

Karluk Lake Nutrient Enrichment Project Proposal

Kodiak Regional Aquaculture Association

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Introduction/Background

Karluk Lake is located on southwestern Kodiak Island (Figure 1), surrounded by lands of the Kodiak National Wildlife Refuge and Koniag, Inc. With a surface area of 38.6 km², it is the largest lake on the Kodiak Archipelago, and along with the Karluk River and associated system tributaries drains a watershed of approximately 275 km² (Uchimaya et al. 2008). It is classified as oligotrophic (Hartman and Burgner 1972; Koenings and Burkett 1987a; Schmidt 2008), and nutrient availability limits system primary production (phytoplankton), and by extension secondary production (zooplankton) and tertiary production (fish; Stockner and MacIsaac 1986); however, historical sockeye salmon return data and paleolimnological investigation suggest that there have been periods during which Karluk nutrient concentrations have been much higher than current levels (Finney 1998; Unpublished report by Dana Schmidt, Ph.D. R.P. Bio., Associate – Senior Fisheries Biologist/Limnologist, Golder Associates. *Kodiak Lake Fertilization Data Review Outline*, 2011, KRAA, Kodiak. Hereafter referred to as Schmidt *Unpublished*).

The Karluk system has a history of very robust productivity, and the most studied index of that productivity is sockeye salmon production. At the height of documented sockeye salmon returns in the late 1800s and early 1900s, Karluk probably had the highest productivity per unit area of any sockeye salmon lake in North America (Foerster 1968). Following the commencement of commercial harvests in the late 1800s, average annual Karluk sockeye salmon returns declined steadily in magnitude, from over 3,000,000 at the turn of the century to under 500,000 in the 1970s (Figure 2). Average annual Karluk sockeye salmon returns improved to approximately 900,000 fish in the 1980s and 1,340,000 in the 1990s, concurrent with and following implementation by the Alaska Department of Fish and Game (ADF&G) of a sockeye salmon eyed egg and fry planting project in Upper Thumb River from 1978 to 1987 (Figure 1) and a nutrient enrichment project in Karluk Lake from 1986 through 1990. The average annual Karluk sockeye return from 2001 through 2007 was 1,511,000, but returns fell abruptly to an average of 414,000 in 2008 through 2010.

A primary cause of the recent decline in Karluk sockeye salmon returns is generally agreed to have been overescapement of the system, although unfavorable climatological conditions also may have contributed to the reduced system productivity (Unpublished memorandum, M. Witteveen, M.B. Foster, and H. Finkle, ADF&G Fisheries Biologists, *Reduced sockeye salmon runs at Karluk Lake*, 2009, Kodiak. Hereafter referred to as ADF&G 2009 *Unpublished*; And, unpublished memorandum, M.B. Foster, M. Witteveen, and H. Finkle, ADF&G Fisheries Biologists, *Reduced sockeye salmon runs at Karluk Lake (II)*, 2010, Kodiak. Hereafter referred to as ADF&G 2010 *Unpublished*.) Total Karluk Lake early-run and late-run sockeye salmon escapement exceeded the upper boundary of the ADF&G biological escapement goal range in 1999, 2001, 2002, and, most notably, in 2003. Negative trends in system productivity at each trophic level (primary, secondary, tertiary) closely track the development of the brood year 2003 sockeye salmon:

1. Karluk Lake zooplankton biomass fell precipitously between 2003 and 2005, from 1671 mg/m² to 269 mg/m², respectively (Schmidt *Unpublished*), concurrent with the entry and residence of the brood year 2003 sockeye salmon fry into the freshwater rearing environment. Zooplankton are a primary food source of juvenile sockeye salmon, and the negative impact of intense top-down pressure (predation) on the zooplankton community is well documented (e.g., Koenings and Kyle 1997). Overgrazing of the standing zooplankton crop would have caused it to decline. Adult sockeye salmon escapements were also strong in 2004 and 2005, and resulting juveniles from those brood years likely sustained top-down pressure on the already diminished zooplankton community.

