

**EGG DEVELOPMENT AND FRY EMERGENCE OF OKANAGAN LAKE
SHORE SPAWNING KOKANEE FOR THE 2002 BROOD YEAR**

by

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Nelson, British Columbia
October 2003

SUMMARY

This study provides some additional insight into the biology and early life history of Okanagan Lake shore spawning kokanee. The relationship between receding lake levels and timing of shore spawning kokanee has been the subject of concern since lake level drawdown in the past has resulted in eggs being stranded and mortality occurring. In 2003, the lake level was drawn down in early October prior to the shore spawning event and then held relatively constant through the egg incubation period resulting in minimal impact. However, despite this optimum drawdown scenario examination of the drawdown zone revealed that some eggs had been stranded. These eggs had most likely been dislodged by wind and wave action from redds located in the water below the drawdown zone.

An initial attempt was made in 2002-2003 to place some egg incubation baskets in the known spawning area to determine egg development and timing of fry emergence. This experiment was only partially successful due to problems of vandalism, a major storm event, and incubation basket design. Despite these problems, it was determined that egg to free swimming fry development occurred between 800-900 accumulated heat units (ATUs) with fry emerging as early as the end of February. This emergence time was far earlier than previously understood. It is recommended that this experiment be repeated in 2003-2004 with improvements made to the design of the incubation baskets.

ACKNOWLEDGEMENTS

The following people are gratefully acknowledged for their contribution of information and administrative assistance during the study:

Okanagan Nation Fisheries Commission

Deana Machin
Howie Wright
Shayla Lawrence

Fisheries Technicians

Jason Webster – Chara Consulting Ltd.
David Cassidy - BCCF Contract Technician
Greg Andrusak - Redfish Consulting Ltd.

British Columbia Ministry of Water Land and Air Protection

Steve Matthews, Penticton
Brian Jantz, Penticton

Funding for this project was made available through the Douglas County Public Utility District in Washington State as part of the Fish Water Management Tools project to compensate for effects of Columbia River impoundments.

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Andrew Wilson¹ and H. Andrusak²

INTRODUCTION

Numbers of Okanagan Lake shore spawning kokanee have seriously declined over the last three decades (Andrusak et al. 2002). Reasons for the decline have been attributed to competitive interaction with introduced *Mysis relicta* for the same zooplanktors and a general decline in lake carrying capacity due to nutrient imbalance (Andrusak et al. 2002). A third explanation for the decline involves regulation of the lake level at time of spawning and egg incubation that potentially results in stranding of eggs and/or early hatched alevins (Andrusak and Jantz 2002).

In recent years, an interest has been expressed by the Federal Department of Fisheries and Oceans Canada (FOC) and the Okanagan Nation Fisheries Commission (ONFC) to explore methods of increasing the abundance of sockeye that utilize the Okanagan River for spawning and Osoyoos Lake for rearing. These two entities and the Ministry of Water, Land and Air Protection (WLAP) formed the Canadian Okanagan Basin Technical Working Group (COBTWG) in 1996 to develop an ecosystem-based management framework for the Okanagan River fish habitat complex in the BC portion of the Okanagan Basin. In 2000, the COBTWG was approached by the Douglas County Public Utility District (DCPUD) in Washington State to undertake a review of options for increasing sockeye production. One option identified by the COBTWG was improved water storage in Okanagan Lake and release schedules that could improve sockeye production in the Okanagan River. In 2001, a multi year project titled Fish/Water Management Tools Project (FWMTP) was launched to incorporate biophysical information that control Okanagan Lake and Okanagan River fish production. A Request For Proposal (RFP) was initiated in April 2002 (COBTWG RFP document, Hyatt et al. April 2002) and ESSA Technologies Ltd. was selected to lead in development of a model that could be used to assist water and fisheries managers to make decisions on water storage and release that would be more "fish friendly".

