased stock size, and greater appreciation of sturgeon as gourmet fare. In 1987, 72,100 white sturgeon were harvested in the lower Columbia River—a recent year record. Research indicates that the harvest rate of 30% of the 3-6 foot population, estimated to have occurred during 1985–87, was twice what the population could sustain in the long term.

Management actions to reduce the annual harvest rate in lower Columbia River sturgeon fisheries to a long-term sustainable level were decided on between 1988–97, and a management accord was struck between ODFW and WDFW to manage fisheries to assume adequate recruitment to the broodstock population. The legal size slot for lower Columbia River white sturgeon eventually was reduced to 42-60 in for sport fisheries and 48-60 in for commercial fisheries. The daily bag limit was reduced to one fish and the annual possession limit to ten fish. Maximum harvest guidelines and allocations also were placed on lower Columbia River sport and commercial fisheries.

White sturgeon historically had access from the ocean all the way to the Columbia's Canadian headwaters and Shoshone Falls in the upper Snake River. Mainstem dams have now fragmented sturgeon habitat into short riverine sections connected by long impoundments. White sturgeon in the Columbia and Snake Rivers have been isolated into at least 30 separate reaches, functionally extirpated from eight reaches, and are likely to become extirpated in another eight without intervention. Remaining subpopulations are restricted primarily to reaches with significant riverine habitat; subpopulations in marginal habitat areas have been lost, or consist of a few remnant individuals. A significant white sturgeon population remains in Bonneville Reservoir between Bonneville and The Dalles Dams, although this impounded population is substantially less productive than the anadromous population in the free-flowing river downstream from Bonneville Dam.

1.1 Life History & Requirements

In addition to pre-spawning recruitment failure mechanisms (e.g. stock limitation) a variety of early life (post-spawn) mortality factors may affect white sturgeon egg, larval, fingerling, and YOY as well as additional density-dependent and density-independent factors. These factors are illustrated in the following charts (Figure 1-3 and Figure 1-4).

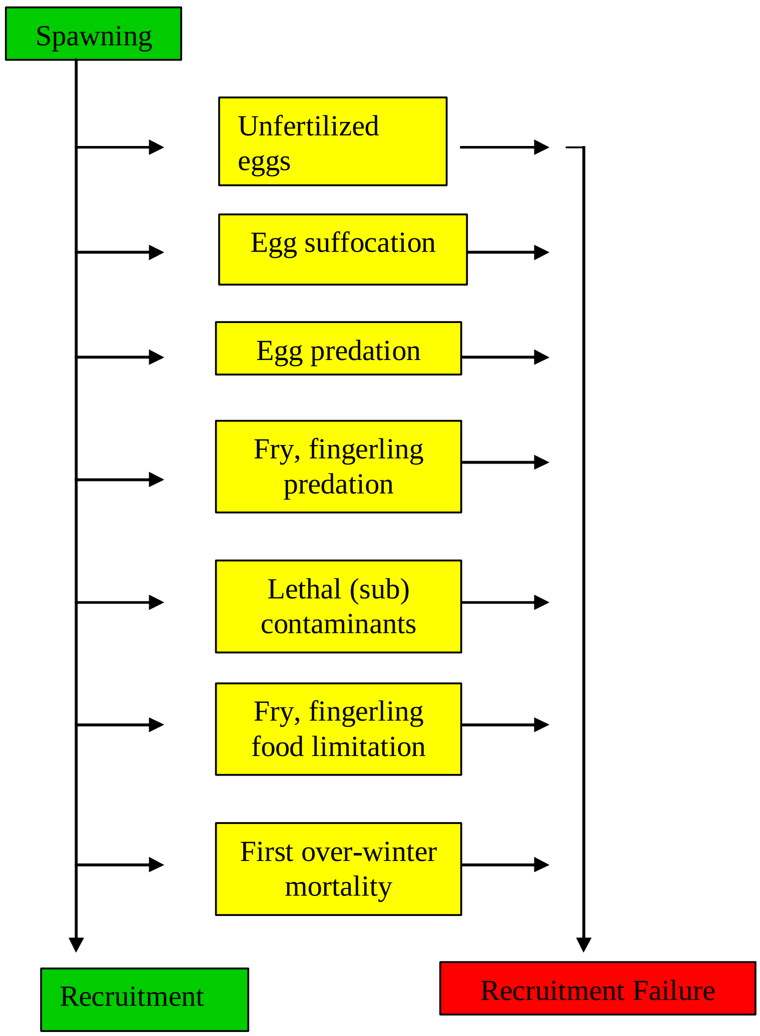

Figure 1-3. Potential early life mortality factors affecting white sturgeon (from Anders et al. 2002).

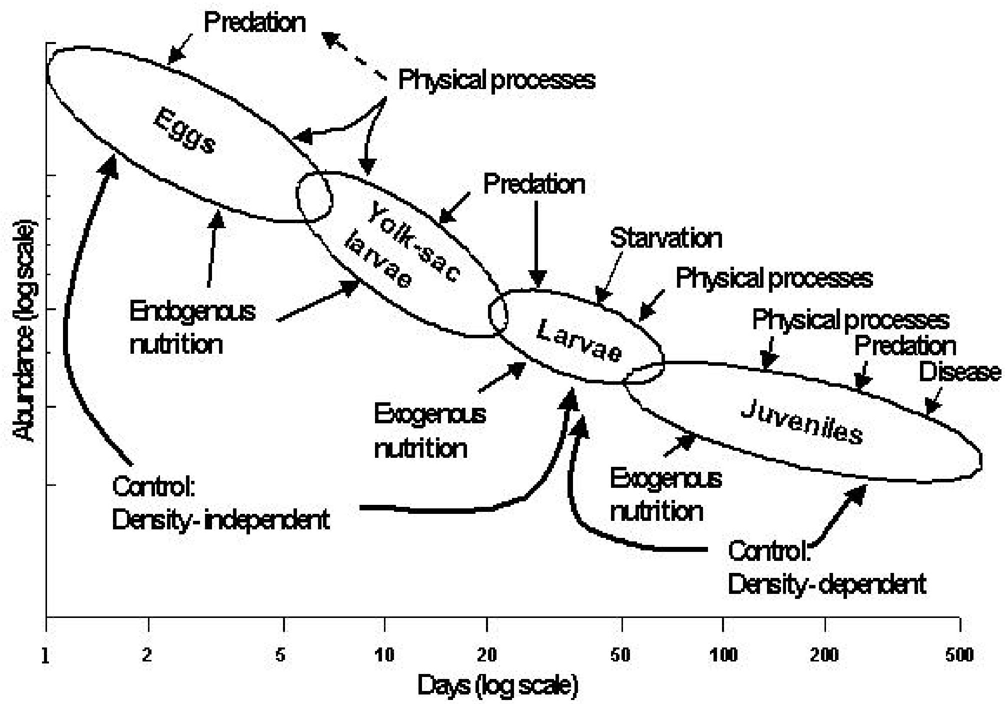

Figure 1-4. Conceptualization of the recruitment process adapted from Houde (1987) for white sturgeon showing probable sources of death, nutrition, and mechanisms likely controlling early life stages. Negative slopes in abundance throughout each life stage are an approximation not a measure of the degree of expected mortality (from Parsley et al. 2002).

1.1.1 Spawn timing and conditions

Timing of white sturgeon spawning is largely a function of water temperature, which varies annually, but is linked to time of year and associated photoperiods. White sturgeon in the Columbia Basin generally spawn from April through July, when water temperatures across the basin range from 46°F (8°C) in upper basin areas to near 68°F (20°C) in lower river areas. Table 1-1 illustrates physical habitat conditions (Parsley *et al.* 2002; Paragamian *et al.* 2001; RL&L 1994, 1996; Golder Associates 2003; IPC 2003). In the lower Columbia River, annual white sturgeon spawning appears to be triggered consistently when water temperature reaches 50°F (10°C) (M. Parsley, US Geological Survey, G. McCabe, NMFS (retired), personal communication). Spawning in the four impoundments farthest downstream occurs exclusively in tailrace areas immediately downstream from hydropower dams when water temperatures reach 54°F (12°C) (Parsley *et al.* 1993). Because water temperatures generally reach spawning temperatures first in downstream areas of the Columbia Basin, annual spawning is usually initiated downstream from Bonneville Dam when water temperatures reach 50°F (10°C), followed by spawning activity in each adjacent upstream tailrace when lower impoundment water temperatures reach and exceed 54°F (12°C). Most spawning occurs in the four farthest downriver Columbia River impounded areas at 57°F (14°C) (Parsley *et al.* 1993; Anders and Beckman 1995) with an optimum range generally cited as 54-57°F (12-14°C) for those areas. Paragamian *et al.* (2001) reported that Kootenai River white sturgeon spawned when water temperatures were between 47 and 54°F (8.5-12°C)

Table 1-1. Physical habitat conditions at sites where white sturgeon (*Acipenser transmontanus*) eggs were collected in the Columbia, Fraser, and Sacramento River basins (from Anders 2002, Chapter 1).

Location		Water Temperature *	Mean Column Velocities (m/s)**	Velocity Near Substrate	Substrate Type	References
Lower Columbia River	1987–91	10-18	1.0-2.8	0.06-2.4	Boulder	Parsley *et al.* 1993
Columbia River Impoundments	1987–91	12-18	0.81-2.10	0.52-1.62	Cobble	Parsley *et al.* 1993
Kootenai River	1994	7.8-11.2	0.03-0.27	—	Fine sediment and sand	Anders 1994
	1995	8.4-12.9	0.68	0.93	Fine sediment and sand	Anders and Westerhof 1996
	1991–98	8.5-12.0	0.19-0.83	—	Fine sediment and sand	Paragamian *et al.* 2001
Columbia River, BC	1993	15.5-17.0	—	—	Clean small boulder, large cobble	Hildebrand and McKenzie 1994
	1995	15.5-21.6	0.5-1.8	—	Bedrock, boulder, cobble	RL&L 1996
Fraser River, BC	1998	15.1	—	—	Bedrock	RL &L 1998; Perrin *et al.* 1999
Sacramento River, CA	1970	14-22	—	—	Gravel	Stevens and Miller 1970
	1973	—	—	—	Mud and sand	Kohlhorst 1976

*°C; **m/s=meters per second

Empirical data generally support negative correlations between elevation, latitude, and mean spawning temperatures (i.e. farthest upstream and farthest north populations spawn at coldest mean temperatures). Wang *et al.* (1985) reported that white sturgeon embryos died when exposed to 164°F (8°C), whereas 68°F (20°C) water temperature was lethal to all exposed larvae. Anders and Beckman (1995) reported 98% mortality (129 of 132) of all eggs collected from The Dalles Pool during 1987 at water temperature of 64°F (18°C) and warmer. However, these authors also documented egg mortality in water 55 to 63°F (13-17°C), indicating additional egg mortality factors.

White sturgeon generally spawn in high velocity areas associated with gravel and larger substrates (Wydowski and Whitney 1979; Simpson and Wallace 1981; RL&L 1994, 1996; Perrin *et al.* 1999; Parsley *et al.* 2002; Paragamian *et al.* 2001; Golder Associates 2003, IPC 2003). Hard-bottom, high-velocity, structured habitats with adequate interstitial space are critical as spawning and incubation substrate and predation refuge areas for broadcast-spawning white sturgeon (Parsley *et al.* 1993; Perrin *et al.* 1999; Parsley *et al.* 2002; Secor *et al.* 2002).

The following three paragraphs on spawn timing and associated conditions are from Parsley *et al.* 2002:

Many physical factors and environmental conditions influence spawning. The amount and quality of spawning habitat available to individual populations of white sturgeon differs among reaches because of channel morphology and among years because of variation in river discharge (Parsley and Beckman 1994). White sturgeon spawning in the Columbia and Snake rivers generally occurs in areas with high water velocities, coarse substrates and water depths of 3 m or more (Parsley et al. 1993; R. L. & L. Environmental Services Ltd. 1994; Parsley and Kappenman 2000). Spawning in high water velocities would separate and disperse the adhesive eggs, and the coarse substrates would provide a good surface for the adhesive eggs to attach.