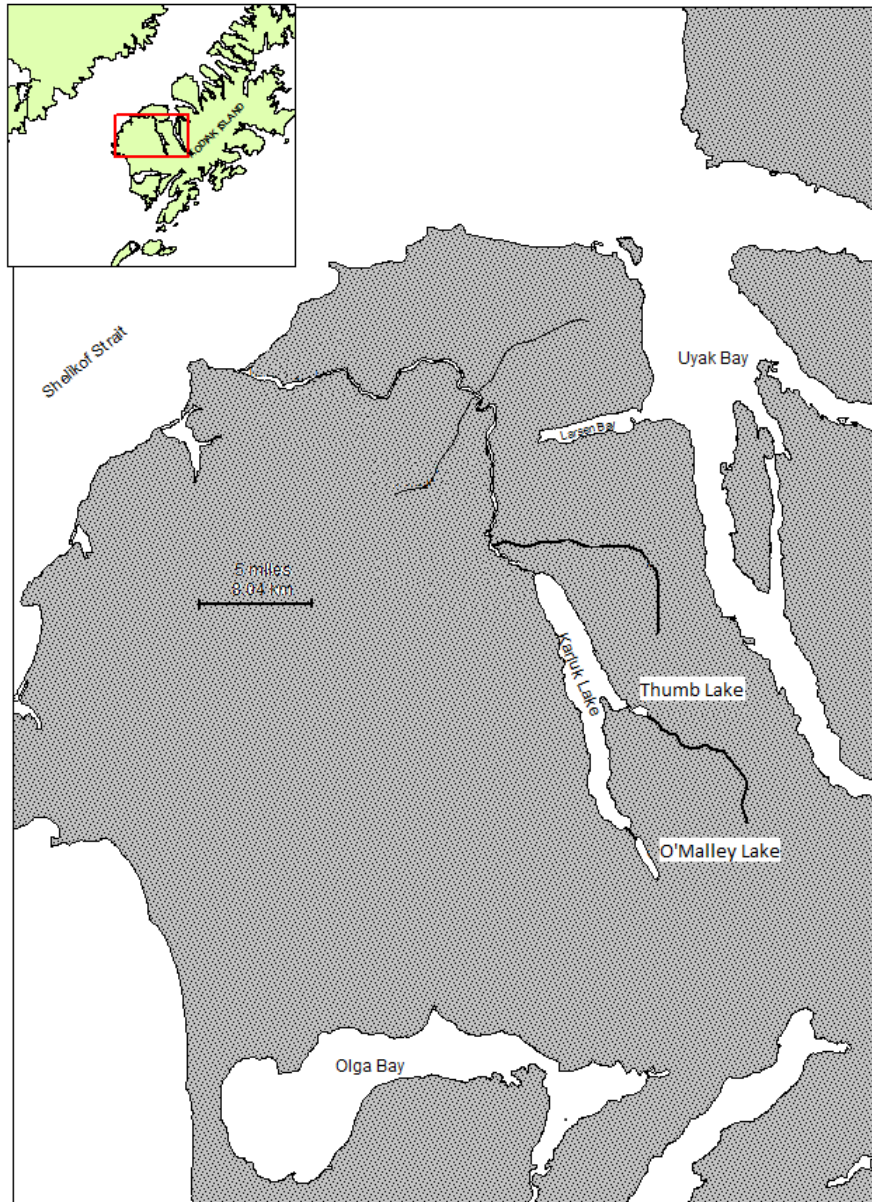


Figure 1. Karluk Lake and vicinity. (Source: ADF&G.)

2. A strong negative trend in Karluk Lake juvenile sockeye salmon biomass became apparent in 2005 and 2006. The number of outmigrating sockeye smolt in those years was low relative to previous years and to the magnitude of their parental escapements (Foster 2011). An unusually high proportion of outmigrants were three year old smolt (Foster 2011); this is indicative of insufficient forage, as undersized juvenile sockeye will remain in fresh water for an additional year prior to smolting (Koenings and Burkett 1987b). Most troubling, however, was the remarkably small size of the smolt. In 2006, the weights of both two year and three year smolt (6.3g and 7.9g, respectively; Foster 2011) was approximately half of the historic average for their age class, and registered the smallest size on record since data began to be collected in the 1920s (ADF&G 2010 *Unpublished*). The data indicates that the severely reduced zooplankton forage base had a substantial negative impact on juvenile sockeye salmon productivity.

3. Adult sockeye salmon returns to Karluk Lake in 2008 fell precipitously from the levels of previous years and remained depressed in 2009 and 2010. A strong positive relationship between sockeye salmon smolt size and marine survival is well established (e.g., Ricker 1962; Kyle et al. 1997), and the poor adult return of 2008 is consistent with the low smolt count and poor smolt condition recorded in 2006. Although there has not been a Karluk sockeye smolt enumeration project since 2006, adult return figures for four and five year old fish from brood years 2004 and 2005 do not suggest a trend of increasing productivity in either summary return figures or in return-per-spawner ratios (Foster 2011).
4. Subsequent to the poor 2008 Karluk sockeye salmon return, the 2009 concentration of the essential nutrient phosphorus in Karluk Lake was found to be low relative to both recent and long-term historic levels, and in 2010 declined further. Decomposing adult sockeye salmon carcasses are a major contributor of phosphorus and other nutrients to freshwater systems (Barnaby 1944; Koenings and Burkett 1987a; Schmidt et al. 1998; see also T.P. Quinn. 2005. *The Behavior and Ecology of Pacific Salmon and Trout*. University of Washington Press. Chapter 7: The Ecology of Dead Salmon); nutrient concentrations will be diminished in years following poor sockeye salmon escapement. The 2010 Karluk Lake areal phosphorus load of 80kg/km² amounts to a drop of over 30% from the average of available data for the twenty year period 1989-2008 (Schmidt *Unpublished*), and represents a P concentration more than 45% below calculated permissible levels for a productive oligotrophic system (10 µg/l; Vollenweider 1976).
5. Karluk Lake concentrations of the algal pigment chlorophyll *a*, which is monitored to estimate phytoplankton abundance, were also recorded at depressed levels in 2009 and 2010. This is not unexpected, as low nutrient levels are a limiting factor in lake primary productivity, and there is a strong correlation between the described Karluk Lake phosphorus levels and the system phytoplankton productivity. The 2010 mean chlorophyll *a* concentration represents a drop of over 55% from the average of available data for the twenty year period 1989-2008 (Schmidt *Unpublished*).

The recent process of decline in Karluk productivity has at this point involved two generations of sockeye salmon. Three consecutive years of depressed escapement have reduced introduction of marine-derived nutrients from sockeye salmon carcasses, and the base of the food web (phytoplankton) remains depleted. It has been noted that zooplankton abundance increased dramatically in 2009 (ADF&G 2010 *Unpublished*) and 2010 (H. Finkle, Commercial Fisheries Biologist, ADF&G, Kodiak, personal communication). However, in light of the diminished bottom-up productivity (phytoplankton), recent zooplankton abundance may be attributed to the lack of top-down pressure (predation) by juvenile sockeye salmon. Zooplankton abundance is not an indicator of full system recovery involving all trophic levels.