An important component of the model is development of a sub model for Okanagan Lake kokanee since any alteration of lake levels potentially impacts on some stages of shore spawning kokanee life history. The purpose of this report is to summarize key relationships between physical conditions (water levels and temperature) and biological conditions (egg deposition and development) of Okanagan Lake shore spawning

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kokanee. Data collected during 2002-2003 is analyzed and compared with earlier results to gain greater insight into the biology of shore spawning progeny.

BACKGROUND

Okanagan Lake kokanee shore spawners utilize specific areas of the shoreline to spawn and they tend to select a very narrow range within the water column, usually < 1 m in depth (Halsey and Lea 1973; Matthews and Bull 1981; Dill *in* Ashley et al. 1998). It is now well established that the vast majority of Okanagan Lake kokanee shore spawners utilize a very restricted water depth of only 0.25 - 0.75 m. The most recent observations made in 2001 and 2002 (Andrusak et al. *in* Andrusak et al. 2002; 2003) were very similar to the results of Dill's at Bertram Park (Dill *in* Ashley et al. 1998) where the majority of fish spawned at a depth of 0.5 m. The differences in observations amongst the various studies probably reflect differences in size of escapements and possibly subtle differences in slope and substrate. While all the evidence points to shore spawners utilizing a very narrow, shallow (< 1 m) band along the shoreline this does not preclude the possibility of spawning at greater depths. Shore counts by boat and from shore on Okanagan Lake are limited to a depth range of about 0-5 m with depths > 5 m usually unobservable due to the steep sided contours throughout most of the lake. Subsurface flows at the deltas of the larger streams would be likely sites for yet-to-be detected shore spawning kokanee.

The fact that shore spawners appear to only utilize a narrow band of the shoreline for spawning is problematic when the lake drawdown regime is considered. Over the last several decades, fisheries workers managing the Okanagan Lake kokanee population have been concerned about the impact of lake drawdown on kokanee eggs deposited in the shoreline substrate. Early work by Halsey and Lea (1973) estimated that 30% of the 1972 brood was lost due to lake drawdown during the winter months when the eggs were developing. Dill (*in* Ashley et al. 1998) reported severe dewatering and stranding of kokanee alevins in 1997 and suggested 50% of the alevins at the Bertram Park site were dewatered and unlikely to have survived. He also concluded that a silt layer averaging 15 cm into the substrate would have prevented the alevins from downward avoidance of dewatering. On the other hand, Matthews and Bull (1981) found alevins at depths of 20-45 cm at three sites in the SE, NE, and NW quadrants of the lake. Andrusak and Jantz (2002) determined that few fish spawned in water depths < 25 cm and that most eggs were deposited at depths > 20 cm. They concluded that 2001-2002 lake drawdown had little impact on the 2001 brood.

Ward and Yassien (*in* Andrusak et al. 2000) summarized the previous 40 year history of lake level drawdown and all available hydrological data on Okanagan Lake. In general, the lake level is operated within a narrow range between elevations 341.32-342.54 m but can be drawn down to as low as 340.4 m in the event of prolonged drought conditions. A target level of 341.92 m set on October 15th has been used to accommodate shore spawning kokanee with a target level after winter drafting of 341.77 m on February 1st. Ward and Yassien's (*in* Andrusak et al. 2000) analysis concluded that since 1974 the lake surface drawdown has exceeded the 15 cm "rule" in

17 of 23 years and exceeded 30 cm in 9 of the 23 years between 1974 and 2000. They suggested there was considerably more flexibility in the timing and extent of drawdown than previously thought. In fact, during the last few years an ad hoc committee has been established to review the annual drawdown pattern and weekly updates are conducted on the watershed inflows/outflows. During the last 10 years there have been some drawdown patterns that remain problematic for shore spawning kokanee. However, the most recent drawdowns (2001-2003) during the winter months have been managed with kokanee in mind and the 2001-2002 pattern was ideal with little or no impact on incubating eggs (Andrusak and Jantz 2002).