Impoundments have reduced the hydraulic slope of the river over vast reaches and inundated many rapids and falls that historically may have provided spawning habitat for white sturgeon. Because of differences in channel morphology and a greater hydraulic slope, the free-flowing reaches provide more spawning habitat than the impoundments at reduced discharges (Parsley and Beckman 1994) causing variability in spawning habitat quantity and quality among areas within years.

Inter-annual variation in spawning timing is also caused by the thermal regime of rivers within the Columbia River Basin. Developments within the Columbia River Basin for hydroelectric power generation and operations at dams that are used to store water for flood control and power generation have resulted in temperature variations from the historic thermal regime. The timing and duration of the spawning season for white sturgeon in any given year vary with water temperature. White sturgeon spawning in the Columbia River Basin generally occurs when water temperatures are between 10-18°C (Parsley et al. 1993; R. L. & L. Environmental Services; Ltd. 1994) with the peak of spawning occurring when temperatures are generally between 13 and 15°C. These temperatures can occur for variable periods during the months of April, May, June, or July. Kootenai River white sturgeon also spawn during May and June but at water temperatures that are much cooler. Typically, spawning by white sturgeon in the Kootenai River begins when temperatures are 8-9°C and ceases when temperatures approach 12°C (Paragamian et al. 1995; Paragamian et al. 1997). Though the primary force behind the thermal regime is regional climatic conditions, the hydropower system is often manipulated to provide cooler water temperatures during the summer to benefit outmigrating juvenile anadromous salmonids. These manipulations can lower river water temperature by several degrees and often occur during times when white sturgeon are spawning. It is unknown, but probable, that these temperature variations disrupt spawning activities by white sturgeon.

1.1.2 Incubation

Recruitment failure in sturgeon populations frequently results from loss and degradation of spawning, incubation and early rearing habitats (Beamesderfer and Farr 1977; Bemis and Kynard 1997; Jager *et al.* 2001; Paragamian *et al.* 2001; Anders *et al.* 2002; Parsley *et al.* 2002). As mentioned above, hard-bottom, high-velocity, structured habitats with adequate interstitial space are critical for broadcast-spawning white sturgeon (Parsley *et al.* 1993; Perrin *et al.* 1999; Parsley *et al.* 2002; Secor *et al.* 2002). Furthermore, hypoxia (oxygen limitation) may have disproportionately negative effects on sturgeons, relative to other fauna, due to their limited capacity to osmoregulate at low dissolved oxygen concentrations (Klyashtorin 1976; Secor and Gunderson 1998 as cited in Secor *et al.* 2002). Although hypoxic effects may be particularly important during the first year of life due to increased sensitivity and reduced ability of sturgeons—especially incubating embryos—to escape anoxia environments (Secor and

Niklitschek 2001), specific oxygen and gas exchange requirements for incubating white sturgeon embryos are currently unknown.

In addition to potential threats of suffocation, hypoxia, and reduced gas exchange, demersal white sturgeon embryos are vulnerable to fish predation (Anders 1994, 1996; Miller and Beckman 1996; Parsley *et al.* 2002). During 1994 and 1995, 632 stomach content samples from predatory fishes collected from the Kootenai River (northern pikeminnow *Ptychocheilus oregonensis*, peamouth chub *Mylocheilus caurinus* and suckers *Catastomus spp*.) were analyzed (Anders 1996). Of 428 naturally-spawned white sturgeon eggs collected from the Kootenai River during 1994 and 1995, 12.2% (52) were collected from 623 predatory fish stomach samples. Although a low percentage of the total catch, predation likely was underestimated due to sampling and observational constraints. Miller and Beckman (1996) reported the occurrence of one to 70 white sturgeon eggs in guts of four omnivorous fishes in the Columbia River. These authors noted that a single largescale sucker (*Catastomus macrocheilus*) consumed 70 white sturgeon eggs.

1.1.3 Emergence

Emergence is typically a term associated with post-hatching salmon ecology and reproductive biology, and is not directly associated with white sturgeon embryos, which typically hatch in less than two weeks at a mean incubation temperature of 50°F (10°C) (Wang *et al.* 1985). Important details concerning subsequent larval white sturgeon behavior and emergence from interstitial spaces within river substrates are provided in the following section.

1.1.4 Larvae

Brannon *et al.* (1985) conducted laboratory studies to characterize distribution behaviors of Columbia River white sturgeon larvae and fry. These authors concluded:

> *substrate composition in a river may influence both the emergence and settling response of white sturgeon larvae and could affect whether they remain in an area once they become bottom oriented. Upon hatching, larvae enter the water column and are subject to the influences of current. Larvae then seek the substrate for places that provide cover. Larvae remained in the substrate until yolk is absorbed and feeding initiated. Larvae were noted to enter just about every conceivable space where they could hide their head. Beneath rocks, gravel interstices, amongst plants, and under detrital material were the places harboring the larvae during the hiding phase.*

Larval white sturgeon were observed in aquaria to burrow into fine sediments, resulting in mortality by suffocation in some observed cases (E. Brannon, University of Idaho, personal communication). If these behaviors represent those in the wild, empirical observation indicates the importance of suitable larval rearing habitats, including interstitial space among substrate particles of appropriate sizes.

The following three paragraphs regarding larval white sturgeon ecology are from Parsley *et al.* (2002):

> *In addition to successful hatching of embryos, onset of exogenous feeding constitutes a critical period of potentially high mortality. However, virtually no empirical data could be found addressing prey selection and food availability for naturally produced white sturgeon at onset of exogenous feeding. The larval stage for white sturgeon generally lasts approximately 25 to 30 days. Following yolk sac absorption, larvae end their hiding phase and move out onto the substrate to begin feeding. Mortality*

of larval fishes is often greatest during the period of transition from endogenous to exogenous feeding (Hjort 1926). It is not known if white sturgeon larvae experience high mortality rates at this juncture in natural populations, but it is probable that some of the variation in year-class strength observed in white sturgeon populations is due to mortality during the larval stage.

Starvation is one biotic factor thought to regulate juvenile fish abundance in some freshwater and marine fish populations (Rice et al. 1987; Sinclair 1988). It is unknown if or when irreversible starvation (May 1974) occurs for larval white sturgeon deprived of food. Muir et al. (2000) found no evidence of larval starvation in the Columbia River downstream from Bonneville Dam and in the two lowermost impoundments. In a laboratory study, if food was not present, white sturgeon larvae re-entered the water column, presumably to be displaced farther downriver to a food source (Brannon et al. 1985a). White sturgeon larvae collected in the Columbia River fed primarily on amphipods of the genus Corophium *(Muir et al. 2000), a food that historically was found in the Columbia River estuary but not upriver in free-flowing environments. Other food items consumed that would have been historically available to larvae upstream of the upper extent of* Corophium *included copepods, Ceratopogonidae larvae and Diptera pupae and larvae.*

Another source of mortality that can have significant affects on year-class strength is predation. Predation on white sturgeon larvae has been noted in laboratory experiments (Brannon et al. 1986) but has not been investigated under natural conditions. Larvae develop sharp scutes as they grow, possibly reducing their vulnerability to predation. Potential predators collected in association with larvae included bridgelip sucker Catostomus columbianus, *largescale suckers, bullheads Ameiurus spp., common carp, peamouth* Mylocheilus caurinus, *chiselmouth* Acrocheilus alutaceus, *northern pikeminnow, prickly sculpin, larger white sturgeon, and starry flounder* Platichthys stellatus.

1.1.5 Juvenile

The following three paragraphs regarding juvenile white sturgeon ecology were taken directly from Parsley *et al.* (2002):

White sturgeon larvae metamorphose into juveniles within 3–4 months after egg fertilization. Predation, starvation, disease, parasitism, and physical processes caused by direct and indirect human actions reduce juvenile white sturgeon numbers. For many fish species, relative year-class strength is set prior to this life stage (Bradford 1992). Losses of juvenile white sturgeon to predation are probably slight because of the protective scutes, benthic habits, and fast growth. Only one juvenile white sturgeon was consumed by a channel catfish Ictalurus punctatus during a study of the gut contents of more than 4,780 northern pikeminnow, 1,050 walleye Stizostedion vitreum, 4,800 smallmouth bass Micropterus dolomieui, and 650 channel catfish (US Geological Survey, unpublished data). Other previously listed predators on young white sturgeon were not examined in that study.

Juvenile white sturgeon feed primarily on benthic invertebrates (McCabe et al. 1993; Muir et al. 2000). Studies investigating productivity of benthic invertebrates that juvenile white sturgeon prey on between free flowing and impounded areas are lacking. Generally, growth rates, mean length at age, and condition factors of juvenile white sturgeon (1-8 years of age) were greater for those captured in the impounded areas than *of those collected in the free-flowing reach (Miller and Beckman 1992), suggesting that food resources for juvenile white sturgeon were more limiting in the free-flowing reach than in the impounded areas at existing white sturgeon densities.*

Losses of fish to disease and parasites in the wild are difficult to quantify. Hatchery reared white sturgeon are susceptible to many of the same diseases and parasites common to other fishes reared in culture facilities (LaPatra et al. 1995; Conte et al. 1988) and the white sturgeon iridovirus can cause significant mortality in cultured fish (LaPatra et al. 1994). This size-specific and stress-mediated virus has been found in white sturgeon throughout the Columbia River Basin (LaPatra et al. 1994). Fish weakened by disease or parasites could be more vulnerable to predation (Mesa et al. 1998) but this has not been investigated in white sturgeon. The nematode parasite Cystoopsis acipenseri is common to smaller white sturgeon and creates blister-like cysts located just under the skin of affected fish (McCabe 1993). The degree of infestation of white sturgeon by the nematode parasite varied spatially and temporally in the lower Columbia River and was greater in smaller white sturgeon (McCabe 1993). However, it is unknown if infestation increases mortality.

Human actions sometimes cause mortality of juvenile white sturgeon. Suction dredging in deep areas (66-85 ft [20-26 m]) in the lower Columbia River is known to seriously injure and kill juvenile white sturgeon (Buell 1992), and there is speculation that the dredging operations may attract feeding white sturgeon, compounding the losses. Lost and abandoned gill nets from commercial and subsistence fisheries can kill substantial numbers of juvenile and adult white sturgeon in impounded areas (M. Parsley, USGS Cook, Washington, Blaine Parker, Columbia River Inter-Tribal Fish Commission, personal communication), and large numbers of fish are occasionally killed during maintenance activities at the dams (J. DeVore, WDFW, personal communication). Mortality among sublegal-sized fish caused by hooking by anglers probably accounts for a minor loss of juvenile white sturgeon, but has not been investigated.

Juvenile white sturgeon recruited to the population after age 1 generally exhibit very high survival (e.g. 90%, Paragamian *et al.* in review). Thus, if habitat suitability and food availability are suitable and not limiting, it would appear that the juvenile white sturgeon life stage does not appear to likely produce population bottlenecks. However, based on results of elasticity analysis of life history attributes of three sturgeon species (Gross *et al.* In Press), the potential to increase population growth rate (λ) remained high for YOY and juvenile age classes. Simulated changes in fecundity had relatively little effect on the potential for increased population growth. Although YOY survival elasticity was equal to that of other juvenile ages, the overall opportunity for affecting λ was strongest at the YOY stage due to its exceptional potential to increase survival.