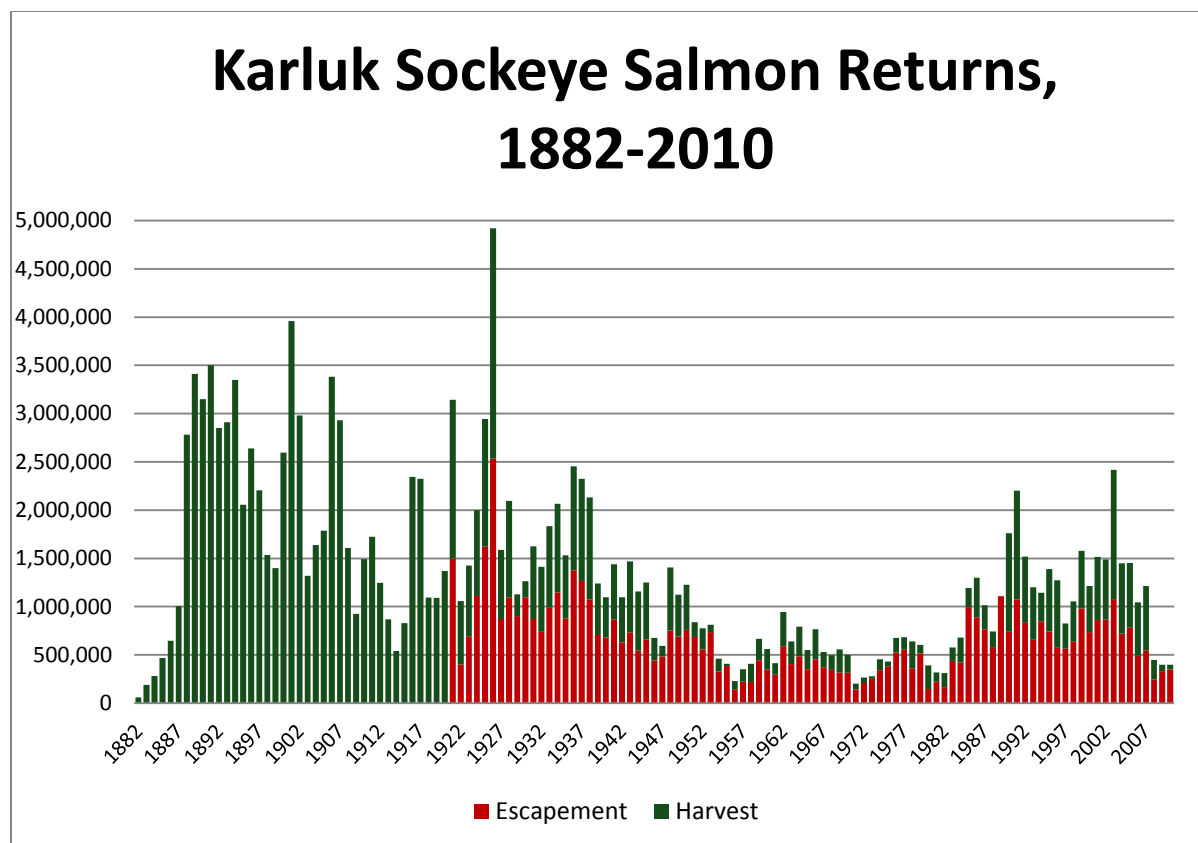


Figure 2. Karluk Sockeye salmon annual returns, 1882-2010. Note that there is no escapement data prior to 1921. (Sources: for 1882-1936, Barnaby 1944; for 1937-1959, USFWS weir reports & agents' reports, ADF&G, Kodiak; for 1960-1980, ADF&G, Comm. Fish. Div. Area Annual Reports, Kodiak; for 1981-2009, Foster 2011; for 2010, ADF&G, 2011 Westward Region Salmon Forecast)

Objective

The objective of the proposed Karluk Lake nutrient enrichment project is to restore the productive potential of the Karluk system to the sustainable levels documented prior to the recent decline by implementing a temporary program of lake nutrient enrichment. The immediate objective of the project is to maintain, for a period of not less than five years, sufficient essential nutrient loads within the lake to provide a base for restored and stabilized system primary production (phytoplankton), secondary production (zooplankton), and tertiary production (fish). The long-term objective of the project is to restore Karluk sockeye salmon returns to a level that will, first, deliver to the system through escapement adequate marine-derived nutrients to support sustained aquatic and associated terrestrial productivity, and second, support robust harvest and utilization by all user groups.

Discussion

Karluk Lake has been the focus of decades of limnological investigation. Study of the system during periods of both high and low sockeye salmon production provides insight into its productivity potential and trophic processes, and informs the evaluation of its current depressed state. During the mid-20th century decline of Karluk sockeye salmon returns, attempts to restore Karluk productivity by manipulating salmon escapement proved unsuccessful and attention became increasingly focused on juvenile sockeye production in the freshwater environment (Koenings and Burkett 1987a).

Since at least the 1920s, the role of nutrients in maintaining lake productivity has been a subject of analysis (Juday et. al. 1932), and investigations have established a clear correlation between the availability of essential nutrients and juvenile sockeye salmon production (Nelson 1959; Koenings and Burkett 1987b; Stockner and MacIsaac 1996; Mazumder and Edmundson 2002). Experiments were conducted using lake nutrient enrichment to rehabilitate and enhance sockeye salmon runs, and the positive effect of these programs on juvenile sockeye salmon growth and recruitment, and on subsequent marine survival and adult returns, has been documented since the 1950s (Nelson 1959; Stockner and MacIsaac 1996; Kyle et al. 1997). Lake nutrient enrichment projects have been employed in many Alaskan lakes in ensuing decades (Kyle et al. 1997; Schrof and Honnold 2003; Hyatt et al. 2004), including Karluk Lake from 1986 through 1990.

