7 RESEARCH, MONITORING, AND EVALUATION NEEDS

During the preparation of this report several physical and biological data gaps were identified regarding sockeye salmon population limiting factors. Some limiting factor data gaps are relatively small because of the extensive physical or biological data currently available. Other data gaps are relatively large, such as where limiting factors were rated as having an unknown degree of impact on the sockeye population. Developing a comprehensive and/or quantitative understanding of all limiting factors will likely remain unattainable because of limited resources and the highly dynamic nature of sockeye salmon and their environment. However, ongoing and expanded monitoring of population integrity and key physical and biological processes will promote a deeper understanding of the most influential limiting factors already outlined in this report.

The following research, monitoring, and evaluation needs are a combination of ongoing efforts that need to recur annually and specific studies or monitoring efforts needed to fill data gaps. Research, monitoring, and evaluation needs are presented by life history stage and include key questions that could be answered by future research. Appendix F contains the working draft research and monitoring priorities developed as part of the draft LFA in 2001. Where applicable, concepts from Appendix F are included below in Sections 7.1 through 7.13

7.1 ADULT SOCKEYE ENTERING SYSTEM

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for the adult sockeye river entry and lake migration life history phase:

- Adult Sockeye Run Size and Run Timing
- Ozette River Stage and Discharge
- Predation (nearshore, estuary, and in-river)
- Ozette River Water Quality
- Ozette River Habitat Conditions
- Ozette River Estuary Conditions and Alterations

Key questions to be addressed through research and monitoring are included in Sections 7.1.1 through 7.1.6.

7.1.1 Adult Sockeye Run Size and Run Timing

It is recommend that adult sockeye run size and timing data continue to be collected. Attempts are needed to improve population estimates and investigate use of fish-friendlier methods of enumeration (e.g., side viewing sonar). Determining accurate run size and abundance trends of the population is critical to attaining recovery of Lake Ozette sockeye. Tracking population fluctuations over time will help determine the success of restoration activities, as well as the success of the overall Lake Ozette Sockeye Recovery Plan. Abundance data are a critical component for developing productivity estimates by life stage. These data will also help answer questions regarding changes in run timing and degree of inter-annual run timing variation.

7.1.2 Ozette River Streamflow

Ozette River discharge during adult migration has been reduced on average. Additional detailed hydraulic and hydrological modeling is required to determine the exact magnitude to which flows have been altered by various factors in combination (river hydraulics such as roughness and sedimentation, climate, hyporheic flow, lake evapotranspiration, and reductions in tributary baseflow inputs). The effect of changes to streamflow on migrating sockeye remains unknown (see Hypothesis 4 in Section 6.2.1.4) and should be a focus of future research and monitoring.

Better quantification of the nature of hyporheic flow through the outlet of Lake Ozette could be fairly easily conducted using standard techniques (Bencala et al. 1983; Harvey et al. 1996; Harvey and Wagner 2000; Packman and Bencala 2000). Additional measurements and modeling data are needed for quantification of shoreline vegetation effects on lake evapotranspiration. Future research should take advantage of modern watershed hydrology modeling to help quantify a range of likely scenarios of how land use has affected water yields and flow regimes in Ozette. For example, a distributed watershed model (Distributed Hydrology Soil Vegetation Model [DHSVM] or similar) could be developed to simulate historic, current, and future lake inflow hydrology as a result of changes in land use, vegetation cover, drainage density, roads, and soil water storage. This model could be coupled with unsteady HECRAS hydraulic model of the Ozette River (Herrera 2005) to develop a fully encompassing watershed hydraulic and hydrologic model of Ozette that incorporates lake inflow, outflow, and evaporation (i.e., a water budget).

7.1.3 Predation

Continued monitoring of in-river predation is an important component for understanding the degree that predation affects the sockeye population at different abundance levels.

7.1.4 Ozette River Water Quality

It is recommend that water quality data (temperature, turbidity, SSC) continue to be collected.

Have stream temperatures increased during the last 50 years? How much? How do high stream temperatures limit Ozette sockeye? Variations in timing of spawning migrations may be in response to river flow and water temperature. During some years, such as 2003, stream temperatures approach lethal levels. During years of high water temperature during the sockeye run, snorkel surveys or other additional surveys of the river should take place in order to determine how much in-river mortality is occurring.