Regarding juvenile food habits, Scott and Crossman (1973) reported that age 0 white sturgeon diets consisted primarily of *Chironomid* larvae. Amphipods (*Corophium spp.)* accounted for 98% of diet items from 149 age 0 white sturgeon (0.78-10.5 in. TL [20-267 mm]) collected from Bonneville and The Dalles pools in the Columbia River from 1988 through 1991 (Sprague *et al.* 1993). Wydowski and Whitney (1979) reported that the stomachs of small white sturgeon in California contained primarily Mysis shrimp (*M. relicta*) and amphipods. Age 0 lake sturgeon *(Acipenser fulvescens)* in the Lake Winnebago system in Wisconsin were observed in close contact with the substrate, oriented upstream, and apparently feeding on drifting benthic organisms (Kempinger 1996). Kempinger (1996) also reported that species of Baetidae nymphs and dipteran larvae were the two principal organisms consumed by lake sturgeons during their first summer of life.

1.1.6 Adult

General life history characteristics of sturgeons were recently summarized by Bemis and Kynard (1997) and Kynard (1997). Sturgeons exhibit several life history forms, including:

- Diadromy—migrate between fresh and salt water
- Anadromy—spawn in fresh water, spend non-reproductive periods in marine environment
- Amphidromy—bi-directional, non-reproductive migration between fresh and salt water
- Potadromy—all feeding and reproductive migrations within a freshwater river system

Facultative potadromy, which occurs when dams prohibit expression of historically anadromous or amphidromous life history strategies is poorly understood, but accounts for most white sturgeon in impounded reaches of the Columbia River system in the US and Canada (Kynard 1997). Where not damlocked, and based on observed life history white sturgeon appear to be best described as facultatively anadromous. Regardless of life history strategies expressed, all sturgeons spawn exclusively in large freshwater river systems, often following upstream migrations of considerable distance (Bemis and Kynard 1997).

Like other sturgeons, white sturgeon are characterized by delayed onset of first reproduction. First maturation generally occurs from 10–20 years of age for males, and from 15 to 30 for females (Scott and Crossman 1973; Semakula and Larkin 1968; Conte *et al.* 1988; Paragamian *et al.* in review). This trait, coupled with empirically confirmed migratory and dispersal ability, are theorized to contribute to gene flow in white sturgeon (Brown *et al.* 1992, 1993). Furthermore, individual longevity ($\leq$ 82 years of age, Simpson and Wallace 1982) infrequently exceeding 100 years (Smith *et al.* 2001) also may contribute to observed migration, dispersal, and gene flow (Brown *et al.* 1993, 1996).

White sturgeon are iteroparous, communal spawners, which broadcast gametes into the water column where fertilization occurs before the demersal, adhesive embryos settle to the substrate (Wang *et al.* 1985; Conte *et al.* 1998; Paragamian *et al.* 2001, and references therein). In demographically viable white sturgeon populations, iteroparity provides the opportunity for within-year reproduction by numerous generations of fish. Reproductive periodicities vary between sexes; males may reproduce every 2-4 years, while females may reproduce no more frequently than at 5-year intervals (Conte *et al.* 1988; Chapman *et al.* 1996, Anders *et al.* 2002; Paragamian *et al.* in review). Simpson and Wallace (1982) reported 4–11 year spawning periodicity for white sturgeon, but made no mention of gender. Little is known regarding reproductive senescence in *A. transmontanus*. One perspective suggests that natural selection would not favor the persistence of this life history trait because longevity beyond reproductive age would serve no advantageous purpose to the population (E. Brannon, University of Idaho, personal communication). Mature adults are thought to spawn numerous times over a 30–40 year period, and possibly longer (S. Doroshov, University of California, Davis, personal communication). If an individual female initially reproduced at age 25 and successfully spawned in subsequent 5-year intervals until age 65, theoretically it could contribute gametes to subsequent generations up to nine times. Finally, communal spawning, along with the above reproductive mechanisms, likely contributes to increased gene flow and maintenance of genetic diversity in white sturgeon relative to that of paired, semelparous fishes (e.g. Salmonidae), especially in the absence of confirmed homing fidelity.

1.1.7 Movements in Fresh Water

White sturgeon movements within fresh water remain somewhat unclear (reviewed in Perrin *et al.* 1999). Semakula and Larkin (1968) reported migrations in the Columbia River, and

Pycha (1956) reported that large fish moved upstream during winter and spring and downstream during summer in the Sacramento-San Joaquin system. Other vague movements, such as from deeper water in winter to shallower water in summer, also have been described (Migdalski 1962; Anders 1991). In the Columbia River, white sturgeon were reported to exist in groups representing distinct geographic cohorts concentrated downstream from impoundments (North *et al.* 1993). Tagged white sturgeon generally moved more within than between reservoirs (Warren and Beckman 1993; ODFW 1996; DeVore *et al.* 1999). However, Galbreath (1985) did not detect clear migration patterns, and suggested that movement appeared to be random. Conversely, DeVore and Grimes (1993) reported that adults migrated upstream during the fall, downstream during spring, and congregated at the Columbia River estuary during summer, presumably in relation to food availability, with such movements exceeding 62 miles (100 km). Alternatively, in the Columbia River in British Columbia, most adult white sturgeon tagged with radio transmitters moved < 3.1 miles (5 km), and only 2% were recaptured > 6.2 miles (10 km) from the point of original tagging (RL&L 1994, 1996). These findings were suggested to have resulted from the close proximity of suitable habitat for feeding, overwintering, and spawning (RL&L 1994).

Review of empirical data on movement also suggested that Columbia River white sturgeon are not completely isolated within individual reservoirs, and where not damlocked (Kynard 1997), can migrate great distances (Warren and Beckman 1993; ODFW 1996; DeVore *et al.* 1999; Gallion and Parsley 200; Paragamian *et al.* 2001). From 1987–94, 9,323 white sturgeon were tagged in the four Columbia River reservoirs that are farthest downstream; of these fish, 1,162 (13%) were recaptured (ODFW 1996). During these years, 661 (57%) of these 1,162 fish were recaptured in the reservoir of original capture and tagging, 68 (6%) were recaptured in downstream reservoirs, or downstream from Bonneville Dam (thus given unimpounded access to the Columbia River estuary and Pacific Ocean), and 2 (0.3%) were recovered in an adjacent upstream reservoir (ODFW 1996).

Regarding movement and migration in unimpounded habitat, 471 white sturgeon were originally tagged in the unimpounded lower Columbia River (downstream from Bonneville Dam) and recaptured in 23 separate locations outside the Columbia River Basin from 1976–97 (DeVore *et al.* 1999). These fish were recaptured in the Fraser River (~310 miles [500 km] to the north in southwestern British Columbia), in the Sacramento River (~560 miles [900 km] to the south in central California), and in 21 additional intermediate locations along the Pacific Coast of Oregon and Washington (DeVore *et al.* 1999). Summarized empirical data from white sturgeon recaptured in the unimpounded lower Columbia River but tagged elsewhere were unavailable. Gallion and Parsley (2001) reported migrations among subadult and adult sturgeon up to 149 miles (240 km) in free-flowing areas of the mid-Columbia River.

Movement of adult white sturgeon in the Kootenai River system, Idaho, and British Columbia, was categorized into five movement patterns, based on ultrasonic telemetry data (Anders 1991). This research revealed seasonal movement and migration patterns between different habitats by over half of the tagged fish; the remaining 47% did not migrate, and their movements were generally < 19 miles (30 km), appearing random (Anders 1991). Although this categorization according to general movement patterns was presented for illustrative purposes, over a 14-month period, white sturgeon exhibited a wide array or a continuum of movement, from very short to considerable (>62 miles [100 km]). Hourly locations determined by ultrasonic telemetry for 24 consecutive hours of 14 adult white sturgeon in the Kootenai system revealed no distinct daily movement or activity patterns; however, most individuals moved slightly during the 24-hour investigations. More recently, Paragamian and Kruse (2001) reported consistent upstream migrations in the Kootenai system during spring and fall from downstream Kootenay Lake and the lower Kootenai River to reported prespawning staging areas in Idaho. These authors also reported that female white sturgeon demonstrated more consistent behavior, appeared more sensitive to changing environmental conditions, and were more useful in predicting the probability of migration to the spawning reach than males.

Before impoundment, white sturgeon were reported to range freely in large systems like the Columbia River (Bajkov 1951), undertaking extensive migrations among habitats to presumably take advantage of scattered and seasonally available resources (Beamesderfer *et al.* 1995). Dam construction and operations reduced access of these fish to different habitats, reduced seasonal hydrographic and thermographic variation, and reduced habitat diversity and heterogeneity (Beamesderfer *et al.* 1995).

1.1.8 Ocean Migration

Although ocean migrations of white sturgeon measured in thousands of kilometers are supported by mark-recapture data (Devore *et al.* 1999) and by widespread distribution of genetic signatures and empirical gene flow measures (Anders *et al.* 2002 [Chapter 2]; Anders and Powell 2002 [Chapter 3]), surprisingly little is known about specific ocean migratory behavior of white sturgeon. Of thousands of white sturgeon originally tagged in the unimpounded lower Columbia River (downstream from Bonneville Dam), just 471 were recaptured in 23 separate locations outside the Columbia River Basin from 1976–97 (DeVore *et al.* 1999). Likewise, statistical comparisons of mitochondria DNA (mtDNA) haplotype frequency distributions revealed a mean distance of over 620 miles (1,000 km) for significant differences in white sturgeon haplotype frequency distributions (Anders and Powell 2002), although not all comparisons involved intermediate marine environments.

Based on mark and recapture data from thousands of white sturgeon tagged in the lower Columbia River (downstream from Bonneville Dam) and recapture of 471 fish during a 21-year period, marine movements and migration of white sturgeon are not uncommon. These fish were recaptured up and down the Oregon and Washington coasts (Table 1-2). These recoveries occurred when few research program dollars were available to sample areas outside the Columbia Basin. No programs have been in place to specifically document migrations and movements of white sturgeon in marine environments. However, with recently increasing interest in green sturgeon—primarily a marine, estuarine, and lower river species—and with increased interest in developing a better understanding of white sturgeon movements and migration in the ocean, increasing effort may be directed at sampling near-shore marine habitats to better understand the species’ use of the marine environment (T. Rien ODFW, personal communication).

Table 1-2. Columbia River white sturgeon out-of-system tag recoveries by recovery area, 1976–97 tag groups.

Recovery											Tag Group												
Area	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	Totals
Sacramento	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Oregon coast	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	4
Coos Bay	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	4	0	0	5
Umpqua	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0	5	0	8	0	1	17
Siuslaw	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	2
Yaquina	1	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	1	2	0	2	0	0	9
Siletz	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Tillamook	0	0	0	0	0	0	0	0	0	1	3	3	1	5	2	0	0	9	1	6	1	12	44
Nehalem	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	1	0	0	0	0	4
Washington coast	0	1	0	1	0	0	1	1	0	3	0	0	0	1	0	0	0	1	0	0	0	0	9
Willapa Bay	2	1	0	3	3	4	4	3	0	4	8	14	8	7	4	10	4	14	1	15	12	6	127
Grays Harbor	1	1	1	1	4	9	4	3	3	4	14	24	11	18	8	17	0	24	5	30	6	3	191
Quinault	0	0	0	0	0	0	0	0	1	2	3	0	3	3	1	0	0	0	0	2	0	0	15
Hoh	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	3
Neah Bay	0	0	0	0	0	0	0	0	1	1	11	4	2	0	0	2	0	0	0	0	0	1	22
SJDF	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	2	0	1	0	0	6
Hood Canal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	3
Puget Sound	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Nisqually	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Duwamish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Snohomish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	2
Stillaguamish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	2
Fraser	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Totals	4	3	2	5	8	14	9	7	5	15	41	45	26	41	17	31	8	64	7	73	22	24	471

1.2 Population Identification & Distribution

Currently, reference to white sturgeon populations is simply a convenient way to describe groups of fish in particular geographic areas, due largely to artificially-imposed migration barriers. Unlike semelparous, paired-spawning salmonids that exhibit strong homing fidelity and distinct population structure (Brannon *et al.* 2002), white sturgeon population structure appears to exist at very large geographic scales, measured in hundreds to thousands of kilometers (Anders and Powell 2002). These authors coined the term "expansive gene flow model" to describe observed population structure of white sturgeon in western North America. This model was strongly supported by empirical white sturgeon genetic, dispersal, life history, and reproductive data. Anders *et al.* (2002) and Anders and Powell (2002) rejected a null hypothesis that all white sturgeon in the Columbia River Basin represented one gene pool based on analysis of geographic heterogeneity of two mtDNA marker systems. Past white sturgeon stock delineation research using protein allozymes (Setter and Brannon 1992; Bartley *et al.* 1985) and mtDNA sequencing (Brown *et al.* 1992) from a relatively limited number of samples and sampling locations in the Columbia, Fraser, and Sacramento river basins also identified statistically significant differences in white sturgeon allele and haplotype frequencies across geography.