In light of its recent depressed productivity, Karluk Lake has again been examined to evaluate its suitability for a program of nutrient enrichment, and its environmental, morphometric and limnological characteristics identify it as a strong candidate to respond favorably to such a program. The lake's water residence time of 4.4 years (Edmundson et al. 1999) indicates that the rate of water outflow will not flush nutrients from the system before they can contribute to productivity, nor act as an impediment to seasonal nutrient carry-over. The Karluk Lake euphotic zone is not limited by low light penetration, turbidity, or lake depth, and its mean depth (21.5m; Schmidt *Unpublished*) provides a large volume in which photosynthesis may occur. Also, the Karluk Lake epilimnion is shallow enough that mixing within this stratum can effectively circulate nutrients within the euphotic zone, allowing for an extended period of uptake by phytoplankton. These characteristics describe a system in which nutrients are efficiently utilized in primary productivity.

The Karluk system's situation within and adjacent to the Kodiak National Wildlife Refuge limits human development within its watershed, ensuring environmental stability, and it can be reasonably anticipated that in the absence of a catastrophic natural event (landslide, volcanic eruption/ashfall, large-scale wildfire) the annual contribution of nutrients to the system from sources within the watershed will remain relatively consistent. Thus, the wide range in annual variability of nutrient levels within Karluk Lake is inextricably linked to the variability of one key source, adult salmon carcasses.

Karluk sockeye salmon escapements since 2008 have not been of sufficient magnitude for introduced marine-derived nutrients to restore phosphorus concentrations to historic levels. At the same time, current nutrient concentrations are not sufficient to initiate restored system productivity at the base of the food chain. These conditions fit the model identified by Koenings and Burkett (1987a), in which a system is fixed at a chronic low level of productivity. In this model, once low productivity has become established, increased adult sockeye escapement will not restore productivity to previous levels; spawner/recruit ratios for increased escapement are poor, because the positive impact of carcass-supplied marine-derived nutrients on primary and secondary productivity is not synchronized to the development of sockeye salmon fry, and fry survival is diminished because forage demand is not met. This model explains why Karluk productivity failed to recover for decades in the mid-20th century, and ultimately recommended the program of lake nutrient enrichment that was implemented in 1986-1990 to increase phytoplankton and zooplankton productivity and improve forage availability during key periods of juvenile sockeye demand. Karluk productivity and sockeye salmon adult returns increased substantially during and following the five year nutrient enrichment program, and remained at robust levels until negatively impacted by the results of the 2003 escapement (Figure 2).

The Kodiak Regional Aquaculture Association believes that implementation of a nutrient enrichment program to restore Karluk productivity is recommended by decades of scientific investigation, current and projected depressed system productivity, the potential for system productivity to become stabilized at a low level, the characteristics that identify Karluk Lake as a strong candidate to respond favorably to

nutrient enrichment, and the positive trends in productivity exhibited following the 1986-1990 program of nutrient enrichment.

Approach and Methods: Pre-enrichment Study

Karluk Lake is the most studied sockeye salmon system in the world, and is described by a relatively robust data set. The recommendation to implement a program of nutrient enrichment was preceded by a thorough analysis of data collected by ADF&G since 1980. Karluk Lake physical, chemical, and biological parameters were studied, and consideration of the ecological, cultural, and economic values of the Karluk system and its productivity informed the process. A preliminary plan for the project has been developed, and baseline datasets are nearly complete. Project plan development, pre-enrichment study, and data collection will continue in 2011.

Recent and current sampling of Karluk Lake water chemistry, limnological parameters, primary production, and secondary production is conducted by ADF&G through two projects funded by the Alaska Sustainable Salmon Fund (AKSSF; project titles: Westward Region Limnology and Karluk Lake Limnology). These grants have continued or re-established monthly data collection at two limno sampling stations in Karluk Lake from May to September. Sample collection and analysis follow ADF&G Near Island Laboratory protocols and procedures. In 2010, KRAA requested and funded ADF&G sampling of phytoplankton in order to establish relative species composition. For 2011, KRAA proposes to add a limno sampling station in Karluk Lake's third major basin, and to add October sampling to the existing program.

The key index used to assess Karluk Lake tertiary productivity has been juvenile sockeye salmon biomass, estimated through hydroacoustic survey or smolt enumeration projects, but these data have been inconsistently collected. The condition of emigrating spring sockeye salmon smolt can also allow some insight into the system trophic status, and this data has been collected more regularly. Most recently, following three years without any smolt project, grab samples of 200 outmigrating sockeye salmon were collected on three dates in 2010, and age, weight, length (AWL) and smolt condition data were recorded. In 2011, the program will be expanded through AKSSF funding (project title: Karluk Lake Smolt), establishing a camp to collect grab samples of emigrating smolt over a three week period in late May-early June; the grant funds this project annually through 2013. The Alaska State Legislature has included in the fiscal year 2012 operating budget an increment to allow ADF&G to re-establish a spring smolt enumeration project on Karluk River; however, the operating budget has not yet (as of May 21, 2011) been signed by the governor.

To further assess tertiary productivity in Karluk Lake, KRAA proposes to implement a hydroacoustic survey of the lake and accompanying species apportionment sampling in September/October 2011. KRAA will work closely with private consultants and ADF&G to develop plans for the project.

Approach and Methods: Active Enrichment Phase - Nutrient application

It is proposed that Karluk Lake be treated with an aqueous nutrient solution to be applied to the surface of the lake on a weekly basis over a fourteen week period to begin in mid-May and end in mid-August. The nutrient solution would be stored at Larsen Bay and delivered to the lake surface by a fixed wing aircraft. Because biological uptake of marine-derived nutrients from sockeye salmon carcasses occurs mostly in the lake's limnetic zone (Kline et al. 1993), and that zone is the primary habitat utilized by juvenile sockeye salmon (e.g., Stockner and MacIsaac 1996), the physical nutrient application pattern will focus on the limnetic zone within a prescribed area that includes the lake's Main, Thumb, and O'Malley Basins (Figure 3).