How much have turbidity and SSC levels increased in Ozette River and Coal Creek during the last 50 years? How do high turbidity and SSC values limit Ozette sockeye? How does sediment deposition over time at the mouth of Coal Creek affect lake levels? Are these sedimentation effects permanent or temporary? How competent is the Ozette River at flushing sediment derived from Coal Creek downstream? How does sediment derived from Coal Creek affect spawning and incubation habitat for Chinook and chum salmon in Ozette River? How does sedimentation in Ozette River affect the unique biota of the river (e.g., net spinning caddis flies, freshwater sponge, endemic mussels, etc.) and thus the ecosystem that sockeye migrate through?

7.1.5 Ozette River Habitat Conditions

Do large logjams that form deep pools in the Ozette river provide important refuge habitat for adult sockeye salmon? Do deep pools provide thermal refuge habitat for adult sockeye? How does habitat complexity and/or simplification affect predation of adult sockeye?

7.1.6 Estuary Conditions

Are there unique tidal prism influences that enhance or are detrimental to the sockeye life cycle? Quantify the changes in estuary volumes and habitat availability over time in response to altered spit morphology at the ocean mouth. Analyze sequential historical photos, in conjunction with field surveys. How has nutrient and salinity exchange changed in the estuary and how has this affected sockeye rearing and migration habitat?

7.2 ADULT SOCKEYE HOLDING IN LAKE OZETTE

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for the adult sockeye lake holding life history phase:

- Predation

- Disease
- Other Lake Holding Mortality Sources

Levels and sources of mortality of adult sockeye holding in the Lake Ozette are relatively unknown. Predation and disease have been only partially investigated. Note that the degree of impact was categorized as unknown for Hypothesis 7 (the number of sockeye surviving to spawn is reduced by predators, disease, and other factors during the extended holding period in Lake Ozette prior to spawning).

What impacts do these factors have on adult sockeye in the lake environment? What is the cumulative effect of stress during migration (e.g., ocean conditions, streamflow timing, temperature, predation wounds) on the development of disease during the lake holding period? How do lake holding conditions affect the development or suppression of disease? How will changes in lake holding habitat into the future (e.g., temperature) affect disease?

Continued monitoring of lake predation (i.e., seal and river otter predation) is an important component for understanding the degree that predation affects the sockeye population at different abundance levels. As a small beginning step, river otter scat samples collected during the summers of 2002 and 2003 need to be examined.

7.3 ADULT SOCKEYE STAGING AT SPAWNING BEACHES

No monitoring or research needs have been identified for this life history stage.

7.4 ADULT SOCKEYE SPAWNING ON LAKE BEACHES

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for the adult sockeye beach spawning life history phase:

- Beach Spawner Distribution and Abundance
- Predation
- Quantify Suitable Habitat/Identify Non-Utilized Suitable Habitat
- Monitor Interaction With Kokanee
- Lake Ozette Water Quality

Key questions to be addressed through research and monitoring are included in Sections 7.4.1 through 7.4.5.

7.4.1 Beach Spawner Distribution and Abundance

Improved enumeration techniques are needed for quantifying annual adult spawning escapement at all beach spawning locations (e.g., intensive dive surveys, mark and recapture, sonar or acoustic estimates). There is a general lack of information relative to the number of successful spawners on the beaches.

Key questions include: How many sockeye spawn each year on each beach? Are other beach spawning areas also used? If so, to what extent? Are secondary areas such as north Olsen's Beach and Cemetery Point used each year and to what degree?

7.4.2 Spawning Habitat Quantification

The total amount of suitable beach spawning habitat has not been quantified. The current distribution of suitable spawning habitat needs to be quantified and mapped. These data will be critical if establishment of new spawning areas is attempted in Ozette (see also Section 7.5.1).

What makes habitat suitable for spawning? Traditionally we have used substrate and depth as indicators of suitable beach spawning habitat. We need to include quantification of additional factors for suitable habitat such as groundwater and hyporheic upwelling presence/absence, pore velocity, wind-driven current velocities, beach slope, vegetation presence/condition, aspect, wind fetch, substrate pore space (e.g., cobble/boulder voids), etc. Habitats need to be differentiated by those suitable for spawning due to upwelling, versus habitat that may be suitable for spawning due to wind or wave or seiche driven currents.