Extensive development of hydropower dams throughout the Columbia River Basin during the past century has severely fragmented large free-flowing river habitats (National Research Council 1996) occupied by white sturgeon. These changes likely have resulted in major alterations to historical gene flow patterns in the Columbia Basin and among large Pacific Coast river systems in North America (Anders and Powell 2002). Thus, future revelation of historical population structure and delineation will become increasingly difficult as historical gene flow signal is lost, and current migrations and gene flow patterns are limited by hydropower development, genetic drift, and recruitment failure in resulting small populations.

1.2.1 Genetic Differences

Small but significant differences in genetic frequencies and diversity are apparent among white sturgeon populations in the Sacramento, Columbia, and Fraser systems based on electrophoretic and mtDNA analysis (Bartley *et al.* 1985; Brown *et al.* 1992; Anders and Powell 2002). White sturgeon populations along the Pacific coast of North America are closely related. Anders and Powell (2002) observed 26 unique mtDNA sequences (haplotypes) in samples from 13 locations in the Columbia, Snake, Kootenai, Fraser, Nechako, and Sacramento Rivers. The two most common haplotypes were represented by 64% of the 260 fish sequenced and were observed at 100% and 85% of the sample sites (Anders and Powell 2002). Similar overlap among populations was reported by Bartley *et al.* (1985) based on electrophoretic analysis of allele frequencies, Brown *et al.* (1992) based on mtDNA, and McKay *et al.* (2002) based on mtDNA. Expansive haplotype distribution indicates little genetic divergence and significant gene flow throughout a major portion of the species' range (Anders and Powell 2002). However, there is little evidence to support high levels of contemporary gene flow, especially in post-impoundment systems (Anders, personal communication). This conclusion is consistent with observed recaptures of small numbers of tagged Columbia River sturgeon in the Sacramento and Fraser Rivers (DeVore *et al.* 1999).

White sturgeon genetic studies have consistently documented decreasing diversity with distance upstream (Bartley *et al.* 1985; Brannon *et al.* 1987; Brown *et al.* 1992; Anders and Powell 2002). Total number of haplotypes were negatively correlated with inland distance from the Pacific Ocean in all river systems studied (Anders and Powell 2002). Genetic differences were most pronounced in the Kootenai River white sturgeon population where heterozygosity was the lowest observed in the Kootenai River (Bartley *et al.* 1985; Brannon *et al.* 1987; Setter and Brannon 1990; Anders and Powell 2002). Kootenai River white sturgeon are believed to be a post-glacially isolated population of ancestral Columbia River stock (Duke *et al.* 1999; USFWS 1999). This population was listed in 1994 as endangered under the ESA (USFWS 1994).

Sturgeon populations impounded in the lower Columbia River mainstem between Bonneville Dam and the Snake River were created by dam construction and do not represent unique genetic units.

1.2.2 Life History Differences

General life history characteristics of Acipenserids were recently summarized by Bemis and Kynard (1997) and Kynard (1997). As discussed above, sturgeons exhibit several life history forms (diadromy, anadromy, amphidromy, and potadromy). Based on observed life history expressions, white sturgeon where not damlocked appear to be best described as facultatively anadromous when dams prohibit expression of historically anadromous or amphidromous life history strategies (Kynard 1997). Regardless of life history strategies expressed, all sturgeons spawn exclusively in large freshwater river systems often following upstream migrations of considerable distance (Bemis and Kynard 1997).

Unlike some Pacific salmonids, expression of specific life history forms do not appear correlated with specific white sturgeon populations. A possible exception may have been a longitudinal gradient (upstream-downstream) in expression of anadromy before such movements were prohibited or severely reduced by hydropower development (NRC 1996). While differences in expression of life history traits are well documented for Pacific salmonids, if such differences exist in within sturgeon they have been severely dampened by extensive hydropower development in the Columbia basin (NRC 1996), and they likely exist at much broader geographic scales, relative to salmonids. The extent of naturally expressed anadromy by white sturgeon in the Columbia Basin is unknown. However, based on gene flow, genetic distance, and geographic distribution of genetic signal (Anders and Powell 2002), the prevalence of expressed anadromy by white sturgeon was likely negatively correlated with inland (upstream) distance.

1.3 Status & Abundance Trends

1.3.1 Below Bonneville

1.3.1.1 Abundance

The current white sturgeon population in the lower Columbia River is considered to be healthy with more than 1 million fish exceeding 2 feet.

The lower Columbia River downstream from Bonneville Dam white sturgeon population is the most productive in the species' range (DeVore *et al.* 1995). This high productivity supports significant sport and commercial fisheries with annual harvest ranging from 40,000 to 55,000 during 1992–2000. The sturgeon fishery ranks as the largest sport fishery in the Columbia Basin in terms of effort with a 10–year annual average of over 175,000 angler trips. Factors most responsible for the favorable production potential of the population are access to marine areas, abundant food resources, and consistently favorable hydrologic conditions during the spawning timeframe, which enhances recruitment (Parsley and Beckman 1994; DeVore *et al.* 1995; Counihan *et al.* in press). This high productivity can be sustained in the long term only with careful, scientifically based management.

WDFW and ODFW cooperatively monitor the lower Columbia River white sturgeon population status through a study supported by federal sport fishing restoration and State of Oregon monies. The objectives of the study are to:

- evaluate natural production,
- estimate population abundance and appropriate fishery exploitation rates, and
- monitor white sturgeon fisheries.

ODFW traditionally captures sturgeon for tagging during the months of May, June, July, and August. They collect recovery data through November of the year following tagging. This allows for mixing of tagged fish within the population (a key assumption for mark and recapture models) and it covers four key sport and commercial fishing periods when most tagged fish are recovered: the initial summer sport fishery, fall and winter commercial fisheries, and the following year's summer sport fishery. Abundance estimates are made about 1-1/2 years after the fish are initially tagged.

The abundance trend has shown a significant increase in the 3-6 foot population since 1989 after size limit and harvest regulatory actions were implemented by Oregon and Washington (Figure 1-5). Oregon and Washington biologists believe the lower Columbia white sturgeon broodstock population is healthy as indicated by significant and consistent production of juvenile fish. Abundance estimates of 36-40 inch (age 9-10) white sturgeon have ranged from 66,400 in 1986 to 256,000 in 1993. These estimates display significant annual recruitment to the legal size age class. The key to maintaining this current high level of productivity is assuring adequate escapement of legal sized fish (42-60 inches) through the fisheries to reach broodstock age and protecting the fish which have reached spawning age (25 years).

Table 1-3. River abundance estimates.

River	River Reach	Abundance Estimates	Year(s)	Reference	River reach length (km)	Fish/km
Columbia	Lower Columbia River	174,900-445,000	1987–97	DeVore *et al.* 1999b	235	744-1,893
	Bonneville Pool	17,900-48,700	1989–99	Kern *et al.* 2001	73	245-667
	The Dalles Pool	4,500-46,800	1987–97	Burner *et al.* 2000	39	115-1,200
	John Day Pool	2,200-24,100	1990–96	Burner *et al.* 2000	123	18-196
	McNary Pool[a]	4,600	1995	Burner *et al.* 2000	185	25
	Upper Columbia, British Columbia	1,427	2001	RL&L Env. Serv. Ltd.	NA	NA
Snake	Ice Harbor Pool	4,560	1996	DeVore *et al.* 1998	51	89
	Lower Monumental	3,891	1997	DeVore *et al.* 1999a	43	91
	Little Goose Pool	4,860	1997	DeVore *et al.* 1999a	60	81
	Lower Granite Reservoir	1,372[b]	1990–91	LePla 1994	66	21
		1,524[c]	1990–91	LePla 1994	66	23
		1,804[b]	1992	Bennett *et al.* 1993	66	27
	Clearwater River-Hells Canyon Dam	3,955[b]	1982–84	Lukens 1985	174	23
	Salmon River-Hells Canyon Dam	1,312[b]	1997–2000	LePla *et al.* 2001	80	16
		1,600[c]	1997–2000	LePla *et al.* 2001	80	20
	Lower Granite-Hells Canyon dams	8,000-12,000	1972–75	Coon *et al.* 1977	224	36-54
	Lower Granite-Hells Canyon reach	3,625	1997–2000	LePla *et al.* 2001	209	18
	Lower Granite Dam-Salmon River	2,544[b]	1997–99	Tuell and Everett 2001	129	20
		1,823[c]	1997–1999	Tuell and Everett 2001	129	14
		3,625	1997–2000	LePla *et al.* 2001	224	16
	Hells Canyon Pool	[d]	1998	LePla *et al.* 2001	42	d
	Oxbow Reservoir	[d]	1998	LePla *et al.* 2001	21	d
	Brownlee-Swan Falls	155	1996–97	LePla *et al.* 2001	277	<1
	Swan Falls Reach	726	1996–97	LePla and Chandler 1997	58	13
	C.J. Strike Reach	2,622	1994–1996	LePla and Chandler 1995	106	25
Kootenai	Kootenai	1,469	1996	Duke *et al.* 1999		