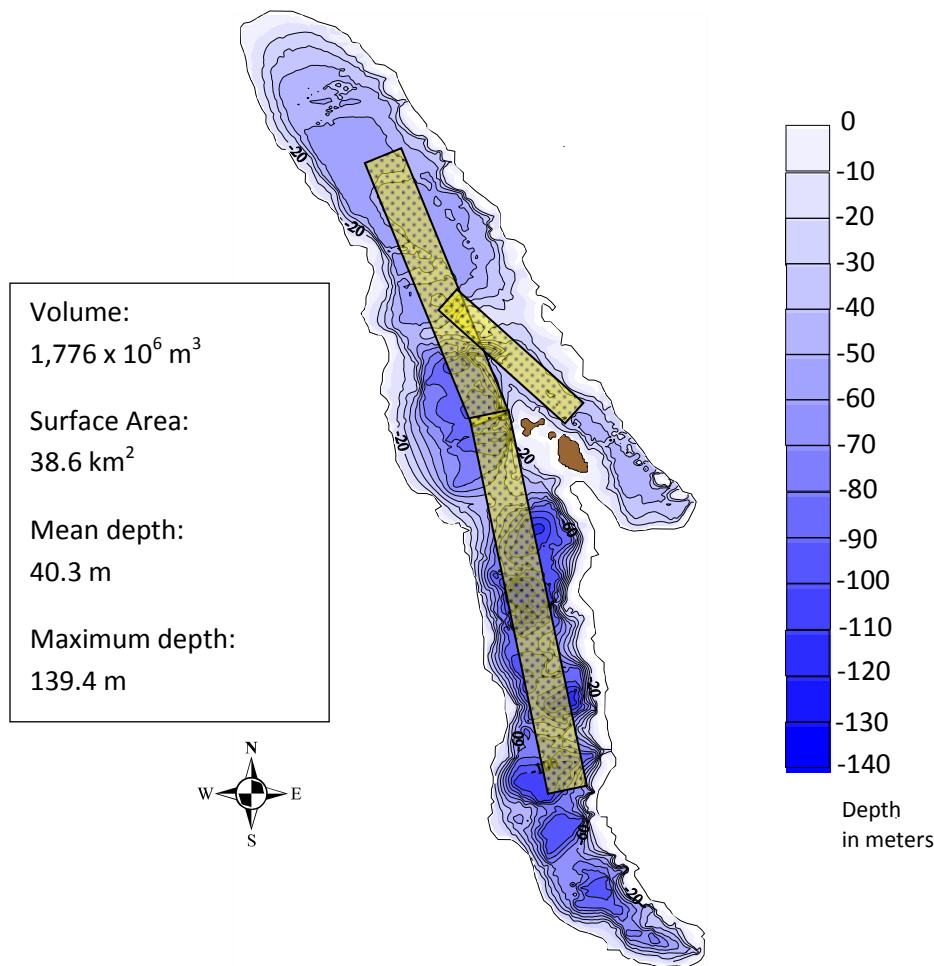


Figure 3. Karluk Lake Bathymetry (Source: Unpublished map, H. Finkle, ADF&G Biologist, 2010, Kodiak). Yellow approximates proposed nutrient application area.

The nutrients proposed to be introduced to Karluk Lake are phosphorus (P), in the form of phosphate, and nitrogen (N), in the form of ammonium nitrate and urea. The fourteen week nutrient application program is adapted from Ashley & Stockner (2003), with goals of maintaining an annual mean P-load of 90% of permissible levels (Vollenweider 1976) and a seasonal N:P ratio of 15:1 (Ashley & Stockner 2003). This approach establishes a P-load goal which falls within naturally occurring parameters documented in Karluk Lake, and ensures that the lake phosphorus level remains within the permissible loading range for an oligotrophic lake.

The proposed Karluk Lake nutrient enrichment model relies on a front end loading concept, which is intended to simulate spring freshet conditions for phosphorus loading and substantially increase spring production on the tail of the freshet P input. This loading pattern results in a late spring peak in P input, declining to a constant summer loading and eventually to a reduced late summer loading. Increasing loads of nitrogen as the season progresses will compensate for the rapid spring biological uptake and gradual depletion of epilimnetic dissolved nitrogen (Ashley and Stockner 2003). The model is designed

to prevent dissolved nitrogen limitation and decrease the likelihood of colonial cyanobacteria (blue-green algae) blooms that are often associated with N depletion or low N:P ratios (Smith 1983; Pick and Lean 1987).

In order to achieve and maintain the lake nutrient profiles targeted in the program model, two different aqueous fertilizer formulations will be employed, with compositions of 10-34-0 and 28-0-0. The amount and ratio of the two formulations to be applied each week will be adjusted as necessary to adhere to the model, based on information collected by the concurrent in-season monitoring program. If inclement weather, the timing of spring breakup, or other logistical challenges preclude timely collection and analysis of early season 2012 limnological data, 2011 data will be used to establish initial 2012 nutrient application levels.

Using 2011 as a model, based upon 2010 nutrient levels, it is anticipated that 14,870.6 kg of 10-34-0 and 48,114 kg of 28-0-0 aqueous fertilizers would be applied to Karluk Lake over the course of a fourteen week enrichment period in 2011, delivering a total of 2,206 kg phosphorus and 14,967.4 kg nitrogen to the system. However, as detailed above, adaptive management will be practiced, and actual nutrient application amounts would be adjusted in season to account for existing nutrient concentrations and system response to the enrichment program. Table 1 provides a theoretical application schedule for nitrogen and phosphorus if a program were to be implemented in 2011.