7.4.3 Predation

It is recommended that annual monitoring of harbor seal and river otter predation take place at known spawning areas of Lake Ozette. The one year in which predation monitoring occurred indicated that significant (10-40%) pre-spawning predation occurred. Key questions include: What percent of beach spawners are consumed prior to spawning? Which predators consume more sockeye salmon? Do river otters forage on sockeye carcasses left by harbor seals?

7.4.4 Kokanee-Sockeye Spawning Interaction

Continue to monitor kokanee-sockeye spawning interaction. Attempt to quantify the number of kokanee spawning on sockeye beaches. This can be done during sockeye spawning ground surveys combined with genetic sampling. Key questions include: How many kokanee or kokanee size *O. nerka* spawn annually with sockeye salmon on the beaches? What effect does this level of hybridization have on the population? Are there increasing numbers of kokanee spawning with sockeye on the beaches?

7.4.5 Water Quality

The frequency of high turbidity events and the direct effect on spawning sockeye are unknown but may include moderate physiological stress, habitat avoidance, and spawning habitat degradation. Turbidity and SSC data are lacking on the extant spawning beaches and these are considered an important data gap. In general, existing beach spawning habitats, especially Allen's Beach, are presumed less susceptible to stream-derived turbidity and SSC (because they are not close to major sediment sources from eastern tributaries).

Key questions include: Is there evidence of anthropogenic impacts on water quality in the lake? If so, to what extent have any changes affected beach spawning sockeye and how do these impacts vary by location? What are the patterns and concentrations of turbidity/SSC across the lake and along different beach habitats during various storm events? What beaches/locations are more susceptible to habitat degradation due to fine sediment deposition? Do spawning habitat and water quality differ between deltaic beach spawning locations and more remote shoreline spawning locations? Is water quality changing over time?

7.5 SOCKEYE EGG INCUBATION ON SPAWNING BEACHES

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for sockeye egg incubation on spawning beaches:

- Spawning Habitat Quality and Quantity
- Egg Predation
- Seasonal Lake Level Changes

Key questions to be addressed through research and monitoring are included in Sections 7.5.1 through 7.5.3.

7.5.1 Spawning Habitat Quality and Quantity

Spawning habitat quality and quantity has been reduced across many beaches around Lake Ozette. Several factors have been implicated for the reduction in the quality and quantity of spawning habitat, including vegetation encroachment, increased fine sediment production and delivery to the lake, changes in lake level, and watershed hydrology. Research focusing on egg-to-fry survival and beach spawning habitat characteristics could greatly improve our understanding of current habitat conditions and aid in the development of recovery strategies for beach spawning habitat. A fully encompassing watershed hydraulic and hydrological model that incorporates lake inflow, outflow, and evaporation (i.e., a water budget) is needed to fully understand changes in lake level dynamics between historical, current, and future watershed conditions.

Additional studies of egg-to-fry survival are needed in various beach spawning habitat conditions (substrate size distribution, substrate pore space (e.g., gravel/cobble/boulder voids), water depth, upwelling hydraulic gradient, pore velocity, beach slope, wind-driven current velocities, vegetation presence/condition, aspect, wind fetch, etc. These studies should differentiate egg-to-fry survival between habitats that may be suitable for spawning due to upwelling, versus habitat that may be suitable for spawning due to wind or wave or seiche driven currents, plus all other factors.

An initial draft proposal has already been developed to research these various egg-to-fry survival factors by testing the success of egg planting and reintroduction efforts in different types of existing and rehabilitated beach habitats (Schneidler 2006). Consult this document before initiating any research ideas, so that existing ideas can be built upon and expanded to fit exact research needs.

7.5.2 Egg Predation

Egg predation remains a data gap for Ozette spawning beaches. Key questions include: How much egg predation occurs? What species are egg predators? What effect does egg predation have on the different spawning aggregations?