a: Includes Columbia and Snake rivers

b: Schnabel estimator

c: Jolly-Seber estimator

d: Too few were captured to generate estimate

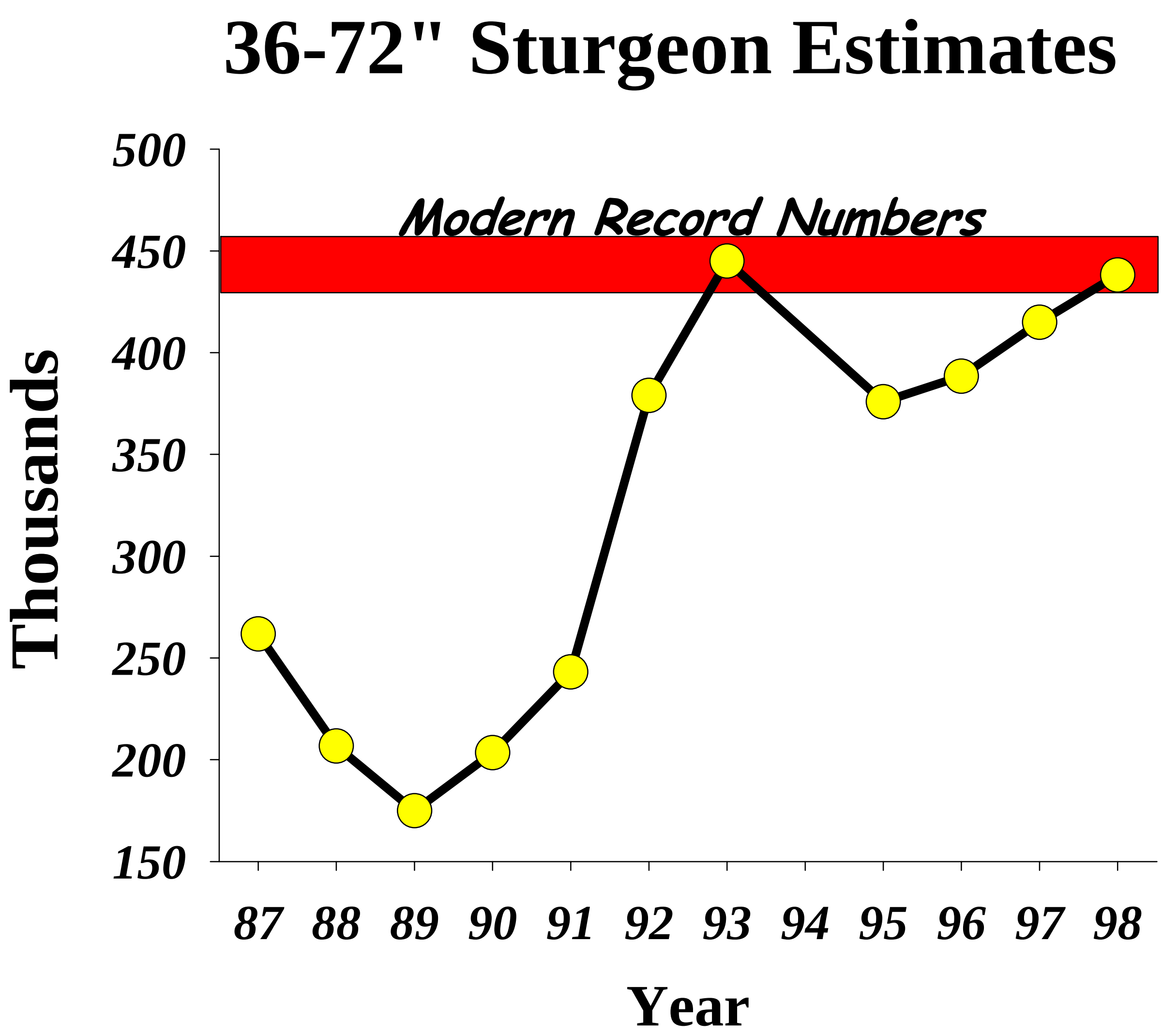

Figure 1-5. Number of 36-72 inch white sturgeon.

Biologists expected an increase in legal-sized white sturgeon abundance following harvest management actions taken in 1997. However, the most recent assessment of data indicates the legal-sized population at best is remaining static at 1996 levels or is more likely declining. The accuracy of the population estimates have been compromised by inconsistencies in sampling approach and an unforeseen mass emigration of sturgeon in 1996 and a reduction in individual growth rates.

Recoveries of tagged white sturgeon from areas outside the Columbia River peaked in 1996. This was believed due to a mass emigration of white sturgeon from the Columbia River that was ostensibly associated with El Niño ocean conditions that devastated eulachon (Columbia River smelt) survival (DeVore *et al.* 1999). Declines in recent years in white sturgeon abundance in the Columbia River were partially attributed to this emigration. Recoveries from outside the Columbia River have since diminished each year, indicating that most of the fish that emigrated had returned by 1997–98. However, population estimates of 42-60 inch fish based on tag recoveries continue to demonstrate a declining trend through 2001 (Table 1-5 in harvest section). Conversely, the sport fishery catch per effort remained steady at 0.19 to 0.21 legal white sturgeon per trip during 1997–2000.

1.3.1.2 Productivity

The white sturgeon population in the Columbia River downstream of Bonneville is among the most productive sturgeon populations in North America. Abundance and biomass have been estimated at 36.1 fish/ac (14.6 fish/ha) and 88 lbs/ac (87.5 kg/ha), respectively (DeVore *et al.* 1995). Current sturgeon biomass in the unimpounded lower mainstem appears similar to levels during pristine conditions before significant exploitation in the late 1800s (Beamesderfer and Farr 1997). Productivity is sufficient to sustain large commercial and sport fisheries. Habitat conditions are suitable for consistent annual recruitment. Large volumes of suitable rearing habitat exist. Large food resources are provided by anadromous fish species including smelt, shad, salmon, and lamprey. Sturgeon range freely throughout the lower river mainstem, estuary, and ocean to take advantage of dynamic seasonal patterns of food availability. Individual growth, condition, and maturation are among the greatest observed for white sturgeon anywhere they occur.

1.3.1.3 Supplementation

No white sturgeon supplementation or conservation hatchery programs exist in the lower Columbia River downstream from Bonneville Dam. Pelfry's, a small-scale commercial sturgeon culture facility downstream from Bonneville Dam, maintains an agreement with ODFW to spawn a small number of wild lower Columbia River broodstock (2-3 per year) for economic/ commercial production purposes. In return, an agreement between Pelfry's and ODFW ensures that a percentage of produced progeny (e.g. 1,000 progeny/female spawned) is returned to the Columbia to compensate for potential lost production associated with removing that fish from the wild population.

1.3.1.4 Harvest

Sturgeon abundance in the lower Columbia River collapsed at the end of the 19th century due to overharvest (Rieman and Beamesderfer 1990). Harvest in the lower Columbia River (US) was so severe that over 30 years elapsed before commercial harvest again became economically feasible (Rieman and Beamesderfer 1990) (Figure 1-6.). The population began to rebound after 1950 when maximum size limits were adopted to protect broodstock-size sturgeon. Since 1950, the population has increased significantly. The lower Columbia River white sturgeon population is currently healthy, with an abundance of more than 1 million fish 2 feet or longer, dominated (>95%) by immature fish (DeVore *et al.* 1999).

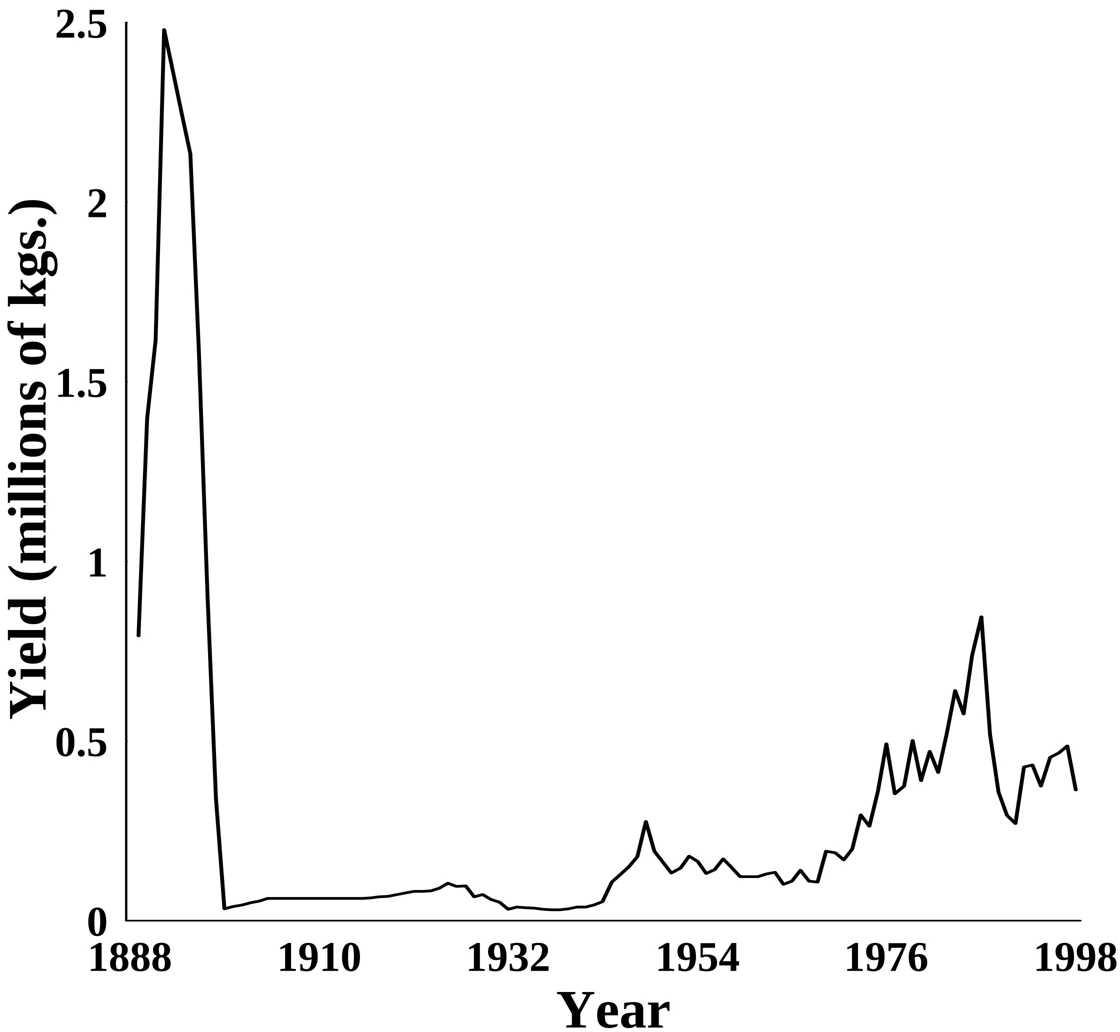

Figure 1-6. Historical yield of Columbia River white sturgeon.

During the 1980s, coincident with reductions in salmon harvest opportunities, sport effort for white sturgeon increased, along with harvest, compared to harvest levels during the 1970s. This increased harvest drove the legal-sized population down to levels of concern. Oregon and Washington responded with several regulation changes (e.g. size and bag limit changes, elimination of commercial target fisheries to control harvest growth). After the 1980s, harvest management increasingly included the setting of empirical abundance-based harvest levels.

Table 1-4 provides a 100-year summary (1899–1999) of white sturgeon management regulations in the lower Columbia River (from DeVore *et al.* 1999).

Table 1-4. Summary of historical changes in Columbia River sport and commercial fishery regulations for sturgeon (DeVore et al. 1999).

	Sport			Commercial	
Year	**Daily Bag Limit**	**Size Limits (in)**	**Other Rules**	**Size Limits (in)**	**Gear & Other Restrictions**
1899	None	None	None	48 min	Chinese gang lines prohibited (snagging setlines)
1899–1908	None	None	None	48 min	Sturgeon sales closed
1909	None	None	None	48 min	Sturgeon sales allowed during salmon seasons
1938	None	None	None	48 min	Beacon Rock-Bonneville Dam sanctuary established
1940	Only 3<48 in	None	None		
1942	3<4' & 2≥48 in	None	None		
1950	3<4' & 2≥48 in	30 min/72 max	None	48 min/72 max	
1951	3 fish	30 min/72 max	None		
1957	3 fish	30 min/72 max	Cannot remove head or tail in field		
1958	3 fish	36 min/72 max			
1968				48 min/72 max	Zone 6 became exclusive treaty Indian fishery
1975–82				48 min/72 max	Setline seasons allowed outside of salmon seasons
1983–85				48 min/72 max	Setline seasons phased out
1983–88				48 min/72 max	Target sturgeon gill net seasons (in lieu of setlines)
1986	2 fish	36 min/72 max	OR—sturgeon tag with 30 annual limit		
1989	2 fish	36 min/72 max 40 min/72 max (effective April 1)	WA—no gaffing, sturgeon tag with 15 annual limit	48 min/72 max	Target sturgeon gillnet seasons eliminated
1990	2 fish	40 min/72 max	Single-point barbless hooks OR—annual limit 15 and no gaffing	48 min/72 max	9 1/4 in max. mesh restriction in late fall salmon seasons
1991	1<48" &1≥48"	40 min/72 max		48 min/72 max	WA—adopted 2 lbs lead/fathom of leadline rule
1992	1<48" &1≥48"	40 min/72 max	WA—60 in max (effective Apr. 16, 1992–Apr 15, 1993), Beacon Rock–Bonn. Dam sanctuary (Apr 16–June 15, 1992)	48 min/72 max	WA—adopted 60 in max. length for fall seasons
1993				48 min/66 max	9 1/4 in max. mesh adopted as permanent rule. Sturgeon sales closed during last 2 weeks of fall salmon season (6,000 catch expectation for 1993 reached)
1994	1<48" &1≥48"	42 min/66 max	Annual limit 10	48 min/66 max	Catch ceiling of 6,000 for year. Sturgeon sales closed after first day of fall salmon season