Loading of Nutrients to Karluk Lake 2011

Week	Dates	% Total N	% Total P	N:P (wt:wt)	N:P (molar)
1	5/15-5/21	0.5%	5.0%	1:1.5	1.5:1
2	5/22-5/28	1.5%	6.0%	1.7:1	3.75:1
3	5/29-6/4	2.5%	7.0%	2.4:1	5.36:1
4	6/5-6/11	8.0%	10.0%	5.4:1	12:1
5	6/12-6/18	13.0%	15.0%	5.9:1	13:1
6	6/19-6/25	13.0%	15.0%	5.9:1	13:1
7	6/26-7/2	13.0%	10.0%	8.8:1	19.5:1
8	7/3-7/9	9.0%	7.0%	8.7:1	19.3:1
9	7/10-7/16	9.0%	6.0%	10.2:1	22.5:1
10	7/17-7/23	9.0%	6.0%	10.2:1	22.5:1
11	7/24-7/30	8.0%	5.0%	10.9:1	24:1
12	7/31-8/6	5.5%	3.5%	10.7:1	23.6:1
13	8/7-8/13	4.0%	2.5%	10.9:1	24:1
14	8/14-8/20	4.0%	2.0%	13.6:1	30.1:1

Table 1. Theoretical nutrient application schedule for a 2011 Karluk nutrient enrichment program.

Approach and Methods: Active Enrichment Phase - System monitoring

Monitoring of water chemistry, limnological parameters, and system productivity (primary, secondary, and tertiary) described in the Pre-enrichment Study section of this document will continue through the active enrichment phase of the proposed project. During the active enrichment period, in-season sampling of N and P levels, and calculated N:P ratio, will inform determination of appropriate weekly nutrient application rates. Speciation of phytoplankton samples will reveal primary production trends within the system, including development of potentially undesirable algae species, and appropriate adjustments to nutrient application amounts and ratios will be made as necessary to counter undesired production trends. Efficient and expedient processing of limnology samples will be critical to achieving timely adjustment of nutrient applications; KRAA will work closely with ADF&G, and potentially contract with outside

laboratories, to achieve this program goal. Monitoring in the later years of the active enrichment phase will inform assessment of the system response, and determine if the program of active enrichment should be extended beyond the initial five year period.

Approach and Methods: Post-enrichment Assessment

Monitoring of water chemistry, limnological parameters, and system productivity (primary, secondary, and tertiary) described in the Pre-enrichment Study section of this document will continue for a minimum of two years following the cessation of active enrichment to inform continued assessment of the system response and determine the potential need for additional action.

Management

The potential for a lake nutrient enrichment project to increase the Karluk system productivity carries management concerns that should be recognized and addressed. These include the potential need to adjust escapement goals to correlate with increased system productivity and the harvest management of potentially increased sockeye salmon returns.

In order for Karluk Lake to achieve restored, sustained productivity, the nutrient enrichment program must be accompanied by escapement levels appropriate to the system's concurrent trophic status. If nutrient and productivity levels increase as anticipated, it may be necessary to adjust escapement goals to provide proper loading of nutrients and fry. The mechanism by which to adjust sockeye salmon escapement goals in order to better align them with improved system productivity is already in place. Regional escapement goals are reviewed every three years at meetings of the Alaska Board of Fisheries. Karluk escapement goals will be reviewed in 2013 and 2016, allowing the opportunity to set appropriate goals in the event that system productivity responds as anticipated.

Difficulties in harvest management of large magnitude Karluk sockeye salmon returns have been documented, particularly for the early-run stock. Unusually large returns and historically unprecedented early run timing of this stock led to very large escapements in the late 1990s and early 2000s. Other Kodiak Archipelago sockeye salmon systems also recorded very strong returns during this period, indicating generally very favorable climatological and marine conditions. The ADF&G Westside Kodiak Management Plan, put into regulation in 1993, was based upon the harvest strategy that had been in place since the 1970s, a period of generally poor Karluk sockeye salmon returns, and from our current perspective may be seen as inadequate to the task of managing the returns of 1999-2004.

The tools available to harvest managers to prevent overescapement of early-run sockeye into the Karluk system have improved since 2005. Most substantially, the Westside Kodiak Management Plan has been altered to allow opening of the commercial fishery as early as June 1, eight days earlier than was previously allowed. In the event that an exceptionally large and early Karluk sockeye salmon return materializes in the future, opening the fishery earlier could control escapement. Additionally, ADF&G Westward Region Finfish Research instituted a test fishery at Cape Uyak in 2010 targeting Karluk-bound early-run sockeye salmon. This test fishery will provide valuable early information regarding run strength to the Area Management Biologist, informing early-run sockeye salmon harvest management decisions.

It should also be noted that salmon prices have increased substantially since the early 2000s, and participation in the commercial fishery has followed suit. Very low fish prices and reduced participation in the commercial fishery were a contributing factor to the high escapements of the past decade. It is highly unlikely under current market conditions that there would be a lack of willing participants in the Kodiak Westside salmon commercial fishery.

ADF&G management biologists, however, believe that additional management tools may be required to prevent overescapement in the event that conditions similar to those of 1999-2003 again materialize. Deployment of a dual-frequency identification sonar (DIDSON) at the mouth of Karluk Lagoon could provide escapement enumeration much earlier than the current weir operation, allowing earlier, more aggressive management to prevent overescapement. Additional changes to regulatory management plans for westside fisheries could be considered and implemented by the Alaska Board of Fisheries.