7.5.3 Seasonal Lake Level Changes

Seasonal changes in lake level have been shown to dewater sockeye redds, potentially resulting in egg mortality. The proportion of redds dewatered due to seasonal changes in lake level varies by year dependent upon several factors. Continued mapping of redd locations and elevations (e.g., redd water depths or heights above water at specific lake stages) is needed across the beach spawning distribution to better quantify redd dewatering or lake level changes on incubation survival or redd conditions (e.g., temperature, water exchange through redd). Currently there is only one year of the data needed to quantify the proportion of spawning area dewatered.

A fully encompassing watershed hydraulic and hydrological model that incorporates lake inflow, outflow, and evaporation (i.e., a water budget) is needed to fully understand changes in lake level dynamics between historical, current, and future watershed conditions, and thus changes in the impacts of redd dewatering.

7.6 LAKE BEACH FRY EMERGENCE AND DISPERSAL

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for sockeye fry emergence and dispersal on spawning beaches:

- Early Life History
- Fry Predation
- Seasonal Lake Level Changes

Key questions to be addressed through research and monitoring are included in Sections 7.6.1 through 7.6.3.

7.6.1 Sockeye Fry Life History

The temporal and spatial distribution of sockeye fry remains unknown. It is generally assumed that Ozette sockeye fry quickly migrate to the pelagic zone upon emergence. Studies are needed to determine nearshore habitat utilization after emergence and aid in understanding predator prey relationships, as well as food type and availability during the fry stage.

7.6.2 Fry Predation

Fry predation remains a data gap for Ozette spawning beaches. Key questions include: How much fry predation occurs? What species of fish (or birds or mammals) are sockeye fry predators? What effect does fry predation have on the different spawning aggregations and beach spawners collectively? Is fry predation at the mouths of tributaries and deltaic spawning locations different from predation of fry off remote extant beaches?

7.6.3 Seasonal Lake Level Changes

Seasonal changes in lake level have been shown to dewater sockeye redds, potentially resulting in egg mortality. If upwelling conditions prevent redd dewatering and thus prevent egg and fry desiccation, emerging fry may still lack access to the lake rearing environment (e.g., fry emerging from a redd on a spring above lake level may be unable to swim down the beach into the lake). Redd dewatering needs to be investigated at meso- and micro-scales to determine the exact mortality factors (e.g., desiccation versus disconnection). The proportion of redds dewatered due to seasonal changes in lake level varies by year dependent upon several factors. Continued monitoring of lake stage and collection of redd elevation data is recommended. Currently there is only one year of the data needed to quantify the proportion of spawning area dewatered. A fully encompassing watershed hydraulic and hydrological model that incorporates lake inflow, outflow, and evaporation (i.e., a water budget) is needed to fully understand changes in lake level dynamics between historical, current, and future watershed conditions, and thus changes in the impacts of redd dewatering.

7.7 ADULT SOCKEYE ENTERING, MIGRATING, AND HOLDING IN TRIBUTARIES

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for sockeye entering, migrating, and holding in Lake Ozette tributaries:

- Population Abundance and Distribution
- Streamflow
- Water Quality
- Predation

Key questions to be addressed through research and monitoring are included in Sections 7.7.1 through 7.7.4.

7.7.1 Population Abundance and Distribution

Currently Umbrella Creek sockeye are enumerated at river mile 0.8 using a weir and trap. It is recommended that weir operations be continued in Umbrella Creek. Methods need to be developed and implemented in all sockeye spawning tributaries (e.g., Big River and Crooked Creek) so that accurate population estimates can be made annually. Abundance data is a critical component of recovery monitoring. Experimentation is needed to improve population estimates and investigate utilization of fish-friendlier methods of enumeration (e.g., side viewing sonar).

Determining accurate run size and abundance trends of the population is critical to attaining recovery of Lake Ozette sockeye. Tracking population fluctuations over time will help determine the success of restoration activities, as well as the success of the overall Lake Ozette Sockeye Recovery Plan. Abundance data are a critical component for developing productivity estimates by life stage.

7.7.2 Streamflow

The hydrology of the Ozette Watershed has been poorly studied over the contemporary settlement period of the Ozette region. It is recommended that streamflow data collection continue over the <u>long term</u> in all major tributaries to Lake Ozette and the Ozette River.