Year	Sport: Daily Bag Limit	Sport: Size Limits (in)	Sport: Other Rules	Commercial: Size Limits (in)	Commercial: Gear & Other Restrictions
1995	1<48" &1≥48"	42 min/66 max	Closed to retention Sept. 1– Dec. 31	48 min/66 max	Annual catch ceiling of 8,000 during salmon seasons of which not more that 6,800 (85%) may be taken in fall fisheries
1996	1 fish as of April 1	42 min/66 max	Beacon Rock-Bonneville Dam sanctuary (closed to boat angling May and June)		
1997–98	1 fish	42 min/60 max	53,840 harvest guideline	48 min/60 max (whites) 48 min/66 max (greens)	Annual harvest guideline of 13,460 whites
1999	1 fish	42 min/60 max	50,000 harvest guideline	48 min/60 max (whites) 48 min/66 max (greens)	Annual harvest guideline of 10,000 whites

Joint Oregon and Washington tagging and recovery programs to estimate annual abundance began in 1989 and these empirical abundance estimates have been used to base harvest management decisions during the past 21 years. Since 1989, fisheries have been managed for an optimum sustained yield (OSY), which requires harvest management plans to allow enough escapement through the legal size slot for optimum levels of sturgeon to recruit to the broodstock population on a sustainable basis. Management measures employed to achieve OSY built the sturgeon legal-sized population back to healthy levels by 1995.

In 1996, Oregon and Washington adopted a 1997–99 Management Accord, which specified white sturgeon harvest management objectives for both states, including total allowable harvest and allocation between sport and commercial fisheries (Table 1-5). The following management objectives were adopted for lower Columbia River white sturgeon:

- Provide adequate recruitment to the broodstock population,
- Manage fisheries for optimal sustainable yield (OSY),
- Maintain an OSY harvest rate determined for the legal-sized population in sport and commercial fisheries,
- Maintain concurrent Washington and Oregon regulations in the Columbia River,
- Provide for year-round sport fishing opportunity,
- Maintain sport and commercial shares in the fishery, and
- Consider emergency regulatory action if harvest is projected to compromise management objectives.

These management objectives were designed to build Columbia River sturgeon populations to carrying capacity for the habitats in which they reside. They also reflect a desire to manage for healthy, stable fisheries that provide a long-term, sustainable yield. Optimal sustainable yield, as defined for lower Columbia River sturgeon management, is a level of harvest that allows enough survival of juvenile fish through the fisheries to insure adequate recruitment into the protected broodstock population (DeVore *et al.* 1995).

The 1997–99 sport and commercial harvest sharing agreement (80% sport, 20% commercial) was renewed by Oregon and Washington for 2000–02. The state commissions also adopted a total allowable annual harvest reduced from 67,300 (1997–99) to 50,000 (2000–02). This harvest reduction was in response to empirical population measures indicating that the growth in the population necessary to achieve OSY was not being met at the 1997–99 harvest level.

Table 1-5. Annual sport and commercial catches of white sturgeon and comparisons to catch guidelines, 1993–2002.

	Sport		Commercial	
Year	**Catch**	**Guidelines**	**Catch**	**Guidelines**
1993	37,900		8,100	6,000
1994	33,500		6,400	6,000
1995	45,100		6,200	8,000
1996	42,800		8,400	8,000
1997	38,200	53,840	12,800	13,460
1998	41,600	53,840	13,900	13,460
1999	39,800	40,000	9,500	10,000
2000	40,500	40,000	10,870	10,000
2001	40,200	39,500	9,430	9,100
2002[1]	37,500	38,500	9,760	9,800

[1] Preliminary. Sport catch includes projection for November 23 through December 31, 2002

In October 2002, Oregon and Washington concluded that although lower Columbia white sturgeon had rebuilt to healthy levels as a result of harvest management actions taken in the past decade, the legal size white sturgeon (42-60 in) had not increased as intended over the past 6 years, as illustrated in Table 1-6. Positive growth in the legal-sized population is important to provide adequate recruitment into the broodstock population (sturgeon 6 ft and larger).

Table 1-6. Estimated abundance of harvestable white sturgeon in the lower Columbia River.

	Total Length Interval		
Year	**42-48 inch**	**48-60 inch**	**42-60 inch**
1989	32,500	16,800	49,300
1990	26,100	12,000	38,100
1991	32,900	11,700	44,600
1992	59,900	8,700	68,600
1993	85,000	14,200	99,200
1994	N/A	N/A	N/A
1995	143,200	59,000	202,200
1996	131,700	33,500	165,200
1997	123,700	33,400	157,100
1998	161,600	24,700	186,300
1999	116,800	17,600	134,400
2000	119,200	17,000	136,200
2001	100,200	22,400	122,600

Consequently, Oregon and Washington reduced annual harvest from 50,000 to 40,000 per year during 2003–05. Commercial and sport shares remain at 80% sport and 20% commercial but the earlier objective of a year-round sport fishery was no longer possible with sport harvest reduced to 32,000 fish annually (Figure 1-7).

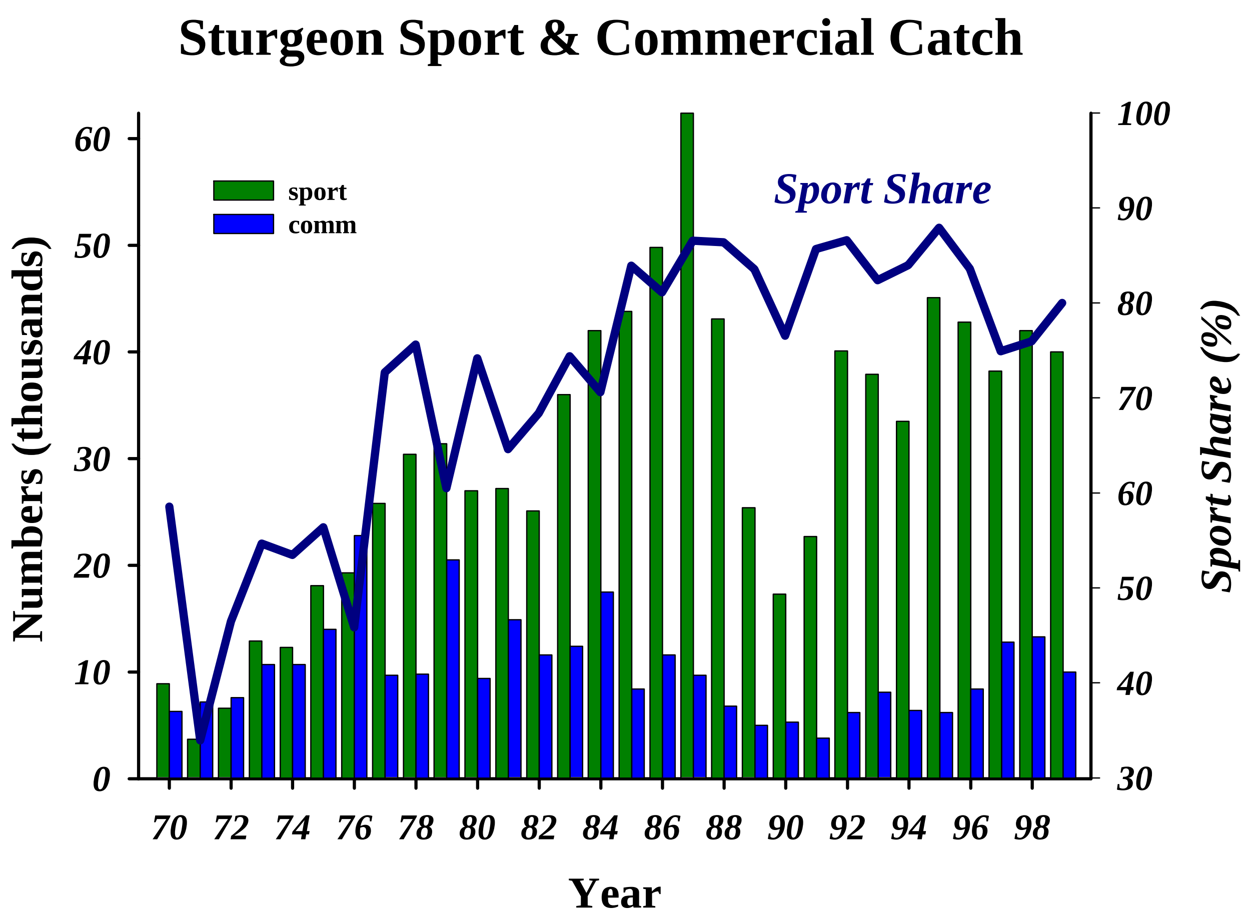

Figure 1-7. Sturgeon sport and commercial catches.

The 3-year Oregon/Washington management agreements provide stability within the annual (in-season) management processes and coincide with the ability to assess population trends needed for recommended management adjustments.

In addition to adjusting total harvest guidelines, Oregon and Washington have established a boat fishery sanctuary in the area between Beacon Rock and Bonneville Dam during peak spawning months (May–July) to reduce handle of broodstock fish by the sport fishery. Washington and Oregon biologists are studying the effect of the sport fishery handle on spawning broodstock and may consider further precautionary regulations in the future.

1.3.2 *Above Bonneville*

1.3.2.1 Abundance

Sturgeon abundance in the three reservoirs immediately upstream from Bonneville Dam is evaluated every 3–5 years using mark-recapture methodology. The Bonneville Reservoir population of 3-6 foot sturgeon was estimated at 48,600 in Bonneville (1999). Population size in 2002 was projected to be 59,300, based on observed growth and mortality rates. Revised population estimates are being developed based on analysis of 2002 mark-recapture data.

1.3.2.2 Productivity

Productivity of the impounded sturgeon populations upstream from Bonneville Dam is much less than that of the population in the free-flowing river between Bonneville Dam and the ocean. Reduced productivity likely results from reduced access to diverse anadromous, estuarine, and ocean food resources as well as sporadic conditions for recruitment. Sturgeon population productivity between Bonneville and McNary Dams (measured in harvestable lb/ac/year) has been estimated at only 15% that of the unimpounded population downstream from Bonneville Dam (Beamesderfer *et al.* 1995). In general, impounded populations grow slower, mature later, and maintain lower condition factors than the unimpounded population. Growth, condition, and maturation of Bonneville Reservoir sturgeon is among the poorest observed in the lower Columbia River basin but it is unclear whether this results from habitat conditions, competition, or contaminants.

Spawning habitat availability is a key determinant in the productivity of impounded sturgeon populations. Impounded reservoirs and river segments no longer provide suitable spawning conditions under all flow conditions. Spawning habitat is generally limited to the high-energy zones of dam tailraces but tailrace morphometry results in variable spawning habitat suitability and varying sensitivity to flow. The tailrace below The Dalles Dam at the head of Bonneville Reservoir appears to provide suitable spawning habitat under most flow conditions, hence, consistent sturgeon recruitment occurs to the Bonneville Reservoir population. In contrast, recruitment below John Day and McNary dams is sporadic, because suitable habitat provided only in years of high spring runoff.

1.3.2.3 Supplementation

No white sturgeon supplementation currently occurs in Bonneville Pool. An ongoing trap and transplant program from downstream of Bonneville Dam to The Dalles and John Day reservoirs is intended to compensate for migration blockage and sporadic recruitment. However, recruitment in Bonneville Reservoir is apparently consistent to seed the available rearing habitat.