It should be recognized that lake nutrient enrichment is not a fast track to system overescapement. However, anticipated increases in sockeye salmon returns associated with restored Karluk Lake productivity could increase the risk of overescapement. To minimize this risk, KRAA supports implementation of additional regulatory and monitoring tools to strengthen ADF&G's ability to manage the Karluk sockeye salmon harvest. It is likely that the full benefit of lake nutrient enrichment will not be realized for five to ten years, and in the interim KRAA will act in concert with ADF&G to identify and obtain additional tools to manage the Karluk sockeye salmon fishery.

Timeline

In recognition of the negative ecological, cultural, and economic impacts of currently depressed Karluk Lake productivity, KRAA is committed to expeditious implementation of the proposed restoration program. To that end, increased system monitoring in 2011 will complete pre-enrichment study and establish a thorough baseline dataset. It is proposed that active nutrient enrichment and associated monitoring of Karluk Lake begin in May 2012 and continue annually for a period of not less than five years. Assessment of system response to the program would determine if further or continuing action is necessary. Following the active enrichment period, monitoring as described in this document would continue for a minimum of two years.

Cost-benefit analysis

Estimated costs and economic benefits of the proposed project are detailed in Table 2. The economic benefit detailed in this table is the projected ex-vessel value of Karluk-bound sockeye salmon to be realized by the commercial fishing fleet; other economic values, such as first wholesale value, or tourism revenues supported by abundant fish and bear populations, are not estimated. In developing cost-benefit estimates, some broad assumptions were made because many of the variables used to calculate these figures are not fixed. Market variability in fuel prices, for example, impacts project costs; sockeye salmon smolt-to-adult survival and market variability of fish prices will largely determine economic benefits. It may be noted that the estimated value of future sockeye salmon returns is based on a conservative assumed value of \$4.00 per fish, which is approximately half the value per fish realized in 2010. Furthermore, calculations in this table assume that the Karluk Lake nutrient enrichment program will share some operational costs with other projects which may or may not be implemented; if the Karluk program is a stand-alone project, costs will be higher. Finally, it should be noted that the table details one-year estimates of both cost and benefit, but while there is a projected end to the nutrient enrichment program, there is not a projected end to restored, sustainable Karluk productivity.

Karluk Lake Nutrient Enrichment Estimated Costs and Benefits

Estimated costs ^a	Fertilizer/MT: \$800 10-34-0; \$500 28-0-0	\$36,000
	Aircraft Costs (14 trips year)-Hours	3
	Aircraft Cost estimates	\$170,000
	Analysis Cost	
	Limnology and Water Quality	\$50,000
	Smolt or Fall Fry Program	\$40,000
Returns	Adult Return Per km ² (1995-2007) ^b	34,987
	Current Escapement Goal ^c	445,000
	Average harvest (2008-2010)	106,394
Projected Benefits	Projected increased return per km ² ^d	40,819
	Projected Increased Harvest ^e	1,056,885
	Discounted Value of increased Harvest ^f	\$4,227,540
	Total Costs	\$296,000
	Total Net Benefits	\$3,931,540
	Cost Benefit Ratio	14.3

Table 2. Estimated costs and economic benefits of the proposed project.

^a Cost estimates are based on January 2011 projections for fertilizer, flight time, and project costs (extant or potential).

^b Estimated total adult sockeye return per unit area calculated by dividing the average return during the time series of non-fertilized years by the surface area of the lake. Adult return data from ADF&G.

^c Escapement goal is a "point" escapement goal (between upper and lower bounds) given in Honnold et al. 2007. No optimal or mid-point was given in this document.

^d Calculation of the projected increased return per unit area assumes a linear response between increased P annual areal load and increased sockeye returns.

^e Projected increased harvest attributable to the nutrient enrichment program is calculated by deducting the current escapement goal and average 2008-2010 harvest figures from the projected increased

^f The discounted value of the total harvest is the total increased harvest x the discounted future value per fish at the time of harvest, currently set at \$4.00/fish.

Outreach and Support

The Kodiak Regional Aquaculture Association has been, and remains, dedicated to informing the public and involving any interested parties in the development of a project proposal and plan to restore Karluk Lake productivity. We invite the participation of all parties interested in this vital resource, whether individuals, governmental agencies, or non-governmental organizations. KRAA has made public presentations regarding the proposed project to the Kodiak Island Borough Assembly and at an open forum during the 2011 Kodiak fishing industry trade show, Com Fish, and has contributed information and interviews to multiple newspaper and radio news articles describing the project. Public input will also be sought in a scoping meeting which will contribute to project development through the NEPA process.

The Kodiak Island Borough Assembly has endorsed the proposed project in the form of a resolution supported unanimously on March 3, 2011. This resolution acknowledges the impact of reduced Karluk lake productivity and the Assembly resolved to support the project through: educating the community on the need for, benefits, and safety of lake nutrient enrichment; facilitating expedited permitting processes; allocation of Borough funds for the project; and pursuing State funding. The Alaska State Legislature has

included funding for the proposed project in the fiscal year 2012 capital budget; however, the capital budget as of this date (May 21, 2011) has not been transmitted to the Governor for his signature.

The Kodiak Regional Planning Team (KRPT) has identified Karluk Lake Evaluation and Sockeye Rehabilitation as a high priority and cites lake nutrient enrichment as a suggested restoration method in the draft Kodiak Comprehensive Salmon Plan, Phase III. The Northwest Setnetter's Association also supports the project.

KRAA staff will rely on the expertise of their peers in the Alaska Department of Fish and Game in the fields of lake limnology, hydroacoustic survey and species apportionment sampling, and standard monitoring protocols. KRAA staff will work closely with Kodiak National Wildlife Refuge staff in matters pertaining to the National Environmental Policy Act process and compatibility with Refuge purposes.

KRAA has committed to funding the project through the project timeline period identified in this document.