Data collection at the following tributary sites should continue in the following order of priority:

1. Coal Creek
2. Umbrella Creek
3. Big River
4. Crooked Creek
5. Siwash Creek

Long-term streamflow data would allow for a comprehensive understanding of the impacts that low streamflow has on adult sockeye migration in tributaries.

A fully encompassing watershed hydraulic and hydrological model that incorporates lake tributary inflow, outflow, and evaporation (i.e., a water budget) is needed to fully understand changes in tributary and lake level dynamics between historical, current, and future watershed conditions. This model could be calibrated to long-term tributary streamflow data. Thus, the range of potential impacts on sockeye salmon survival both in tributaries and the lake could be more thoroughly understood.

7.7.3 Water Quality

Collection of summer and fall temperature data in all Ozette tributaries needs to continue and be slightly expanded to ensure adequate records and coverage for each major tributary. These data would allow for a better understanding of the impacts of high fall stream temperatures on initial adult sockeye migration into tributaries.

Collection of continuous turbidity and SSC measurements in all Ozette sockeye tributaries needs to continue over the long term, with the goals of understanding the magnitude and duration impacts of high sediment loads on adult sockeye migration into tributaries and detecting long-term (decadal) trends in turbidity and suspended sediment concentration.

7.7.4 Predation

During the period that adult sockeye enter, migrate, and hold in lake tributaries they are primarily susceptible to predation by river otters, harbor seals, and terrestrial mammals. While not likely a major or key limiting factor, tributary predation on adults remains a data gap. Little information exists on the rates of predation, species involved, or relative impacts to the overall population of tributary spawners.

7.8 ADULT SOCKEYE SPAWNING IN TRIBUTARIES

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for sockeye spawning in tributaries:

- Streamflow and Adult Spawning Locations
- Spawning Habitat Quality
- Spawning Habitat Quantity
- Water Quality During Spawning
- Competition with Other Species

Key questions to be addressed through research and monitoring are included in Sections 7.8.1 through 7.8.5.

7.8.1 Streamflow

See Section 7.7.2.on streamflow for additional description of streamflow monitoring needs in Ozette tributaries.

Long-term streamflow data would allow for a better understanding of the impacts streamflow has on adult sockeye spawning timing and locations in tributaries. Tradeoffs exist between spawning low in a cross-section and avoiding dewatering, compared to spawning higher in the cross-section and avoiding bedload transport and scour. High streamflow variability during the sockeye spawning and incubation period can result in reduced probabilities of successful egg-to-fry survival. Quantification of natural and human induced streamflow impacts on egg-to-fry survival in Ozette tributaries remains a major data gap.

7.8.2 Spawning Habitat Quality

The quality of spawning habitat in Ozette tributaries has been reduced due to fine sediment deposition, LWD removal, and channel destabilization, with resultant changes on hyporheic flow paths and scour depths. The extent that these changes have altered adult sockeye spawning site selection or spawning success is unknown and needs to be quantified.

7.8.3 Spawning Habitat Quantity

In many Ozette tributaries, the quantity of suitable spawning habitat area has been reduced due to the effects of LWD removal, reduced LWD recruitment, increased fine sediment inputs and abundance, channelization and bank armoring, gravel mining, and colonization of bar deposits by non-native vegetation. In some reaches of Big River and Umbrella Creek, spawning gravel beds have been completely converted to sand bed or cobble bed, respectively. No attempts have been made to quantify loss of available spawning habitat over time, which remains a data gap.

7.8.4 Water Quality

Collection of continuous turbidity and SSC measurements in all Ozette sockeye tributaries needs to continue over the long term, with the goals of understanding the magnitude and duration of impacts of high sediment loads on adult sockeye spawning in tributaries and detecting long-term (decadal) trends in turbidity and suspended sediment concentration.