1.3.2.4 Harvest

The productivity of impounded sturgeon populations between Bonneville and McNary Dams is sufficient to provide for limited harvest in Treaty Indian commercial, Treaty Indian subsistence, and non-Indian sport fisheries. The Bonneville Reservoir sturgeon population accounts for a substantial share of the harvest. Since 1991, annual harvests in combined fisheries generally have ranged from 2,000 to 3,000 sturgeon per year.

Sturgeon catch guidelines and sport/treaty commercial allocations have been reviewed annually since 1987 by the Sturgeon Management Task Force (SMTF), made up of representatives from state fish management agencies and the Columbia River treaty Indian tribes.

Guidelines are based on desired harvest rates and current stock assessments. In March 1997, the SMTF agreed to pool-specific management with catch guidelines based on OSY designed to allow for survival of adequate numbers of juvenile sturgeon through existing fisheries to increase harvestable and broodstock numbers. Commercial and sport retention is closed for the year when fishery-specific guidelines are reached.

Allocation is approximately 50:50 between sport and tribal fisheries, although reservoir-specific guidelines are shaped to meet fishery demands. For instance, the sport fishery is allowed a greater share of the Bonneville Reservoir catch, while the treaty Indian fishery is allowed a greater share of the catch in The Dalles and John Day reservoirs. Treaty Indian fishers may continue to take sturgeon for subsistence purposes after commercial seasons have been completed. Subsistence catch is estimated through a monitoring program conducted by the Yakama Indian Nation and annually averages less than 300 sturgeon. Subsistence catch is not included in the aforementioned catch guidelines. Sport anglers may continue to fish for sturgeon and release them unharmed when catch guidelines are reached and retention is prohibited.

Current sturgeon size limits are 48-60 inches for all treaty Indian fisheries, 48-60 inches for sport fisheries in The Dalles and John Day reservoirs, and 42-60 inches in the Bonneville Reservoir sport fishery. (Catches are shown in Table 1-7.) The Bonneville Reservoir size regulation matches that in the lower Columbia and is consistent with lower growth rates in Bonneville than in the upstream reservoirs.

Table 1-7. Sturgeon catches in Zone 6 reservoirs above Bonneville Dam, 1991–2001.

	Non-Indian Sport				Treaty Indian Commercial				
Year	Bonneville	The Dalles	John Day	Total	Bonneville	The Dalles	John Day	Total	Subsistence
1991	2,270	200	150	2,620	1,000	460	40	1,500	NA
1992	1,720	140	150	2,010	1,150	430	20	1,600	210
1993	2,310	160	140	2,610	1,420	580	10	2,010	260
1994	2,220	155	235	2,610	1,175	310	115	1,600	650
1995	1,370	50	90	1,510	1,420	310	310	2,040	1,150
1996	1,360	90	80	1,530	1,000	230	360	1,590	480
1997	1,470	180	480	2,130	1,852	498	1,260	3,610	236
1998	1,625	857	599	3,081	1,462	1,108	1,100	3,670	240
1999	1,236	694	422	2,352	1,280	1,051	760	3,091	244
2000	1,262	809	437	2,508	1,145	1,456	846	3,447	324
2001	1,422	677	300	2,399	1,019	1,258	684	2,961	476

1.4 Factors Affecting Population Status

1.4.1 Harvest

1.4.1.1 Below Bonneville

Lower Columbia River sturgeon populations collapsed at the beginning of the 20th century due to excessive harvest exploitation and a lack of regulations protecting broodstock fish (sturgeon 6 feet and greater). The sturgeon population rebounded after a maximum size limit of 6 feet was implemented in 1950. The population was stable during the 1970s, when harvest of 3-6 foot fish averaged about 30,000. A significant increase in harvest in the 1980s reduced the 3-6 foot population and consequently reduced recruitment to the broodstock population for future years. Management response in the 1990s focused on increasing future recruitment to the broodstock population by maintaining harvest levels that would provide annual growth in the legal harvest- sized population. To reduce the number of years in which sturgeon are subject to harvest, Washington and Oregon lowered the minimum size limit for white sturgeon to 42 inches, and the maximum to 60 inches.

History has shown that harvest can risk the health of the Columbia River sturgeon population unless the harvest is managed to protect broodstock and to pass enough younger sturgeon through the fishery to provide replacement broodstock for the future. Recent management policies adopted by Washington and Oregon assure long-term sturgeon health, but depend on adequate monitoring of the population status and the fisheries.

Interest in lower Columbia sturgeon sport fishing has increased dramatically in the past 25 years, rising from 60,000 angler trips in 1975 to over 200,000 in 1997, 1998, and 2000 (see Figure 1-8). Lower Columbia commercial sturgeon harvest has been stable compared to sport harvest over the same time period, primarily due to reductions in seasons due to salmon declines in the 1970s and 1980s and sturgeon catch allocations in recent years. Interest in commercial sturgeon fishing is also increased due to reduced opportunity for salmon and a stable market for sturgeon landings compared to salmon landings.

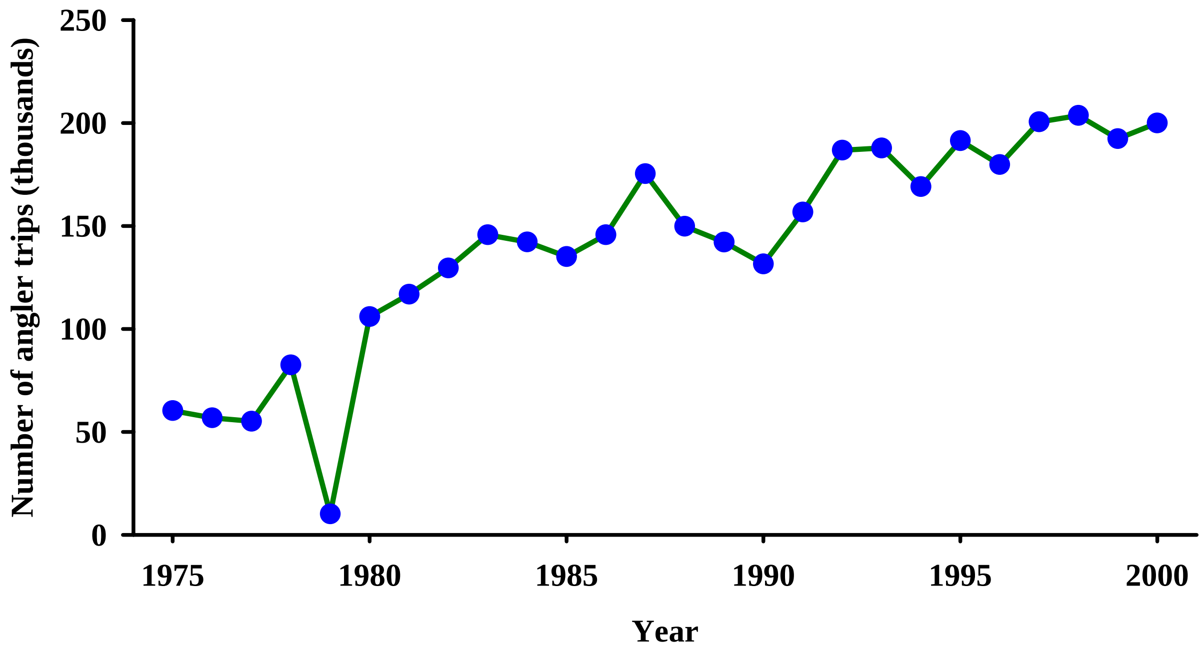

Figure 1-8. Sturgeon angler trips in Section 1-10 on the lower Columbia River, 1975–2000.

1.4.1.2 Above Bonneville

Intensive management of sturgeon fisheries upstream from Bonneville Dam is required by the reduced productivity of these impounded populations. These fisheries provide the only significant opportunity for Columbia River treaty Indian fishery access to sturgeon. Sport fisheries are managed for equal opportunity. Intensive management involves regular assessments of stock status, population modeling to identify sustainable fishing levels, fishery monitoring and in-season management to limit annual catches within prescribed guidelines, and an annual fishery management and allocation process. The objectives are similar to those in the lower river (i.e. ensure adequate broodstock escapement.

1.4.1.3 Ocean/Estuary

White sturgeon are not directly harvested in ocean fisheries but can be taken incidentally at very low numbers in trawl fisheries. Columbia white sturgeon are also harvested in Washington and Oregon Coastal estuaries. Oregon and Washington management agreements require that estuary fisheries do not increase from historical impacts to white sturgeon.

1.4.1.4 Supplementation

Unlike the proliferation of salmon supplementation hatcheries throughout the Columbia River Basin (NRC 1996; Lichatowich 1999; Brannon *et al.* 1999), white sturgeon supplementation hatcheries do not exist in the Columbia Basin. The slow and deliberate development of a few sturgeon conservation hatcheries responds to the competing forces of real and perceived hazards of salmon supplementation hatcheries and the need to demographically support remnant sturgeon populations in the Columbia and Fraser river basins experiencing ongoing recruitment failure. To date, the Kootenai Hatchery, which captively rears progeny of wild parents for release at ages between 3 days and 2 years for conservation purposes, constitutes the only program with a stocking history dating back to the early 1990s (Kincaid 1993; Duke *et al.* 1999; Ireland *et al.* 2002).

1.4.2 Water Development

Hydropower development at the Columbia River Basin scale has extensively fragmented numerous historically free-flowing river reaches (NRC 1996). Dams result in population fragmentation and reduce or eliminate migration and non-reproductive and genetically effective migration (gene flow) among historically connected areas.

Population fragmentation—Population fragmentation represents a critical threat to the status of many sturgeon taxa, including *A. transmontanus* (Jager *et al.* 2000, 2001). Fragmentation can reduce population size, and it has long been known that isolated populations lose neutral genetic variability at a rate directly proportional to how small they are (Wright 1931). Because fragmentation can reduce population or deme size, and small population size can negatively affect genetic variation, fragmentation can indirectly reduce genetic variability. An important additional effect of such river fragmentation on white sturgeon is the artificial creation of a series of relatively isolated sub-populations, with artificial population genetic characteristics (Jager 2000, 2001; Secor *et al.* 2002). Fragmentation by hydropower dams can also result in variable and reduced productivity in post-impoundment river reaches (Bevelhimer 2001).

Population and habitat fragmentation by dams is especially critical for a migratory species like *A. transmontanus* because it may also impose predominantly or exclusively downstream gene flow on a species that likely historically exhibited upstream and downstream migration and gene flow. Jager *et al.* (2001) simulated the effects of dam creation (fragmentation) on white sturgeon population viability and genetic diversity, using two different simulations of an individual-based genetic metapopulation model. The first simulation fragmented a 124-mile (200 km) river reach by sequentially building 1-20 dams. These dams resulted in the exponential decline in the likelihood of persistence, but failed to produce any extinction threshold indicative of any minimum river length required for theoretical population persistence. Adding more dams in this simulation consistently eroded genetic diversity within and among populations. The second simulation of Jager *et al.* (2001) evaluated the effects of various levels of upstream and downstream migration between river segments. Results of the second simulation supported the view that migration plays a major role in the viability of riverine fishes, such as white sturgeon, when their habitat is fragmented by dams. Likelihood of extinction was high for populations linked by high downstream and low upstream migrations, as is often the case in extremely fragmented systems.

1.4.3 Flow Alterations

Altered daily and seasonal river discharge and thermal regimes resulting from impoundment and dam operations also may alter migration, limit habitat availability, and affect timing, location and success of reproduction (Paragamian and Kruse 2001; Paragamian *et al.* 2001; Anders *et al.* 2002; Cooke *et al.* 2002; Jager *et al.* 2002; Secor *et al.* 2002). Parsley *et al.* (2001) simulated drawdown of a Columbia River reservoir and concluded that the quality and quantity of white sturgeon spawning habitat would increase as reservoir levels were lowered. However, these authors suggested this outcome was due to increased availability of suitable velocities for spawning (Parsley *et al.* 1993) despite a decrease in total area of the river (Parsley *et al.* 2001).

