Effects of Lake Fertilization on Kokanee in Kootenay Lake, B.C.

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Presentation Outline

• Effect of upstream impoundments and *Mysis* introduction on Kootenay Lake
• Lake fertilization experiment
• Response of kokanee and Gerrard RBT’s to enrichment
• Conclusions
Mysid-kokanee history in BC

• 1949 – first BC introduction to Kootenay Lake: an inappropriate model due to unique morphometry + nutrients

• 1968+1974 - Upper and Lower Arrow
• Mysids added to 16 more BC lakes by 1980 and throughout Western North America and Scandinavia
Patterns of major human disturbance: Kootenay Lake

• Dam construction and operation
  – Duncan Dam - 1967 (Columbia River Treaty on inflow Duncan River)
  – Libby Dam - 1973 (Columbia River Treaty on inflow Kootenai River)

• Cominco fertilizer plant operations
  – Kimberly production starts - 1953
  – production doubles to triples - 1962 to 1965
  – pollution control measures - 1969 to 1979
  – plant closure - 1987

• Biological manipulations
  – Mysid shrimp introduction - 1949 + 1950
Figure 1.—Kootenay Lake and its drainage basin. The lake's west arm is a discharge waterway arising at the junction of the north and south arms.
Figure 4.—Schematic diagram of the midday and midnight vertical distributions of *Mysis relicta* and the entrainment of mysids across the outlet to the west arm. Stippled areas indicate mysid distribution.
Effect of *Mysis* on productivity of CDN North Temperate Lakes and Reservoirs

Kootenay Lake experience provided distorted picture

Studies later indicated *M. relicta* major competitor with kokanee

Severe negative impacts on kokanee populations

Experiences in other lakes well documented
Kootenay Lake Food Web

- Trout (Yellowfin, Gerrard, bull trout)
- Kokanee
- Mysis relicta (cannibalism)
- Macrozooplankton
- Rotifers
- Phytoplankton

Total Phosphorus Concentration (in lake)
Total Phosphorus Load
Annual Phosphorus Load to Kootenay Lake

- **Duncan River input**
- **Kootenai River input**

![Bar chart showing annual phosphorus load to Kootenay Lake from 1960 to 1995.](chart.png)
Predicted Surface Total Phosphorus Concentrations (July)

Surface Total Phosphorus (mg/L)

Year

natural Kootenai hydrograph
natural Duncan hydrograph
Baseline Surface TP
Kotenay Lake North Arm Kokanee escapement

Year

Effect on oligotrophic food webs

• Mysid introduction generally leads to delayed collapse of pelagic planktivores (kokanee), particularly in oligotrophic lakes and reservoirs
• kokanee collapse was confounded/masked/delayed by multiple basin sale manipulations (nutrients, impoundment)
• planktivore collapse predicted to be followed by collapse of obligate piscivores (Gerrard RBTs)
• restoration of kokanee required innovative solutions
• hatchery solutions were not an option
Adaptive Management

• Active adaptive management

• Definition: policies that rely on deliberate probing for information (Walters, 1986)
Adaptive Management Recovery plans: Kootenay Lake

- large scale fertilization experiment
- used in-lake north-south nutrient gradient design

Fertilizer Loading schedule:
- Phase 1 (5 years): 1992-1996 – constant at 47.1 MT P
- Phase 2 (5 years): 1997-2001 – variable P loading:
  - 1997- 29.5 MT, 1998 – 22.9 MT, 1999 – 22 MT
  - 2000 – 29 MT, 2001 – 47.1 MT, 2002 – 47.1 MT
Kootenay kokanee abundance (Maximum Likelihood Estimates) from fall acoustic surveys, 1985-99.
Kootenay L. kokanee - abundance by age group (stacked)

- Age 0
- Age 1-3

Millions of kokanee

Fall survey year

85 86 88 89 90 91 92 93 94 95 96 97 98 99 00 01
Kootenay L kokanee - North vs South Arm

Millions of kokanee

Fall survey year

South Arm
North Arm
Mean length (cm) of Meadow Creek kokanee spawners and fecundity
y = 30.269x - 408.35
$R^2 = 0.8983$
Meadow Creek and Lardeau kokanee escapement and fecundity
Meadow Creek fry measured production estimates compared to total in-lake fry hydroacoustic estimates
Kokanee length-at-age over time (1985-2001). Data from trawl caught fish for ages 0+ to 2+ with lengths standardized to account for different capture dates between years. Age 3+ lengths are mean lengths of spawners from Meadow Creek.
Annual escapement of Gerrard rainbow trout measured by the highest single day count (Total count is x 2.3)
Comparison of number of kokanee all ages and numbers of large fish assumed to be predators from acoustic monitoring

Kootenay Lake kokanee and Gerrards

<table>
<thead>
<tr>
<th>Year</th>
<th>No of kokanee (all ages)</th>
<th>No of fish &gt;32 cm length (predators)</th>
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<td>92</td>
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</table>
Figure 11. Trends in prey to predator ratios in Kootenay Lake during the fertilization period based on acoustic monitoring. Note: 700 kokanee/rainbow is considered minimum levels to maintain prey populations in Idaho.
Hydroacoustic Surveys
Transects 1 - 20

Trawl Survey
Trawl Locations T(1 - 6)
T1 Shelter Bay
T2 Halfway River
T3 Nakusp
TE Below Narrows (extra)
T4 Edgewood
T5 Bowman Creek
T6 Cayuse Creek

Study area reach breaks

British Columbia
Upper and Lower Arrow Reservoir kokanee escapement

Year

Total escapement

0

200000

400000

600000

800000

1000000

Closing comments

• Lake enrichment has been successful to date in restoring kokanee in Kootenay Lake and Arrow Reservoir
• these ecosystems are large, but fragile - kokanee are the canary in the coal mine
• restoration can be expensive, and uncertain
• Active adaptive management approach is a key part of BC’s lake/reservoir kokanee recovery plans
• remember Aldo Leopold: “The first rule of intelligent tinkering is to keep all of the parts”.