7.8.5 Competition

Both intraspecific and interspecific competition exists in Ozette tributaries: sockeye competing with one another for spawning habitat, sockeye competing and/or spawning with kokanee for spawning habitat, and sockeye competing with coho salmon for spawning habitat. The degree and type of competition thought to occur in tributaries varies by stream system, species population abundance, and habitat quality and availability. Within certain reaches with modest numbers of sockeye (Umbrella Creek), competition can be intense and redd superimposition can play a significant role in egg-to-fry survival. Spawning competition with coho salmon also occurs since these species spawn at the same time/habitat, but coho populations will need to increase for this to become a significant factor. Competition and interaction with kokanee is thought to be minimal in Umbrella Creek since few kokanee spawn in this stream system, but is more common in other streams (e.g. Crooked Creek), where sockeye numbers are low but kokanee numbers are moderate. Future monitoring and data collection are needed to quantify this intraspecific and interspecific competition.

7.9 SOCKEYE EGG INCUBATION IN TRIBUTARIES

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for sockeye egg incubation on spawning beaches:

- Spawning Habitat Quality
- Spawning Habitat Quantity
- Egg Predation

Key questions to be addressed through research and monitoring are included in Sections 7.9.1 through 7.9.3.

7.9.1 Spawning Habitat Quality

Under post-disturbance conditions, Lake Ozette tributaries have some of the highest levels of fine sediment (18.7% volumetric) in spawning gravels sampled on the north Olympic Peninsula. Salmonid egg-to-alevin survival decreases drastically when fine sediment (<0.85mm) exceeds 13% (volumetric). While no pre-disturbance fine sediment data are available for Ozette tributaries, in nearby undisturbed drainage basins with similar geology, fine sediment levels rarely exceed 10%. Future data collection of fine sediment levels in spawning gravel in Ozette tributaries is needed to track fine sediment impacts over time and document watershed efforts to reduce sedimentation and restore watershed processes sockeye depend on. In addition, other data on sockeye spawning habitat quality are lacking, such as hyporheic flow conditions within redds and the influence of increased fine sediment levels on egg-to-fry survival.

In Ozette tributaries, it is hypothesized that the combined influence of increased sedimentation of spawning reaches, reduced wood loads, increased common peak flood magnitude, and/or channelization and floodplain disconnection have synergistically destabilized relative bed stability and reduced sockeye egg-to-fry survival. However, since data are lacking in Ozette regarding: 1) scour depths at sockeye redds, 2) the effects of flood peak magnitude on scour depths, 3) the effects of fine sediment on scour, 4) the effect of sediment transport imbalances on scour, and 5) the effect of overall wood load and channel stability on scour, no quantitative conclusions can be made regarding the impact on sockeye egg-to-fry survival. The above-mentioned hypotheses and physical processes need to be tested in Ozette tributaries in order to understand the relative importance of each separate or cumulative effect on scour and sockeye egg-to-fry survival. Thus, scour and bed stability remains a critical data gap.

7.9.2 Spawning Habitat Quantity

In many Ozette tributaries, the quantity of suitable spawning habitat area has been reduced as a result of the effects of LWD removal, reduced LWD recruitment, increased fine sediment inputs and abundance, channelization and bank armoring, gravel mining, and colonization of bar deposits by non-native vegetation. In some reaches of Big River and Umbrella Creek, spawning gravel beds have been completely converted to sand bed or cobble bed, respectively. No attempts have been made to quantify loss of available spawning habitat over time, which remains a data gap.

7.9.3 Egg Predation

No attempt to measure sockeye egg predation in the tributaries has been conducted nor has it been suggested that significant levels of egg predation are occurring. Within other sockeye populations, predatory fishes and birds have been observed feeding on eggs, but most observers have concluded that the bulk of eggs eaten are dislodged by late-arriving spawners and would have had a low chance for survival. In a general review of sockeye salmon life histories, Burgner (1991) concludes that less is known about predation on eggs and alevins in the redds than at other life stages, but physical and chemical factors such as redd desiccation, freezing, lowered DO resulting from siltation, reduced flow, and dislodgment (scour or superimposition) are probably more important as mortality factors. However, egg predation remains a data gap in Ozette tributaries.

7.10 TRIBUTARY FRY EMERGENCE AND DISPERSAL

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for sockeye egg incubation on spawning beaches:

- Streamflow
- Predation
- Water Quality
- Fry Abundance

Key questions to be addressed through research and monitoring are included in Sections 7.10.1 through 7.10.4.