Important empirical correlations between water year; discharge characteristics during June, July and August; and recruitment measured during September in the lower Columbia River impoundments attest to the importance of flow alterations on white sturgeon recruitment (Counihan *et al.* in press). An understanding of a positive relationship between discharge (water years) and natural production of Columbia River white sturgeon has existed since the late 1980s (Beamesderfer and Nigro 1995). Furthermore, consistent annual recruitment in the lower Columbia River, in the Bonneville Dam tailrace, and downriver areas were associated with conditions representing good water years due to the artificial constriction of the Columbia River through Bonneville Dam; as such hydro development has artificially created what functionally amounts to white sturgeon spawning channels downstream from Bonneville Dam, resulting in reliable annual recruitment (L. Beckman USGS (retired), G. McCabe Jr. NMFS (retired), M. Parsley, USGS, Cook Washington. personal communication).

Flow alterations can also affect white sturgeon spawning and embryo hatching success, to the extent that flow they alter downstream thermographs. (See Sections 1.1.1 Spawn timing and conditions, and 1.1.2 Incubation for more detailed discussions of temperature effects on spawning and incubation success.)

1.4.4 In-Channel Habitat Conditions

Sturgeon are particularly abundant in deep-water habitats of the Columbia River subject to channel maintenance and dredging activities. Suction dredging in deep areas (66-85 ft [20-26 m]) in the lower Columbia River is known to seriously injure and kill juvenile white sturgeon (Buell 1992) but the magnitude of the population impact is unclear. Channel deepening also may affect sturgeon directly via entrainment or indirectly via habitat or food interactions, but the net effect is unclear and speculation continues.

1.4.5 Water Quality

Hypoxia (oxygen limitation) may have disproportionately negative effects on sturgeons relative to other fauna, due to their limited capacity to osmoregulate at low dissolved oxygen concentrations (Klyashtorin 1976; Secor and Gunderson 1998 as cited in Secor *et al.* 2002). Although hypoxic effects may be particularly important to sturgeons during their first year of life due to their increased sensitivity and reduced ability—especially incubating embryos—to escape anoxia environments (Secor and Niklitschek 2001).

1.4.5.1 Temperature

Refer to Section 1.1.2 Incubation for a review of the potential effects of temperature on white sturgeon spawning and incubation. Since system productivity and fish growth and metabolism are positively temperature-dependent, variation in temperature affects these parameters. However, such effects are expected to be more pronounced in the upper Columbia Basin areas due to the thermal tempering effects of the increasingly large water volumes in areas of the lower Basin.

Because sturgeons are poikilotherms (cold-blooded), the rates and timing of metabolic activities vary in latitudinal and upstream (elevational) perspectives. Natural spawning of white sturgeon in the lower Columbia River (downstream from Bonneville Dam) routinely began at 8°C, whereas spawning was routinely initiated in the three furthest downstream dam tailraces when water temperature reached at least 10°C (M. Parsley, USGS, Cook, Washington, personal communication). Spawning was also generally first observed downstream from Bonneville Dam, and at intervals close to 2 weeks subsequently at the upstream series of Columbia River dam tailraces (e.g. The Dalles, John Day, and McNary Dams). Natural spawning of white sturgeon was documented to occur as late as July or August in upstream reaches of the Columbia River in British Columbia (Colin Spence, BC Ministry of Land, Water and Air Protection, pres. Comm.). Kootenai River white sturgeon, found at elevations several thousand feet higher and farther north (~ 49th parallel) than lower Columbia fish, spawned in water as cold as 8°C, or slightly colder. Spawning also occurs earlier in the spring season in downriver areas compared to upriver areas of the Columbia River Basin.

Finally, thermal regimes also dictate the length of the growing season for sturgeons throughout the Columbia Basin. Length at age and condition factor measures generally increase in a downstream orientation throughout the Columbia River basin. These variables also parallel longitudinal clines in food production and availability, which are positively affected by thermal regimes (increasing temperatures).

1.4.5.2 Turbidity

Having evolved in reproductive association with the world’s large river systems, sturgeons successfully adapted and flourished in systems that seasonally became very turbid. Highly- developed sensory organs for chemical (olfactory) and mechanical reception, and the lack of well-developed vision in sturgeons (Moyle and Cech 1983; Long 1995) suggest that turbidity may not be an important limiting factor for sturgeon, since they have adapted in its presence. Furthermore, turbidity could serve a positive role in concealment of planktonic white sturgeon early life stages, thereby reducing the effectiveness of visual predation.

1.4.5.3 Dissolved Gas

Counihan *et al.* (1998) conducted laboratory experiments investigating the effects of dissolved gas supersaturation on white sturgeon yolk-sac larvae and found that signs of gas bubble trauma were evident in 1–2 day old fish after only 15 minutes of exposure at 118% supersaturation. Yolk-sac larvae exposed to total dissolved gas (TDG) levels of 118% experienced no mortality, though their behavior was significantly different from control groups. Because of the development of a bubble in the buccal cavity, these fish were unable to descend from the surface. Yolk-sac larvae exposed to TDG levels of 131% experienced 50% mortality after 13 d of exposure.

Hypoxia (oxygen limitation) may have disproportionately negative effects on sturgeons, relative to other fauna, due to their limited capacity to osmoregulate at low dissolved oxygen concentrations (Klyashtorin 1976; Secor and Gunderson 1998). Although hypoxic effects may be particularly important during the first year of life due to the increased sensitivity and reduced ability of sturgeons (especially incubating embryos) to escape anoxic environments (Secor and Niklitschek 2001), specific oxygen and gas exchange requirements for incubating white sturgeon embryos are currently unknown.

1.4.5.4 Chemicals

The following passage on water quality and pollutant sensitivity in white sturgeon yolk-sac larvae was taken directly from Parsley *et al.* (2002): White sturgeon yolk-sac larvae are sensitive to poor water quality and pollutants. Brannon *et al.* (1985b) reported that water quality parameters for chlorine and gas supersaturation might be more critical for white sturgeon than for salmonids. The anti-sap stain wood preservative Bardac 2280 (principal active ingredient 80% didecyldimethylammonium chloride, DDAC) a common wood preservative, has been found to be particularly toxic to white sturgeon yolk-sac larvae with a 24-hour 50% lethal concentration (LC50) value between 1 and 10 ppb. Spill at dams can cause supersaturation of atmospheric gases in waters during yolk-sac larval dispersal.

Kruse and Scarhechhia (2002) studied contaminant uptake and survival of white sturgeon embryos in the laboratory. Uptake of organochlorine pesticides, Aroclor 1200 series PCBs, and metals were assessed relative to embryo survival. Eight metal species and two organichlorine compounds (DDE and PCB Aloclor 1260) were detected in embryos, thus confirming that they were uptaken from the incubating environment. These authors concluded that copper and Aloclor 1260 in the rearing media had negative effects on survival of white sturgeon embryos.

No literature was available on direct roles of nutrients on white sturgeon. However, sturgeon in parts of the Columbia River basin characterized by increased nutrient availability and abundant food resources (e.g. lower Columbia River and estuary) typically exhibit increased growth rates, length, and condition factor values compared to fish in upstream and culturally denutrified reaches (e.g. Kootenai River system). Growth rates of juvenile white sturgeon in the farthest downstream impoundments appeared to surpass those of fish in the lower river until about age 7 or 8, when access to marine-derived nutrients and estuarine food resources appeared to provide higher growth rates than those in upstream impounded fish (M. Parsley, USGS, Cook, Washington, personal communication).

1.4.6 Species Interactions

1.4.6.1 Competition

Little information exists on interspecific competition with sturgeon. Sturgeon occupy a unique niche among Columbia River fishes. Intraspecific competition and density-dependent effects on population dynamics are likely to be much more important for white sturgeon than interspecific competition. The potential for intraspecific competition between juvenile and adult is limited by diet shifts as larger fish are able to capitalize on larger prey, particularly including adult lamprey, shad, and salmon.

1.4.6.2 Predation

In fresh water, predation appears to be an important issue only for early life stages of white sturgeon, before age 1. In the estuary and ocean, predation on juvenile and subadult sturgeon is also likely.

Eggs—Demersal white sturgeon embryos are vulnerable to fish predation (Anders 1994, 1996; Miller and Beckman 1996; Parsley *et al.* 2002). During 1994 and 1995, 632 stomach content samples from predatory fishes collected from the Kootenai River (northern pikeminnow *Ptychocheilus oregonensis*, peamouth chub *Mylocheilus caurinus* and suckers *Catastomus spp*.) were analyzed (Anders 1996). As discussed above, of 428 naturally spawned white sturgeon eggs collected, 12.2% (52) were collected from 623 predatory fish stomach samples analyzed. Miller and Beckman (1996) reported the occurrence of one to 70 white sturgeon eggs in guts of four omnivorous fishes in the Columbia River. These authors noted that a single largescale sucker (*Catastomus macrocheilus*) consumed 70 white sturgeon eggs.

Larvae/juveniles—Recent empirical research revealed species-specific predatory behavior by several Columbia River omnivorous fish species on YOY white sturgeon (Gadomski *et al.* 2000, 2001, 2002). Researchers reported that adult northern pikeminnow and channel catfish (16-24 in TL [400-600 mm]) ingested sturgeon juveniles up to about 5 in 5 in (120 mm). Similarly-sized adult walleye ingested almost no sturgeon juveniles. However, juvenile walleye (6-8 in [150-200 mm]) ate sturgeon larvae and juveniles up to about 1.6 in (40 mm). Prickly sculpins (4-8 in [100-200 mm]) ate sturgeon up to 2 in (50 mm). When rock substrate was available, fewer sturgeon larvae were ingested by sculpins. When equal numbers of alternate prey were available, sculpins presented with both sturgeon and goldfish ate more sturgeon. Pikeminnow with smaller sturgeon and coho salmon prey available consumed both about equally. When sturgeon and coho prey were both larger, more coho were ingested. (Gadomski *et al.* 2000, 2001, 2002). Thus, predation appears to be an important natural mortality factor, at least with white sturgeon age 0 and younger life stages. However, beyond age 0, body size and scute development appeared to function as successful anti-predatory mechanisms.

1.4.6.3 Ocean & Estuary Conditions

White sturgeon, like other Acipenserids, are able to move freely between freshwater, marine, and estuarine habitats without requiring developmental and age-specific physiological adjustment (e.g. smoltification). However, little is known about specific effects of ocean and estuary conditions on white sturgeon. Likewise, little is known about how variability in ocean conditions may affect white sturgeon. Seasonal and inter-annual variation in productivity and food availability resulting from dynamic ocean and estuary conditions likely affect white sturgeon diet and habitat use in these areas. However, no studies directly linking ocean and estuary conditions to measurable physiological performance or behavior of white sturgeon were found.

1.4.6.4 Food Source Abundance

Very little is known regarding the effects of food source abundance for white sturgeon in marine and estuarine environments, but, based on empirical growth studies of white sturgeon in the four Columbia River impoundments farthest downstream and in the lower Columbia River, annual juvenile growth rates in the impounded areas generally surpassed those in the lower Columbia River until approximately age 7 or 8. Following this age, mean annual growth rate in the lower Columbia River, possibly including the estuary, generally exceeded rates in the impoundments (M. Parsley, USGS, personal communication). This increase in relative growth rate for juvenile white sturgeon downstream from Bonneville Dam was thought to result from access to food items unavailable in the impoundments (e.g. eulachon) (DeVore et al. 1995; M. Parsley, J. Devore, personal communication).

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