Literature Cited

- Ashley, K.I. and J.G. Stockner. 2003. Protocol for applying limiting nutrients to inland waters. In: Nutrients in salmonid ecosystems: Sustaining production and biodiversity, pp. 254-258 .
- Barnaby, J.R. 1944. Fluctuations in abundance of red salmon, *Oncorhynchus nerka* (Walbaum), of the Karluk River, Alaska. U.S. Fish and Wildlife Serv. Fish Bull. 39, 50: 237-295.
- Edmundson, J.A., D. Schmidt, S.R. Carlson, and G Kyle. 1999. Alaska lake fertilization program: restoration and enhancement of sockeye salmon. In: Restoration of Fisheries by Enrichment of Aquatic Ecosystems, Proceedings of International Workshop at Uppsala University March 30-April, 1998 (eds. J.G. Stockner and G. Milbrink), pp. 49-82.
- Foerster, R.E. 1968. The sockeye salmon (*Oncorhynchus nerka*). Fisheries Research Board of Canada, Ottawa, Canada. Bulletin 162. 422p.
- Foster, M. B. 2011. Kodiak management area salmon escapement and catch sampling results, 2010. ADF&G Fishery Management Report No. 11-30 Anchorage.
- Honnold Steven G., Mark J. Witteveen, Matt Birch Foster, Ivan Vining, and James J. Hasbrouck. 2007. Review of escapement goals for salmon stocks in the Kodiak Management Area. ADF&G Alaska Fishery manuscript No. 07-10.
- Hyatt, K.D., D.J. McQueen, K.S. Shortreed, and D.P. Rankin. 2004. Sockeye salmon (*Oncorhynchus nerka*) nursery lake fertilization: Review and summary of results. Environ. Rev. 12:133-162.
- Juday, C., Rich, W.H., Kemmerer, G.I., and Mann, A. 1932. Limnological studies of Karluk Lake, Alaska, 1926-1930. Bull. Bureau Fish. 47: 407-436.
- Kline, Thomas C. Jr., John J. Goering, Ole A. Mathisen, Patrick H. Poe, Patrick L. Parker, and Richard S. Scalan. 1993. Recycling of elements transported upstream by runs of pacific salmon: II. $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ evidence in the Kvichak River watershed, Bristol Bay, southwestern Alaska. Can. J. Fish. Aquat. Sci. 50:2350-2365.
- Koenings, J.P. and R.D. Burkett. 1987a. An aquatic rubik's cube: restoration of the Karluk lake sockeye salmon (*Oncorhynchus nerka*). Can. Spec. Publ. Fish. Aquat. Sci. 96:419-434.
- Koenings, J.P. and R.D. Burkett. 1987b. Population characteristics of sockeye salmon (*Oncorhynchus nerka*) smolts relative to temperature regimes, euphotic volume, fry density, and forage base within Alaskan lakes. In Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Edited by H.D. Smith, L. Margolis, and C.C. Wood. Can. Spec. Publ. Fish. Aquat. Sci. 96:216-234.
- Koenings, J.P. and G.B. Kyle. 1997. Consequences to juvenile sockeye salmon and the zooplankton community resulting from intense predation. Alaska Fishery Research Bulletin 4(2):120-135.
- Kyle, G.B., J.P. Koenings, and J.A. Edmundson. 1997. An overview of Alaska lake-rearing salmon enhancement strategy: Nutrient enrichment and juvenile stocking. In: Freshwaters of Alaska – ecological synthesis. Edited by A. Milner and M. Oswood. Springer-Verlag, New York, pp. 205-227.
- Mazumder, A., and J.A. Edmundson. 2002. Impact of fertilization and stocking on trophic interactions and growth of juvenile sockeye salmon (*Oncorhynchus nerka*). Can. J. Fish. Aquat. Sci. 59: 1361-1373.
- Nelson. P.R. 1959. Effects of fertilizing Bare Lake, Alaska, on growth and production of red salmon (*O. nerka*). U.S. Fish and Wildlife Serv. Fish. Bull. 59:59-86.
- Pick, Frances R. and D.R.S. Lean. 1987. The role of macronutrients (C,N,P) in controlling cyanobacterial dominance in temperate lakes. New Zealand Journal of Marine Freshwater Research.

- Ricker, W.E. 1962. Comparison of ocean growth and mortality of sockeye salmon during their last two years. *J. Fish. Res. Board Ca.* 19: 531-560.
- Schmidt, Dana C., Stan R. Carlson and Gary B. Kyle. 1998. Influence of carcass-derived nutrients on sockeye salmon productivity of Karluk Lake, Alaska: Importance in the assessment of an escapement goal. *North American Journal of Fisheries Management.* 18:743-763.
- Schrof, S.T. and S.G. Honnold. 2003. Salmon enhancement, rehabilitation, evaluation, and monitoring efforts conducted in the Kodiak management area through 2001. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 4K03-041, Kodiak.
- Smith, A.J. 1983. Modes of Cyanobacterial carbon metabolism. *Annales de l'Institut Pasteur, Microbiologie.* July-August, 1983 pages 93-113
- Stockner, J.G. and E.A. MacIsaac. 1996. British Columbia lake enrichment programme: Two decades of habitat enhancement for sockeye salmon. *Regulated Rivers: Research and Management* 12:547-561.
- Uchimaya, Tadayasu, Bruce P. Finney, and Milo D. Adkison. 2008. Effects of marine-derived nutrients on population dynamics of sockeye salmon (*Oncorhynchus nerka*). *Can. J. Fish. Aquat. Sci.* 65: 1635-1648.
- Vollenweider, R.A. 1976. Advances in defining critical loading levels for phosphorous in lake eutrophication. *Mem. Ist. Ital. Idrobiol.* 33:53-83.