7.10.1 Streamflow

It is assumed that higher flows and increased stream velocities increase the rate of emigration into the lake, decreasing exposure to predation. It is hypothesized that predation rates are lower on emigrating juveniles during high streamflow. But these key questions and data gaps still need to be answered. How do high streamflows influence fry emigration survival? How does natural streamflow variability and/or changes in streamflow variability affect juvenile sockeye emigration survival?

7.10.2 Predation

Upon emergence from the spawning gravel, sockeye fry are vulnerable to predation in tributaries. No studies have been conducted to estimate emergent sockeye fry predation in the tributaries. Potential predators at this life history stage include sculpin (sp), cutthroat trout, juvenile steelhead trout, and juvenile coho salmon. Predator interactions at this early life history stage remain a data gap and it is possible that significant levels of predation occur in Umbrella Creek and Big River.

7.10.3 Water Quality

Collection of continuous turbidity and SSC measurements in all Ozette sockeye tributaries needs to continue over the long term, with the goals of understanding the magnitude and duration of impacts of high sediment loads on sockeye fry emigration from tributaries and detecting long-term (decadal) trends in turbidity and suspended sediment concentration.

7.10.4 Fry Abundance

Fry abundance data within Ozette tributaries is very sparse. No sockeye fry emergence data have been collected from sockeye redds to quantify the incubation success and population of initial fry recruits. In addition, fry survival and abundance data within the tributary environment are lacking. Enumerating fry with fyke nets occurred during one year, but results were marginal and impacts on fry survival were questionable. Future efforts need to focus not only on egg-to-fry survival and emergence success, but also on the survival and population abundance of fry between initial tributary emergence and lake rearing. However, enumeration techniques need to be developed that can both accurately estimate fry abundance and also ensure low levels of mortality from enumeration efforts. New technologies may be available to aid in this challenging enumeration issue.

7.11 JUVENILE FRESHWATER REARING

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for juvenile sockeye freshwater rearing in Lake Ozette:

- Fry-to-Smolt Survival Rates and Predation
- Zooplankton Abundance and Lake Productivity

Key questions to be addressed through research and monitoring are included in Sections 7.11.1 and 7.11.2.

7.11.1 Fry-to-Smolt Survival Rates and Predation

Lake Ozette juvenile sockeye productivity and survival are currently not limited by food availability or competition. Consumption demand by kokanee and juvenile sockeye is satisfied by less than 1% of the instantaneous production of the preferred large Daphnia (*Daphnia sp*.) throughout the growing season. In addition, Ozette sockeye smolts are the third largest (by length and weight) yearling sockeye smolts documented in the recorded literature.

The exact degree that predation in Lake Ozette limits smolt production still remains partially unquantified. Juvenile sockeye and smolts are preyed upon by a host of predators in Lake Ozette, including northern pikeminnow, cutthroat trout, sculpin, other native and non-native fishes, and birds. In the limnetic (open water) zone of Lake Ozette, cutthroat trout have been documented to be the major predator of juvenile *O. nerka*, whereas northern pikeminnow have a reduced predation influence because of limited limnetic feeding. However, northern pikeminnow, sculpin, cutthroat trout, juvenile steelhead trout, juvenile coho salmon, yellow perch, and largemouth bass may be significant predators of juvenile sockeye along lake margins and near tributary confluences.

Monitoring is needed to better define the rates of sockeye survival from emergent fry-to-smolts within Lake Ozette. Key questions that need to be answered into the future include: What are the major and minor sources of mortality of juvenile sockeye fry in Lake Ozette? What species are the primary predators of juvenile sockeye along lake margins, in the limnetic zone, and in and near the Ozette River? With future population recovery, will sockeye fry be capable of swamping predation in the lake? Will increased numbers of sockeye fry increase fry-to-smolt survival rates by swamping predators?

7.11.2 Zooplankton Abundance and Lake Productivity

Lake productivity and zooplankton production have been the focus of much research attention in the past in Lake Ozette. While current lake productivity is high and current zooplankton biomass consumption is low, these conditions may not remain constant into the future as sockeye populations recover. Under increased pressure from recovering sockeye fry and smolt levels (or other species), the standing crop of zooplankton may begin to wane to a point that lake productivity and zooplankton abundance become significant limiting factors on the entire sockeye population. Therefore, as sockeye recovery progresses into the future, additional monitoring of lake productivity and zooplankton abundance is essential to understand how the lake ecosystem responds to and supports increasing sockeye (and salmonid) abundance.

7.12 SEAWARD MIGRATION

The following bulleted list is a non-prioritized inventory of recommended research and monitoring parameters/activities for juvenile sockeye smolts during seaward migration:

- Streamflow
- Habitat
- Predation
- Water Quality
- Estuary Alterations

Key questions to be addressed through research and monitoring are included in Sections 7.12.1 through 7.12.5.

7.12.1 Streamflow

Ozette River discharge during juvenile emigration has been reduced on average. Additional detailed hydraulic and hydrological modeling is required to determine the exact magnitude that flows have been altered by various factors in combination (river hydraulics such as roughness and sedimentation, climate, hyporheic flow, lake evapotranspiration, and reductions in tributary baseflow inputs). The effect of changes to streamflow on emigrating sockeye remains unknown (see Hypothesis 48 in Section 6.2.12.4) and should be a focus of future research and monitoring.

7.12.2 Habitat

Do large logjams that form deep pools in the Ozette river provide important refuge habitat for juvenile sockeye salmon during emigration? Do deep pools provide thermal refuge habitat for juvenile sockeye? How do habitat complexity and/or simplification affect predation on juvenile sockeye?

7.12.3 Predation

Juvenile sockeye smolts are preyed upon by a host of predators in the Ozette River, including river otters, seals, northern pikeminnow, cutthroat trout, birds, and terrestrial mammals. Continued and expanded monitoring of in-river predation on juvenile sockeye is an important component for understanding the degree that predation affects the sockeye population at different abundance levels.

7.12.4 Water Quality

It is recommended that water quality data (temperature, turbidity, SSC) continue to be collected. Have stream temperatures increased during the last 50 years? How much? How do high stream temperatures limit Ozette sockeye juvenile emigration? Are variations in timing of juvenile emigrations a response to river flow and water temperature?

How much have turbidity and SSC increased in Ozette River and Coal Creek during the last 50 years? How do high turbidity and SSC values affect Ozette sockeye juvenile physiology, behavior, and habitat? How does sediment derived from Coal Creek affect rearing habitat further downstream in Ozette River (i.e., pool depth, refugia availability, and predator visual site distance)? How does sedimentation in Ozette River affect the unique biota of the river (e.g., net spinning caddis flies, freshwater sponge, endemic mussels, etc.) and thus the ecosystem that juvenile sockeye migrate through and feed in?

7.12.5 Estuary Alterations

Little is known about the behavior of juvenile Ozette sockeye emigration down the Ozette River. However, at least some populations of sockeye are known to rear in the estuarine environment for extended periods in systems with sizable estuaries. Many populations of sockeye use the nearshore for at least 2-6 weeks following emigration from their natal stream (Burgner 1991). The Ozette system does not include a sizeable estuary, but the nearshore region surrounding the mouth of the Ozette River is an extensive, complex, and productive shallow sub-tidal environment.

To what extent do Ozette juvenile sockeye use the Ozette River estuary for rearing during emigration? Are there unique tidal prism influences that enhance or are detrimental to juvenile sockeye? Quantify the changes in estuary volumes and habitat availability over time in response to altered spit morphology at the ocean mouth. Analyze sequential historical photos, in conjunction with field surveys. How has nutrient and salinity exchange changed in the estuary and how has this affected sockeye rearing and emigration habitat?

7.13 MARINE OCEAN PHASE

Limited marine survival data indicate that *total* marine survival rates are good, averaging 15 to 27%. Marine survival for large sockeye smolts (>115mm) in the southern range (latitude <55°N) averages 17.1%. However, additional data are needed to better define the inter-annual variability in marine survival, as well as to document population trends and mortality factors through time.

It is unknown to what degree Ozette sockeye use the nearshore environment prior to their migration to northern inshore or offshore marine rearing environments. Marine geographic and habitat usage for Ozette sockeye during the entire marine life history phase remains a major data gap.