It is quite apparent that the key difference between the operating regimes today (especially 2001-2002) compared to the past is that the lake level is set lower in early October so that spawning occurs after the lake has been partially drafted for winter conditions. While some drawdown occurs between October and March, the preferred option for kokanee is to minimize the degree of drawdown until at least mid February when the eggs have developed to the mobile, late alevins stage. This early drawdown strategy should be considered as the preferred scenario of the current model being developed by ESSA.

Water temperature controls the rate of fish egg development, therefore, it is important to monitor lake surface water temperatures to understand when kokanee eggs hatch and emerge to free swimming fry. Wilson and Wilson (*in* Andrusak et al. 2003) summarized water temperature profiles for the north, middle and south parts of Okanagan Lake from 1996-2002. It is apparent from this data summary that minor differences in surface temperatures exist with the southern stations cooler in the spring and fall months compared to the mid lake and northern stations. Commencing in 2002, Tidbit temperature loggers have been installed to monitor lake surface temperatures at the primary shore spawning sites in the SE, NE and NW quadrants of the lake. Andrusak and Matthews (2002) summarized surface water temperatures for the three quadrants expressed as Accumulated Thermal Units (ATUs) to understand kokanee egg development and noted the NW temperatures expressed as ATUs were slightly warmer than the NE temperatures that in turn were slightly warmer than the SE. The ATUs suggests that during the development period kokanee eggs deposited in the SE quadrant would develop slower than those deposited in the NE and NW quadrants.

Work to date on Okanagan Lake shore spawning kokanee has focused on spawner distribution, their numbers, depth of spawning, and egg development. Some information was obtained in 2002 on timing of development from egg to alevins to fry (Andrusak and Jantz 2002; Andrusak and Matthews 2002) but most of this information has been inferred from ATU calculations with little empirical data available on fry emergence.

Following evaluation of kokanee shore spawners in 2002 (Andrusak et al. *in* Andrusak et al. 2003), investigations were continued through the winter of 2002-2003. This work was directed at documenting egg development relative to lake level and surface water temperatures and experiment with fry emergence traps to determine the timing of fry

development and emergence. This report provides an analysis of development of the 2002 brood relative to lake surface water temperatures and lake levels, and compares results to previous Okanagan Lake shore spawning kokanee egg development data.

OBJECTIVES OF REPORT

Following from egg incubation investigations conducted on the 2001 Okanagan Lake shore spawning kokanee brood year, the 2002 investigations focused on addressing four objectives:

1. Determine the shore spawning kokanee egg and alevin mortality associated with Okanagan Lake water level manipulations;
2. Refine the understanding of egg and alevin development timing;
3. Evaluate inter-gravel temperature relationships along depth gradients over the incubation period and contrast with Water Survey of Canada temperature logger at the Kelowna Bridge site;
4. Determine fry swim-up timing, including initiation, peak and 100% emergence.

SITE DESCRIPTION

Dominating the Okanagan Valley is Okanagan Lake located in the southern interior of BC near the 49th parallel positioned in a north-south axis between the Monashee and Cascade mountain ranges. The lake is located entirely within the warm, dry southern interior and receives an average annual precipitation annually of only 315 mm (Ward et al. *in* Ashley et al. 1999). The lake is approximately 135 km long, but only 4-5 km wide with a surface area of about 35,112 hectares. Despite this size, the lake has a maximum depth of 242 m and a mean depth of only 76 m. Map 1 illustrates the longitudinal profile of the lake that is divided into three basins created by underwater sills located at Squally Point and at the site of the Kelowna Bridge.

There is no major river system that feeds into Okanagan Lake with inflow coming from very few tributary streams of any size. Mission Creek is the largest tributary to the lake. The Okanagan River flows out of the south end of the lake near Penticton, British Columbia into Skaha Lake, then south through Osoyoos Lake and eventually joins the Columbia River in northern Washington. At the outlet located near Penticton is a small dam that effectively regulates the lake between elevations 341 m to 342.5 m (see Ward et al. *in* Ashley et al. 1999 for more detail). The average throughflow of water is relatively small because of the arid climate of the Okanagan Valley, hence, low annual runoff. Lake residence time has been calculated at 50 years (Lawrence *in* Anon 2003).

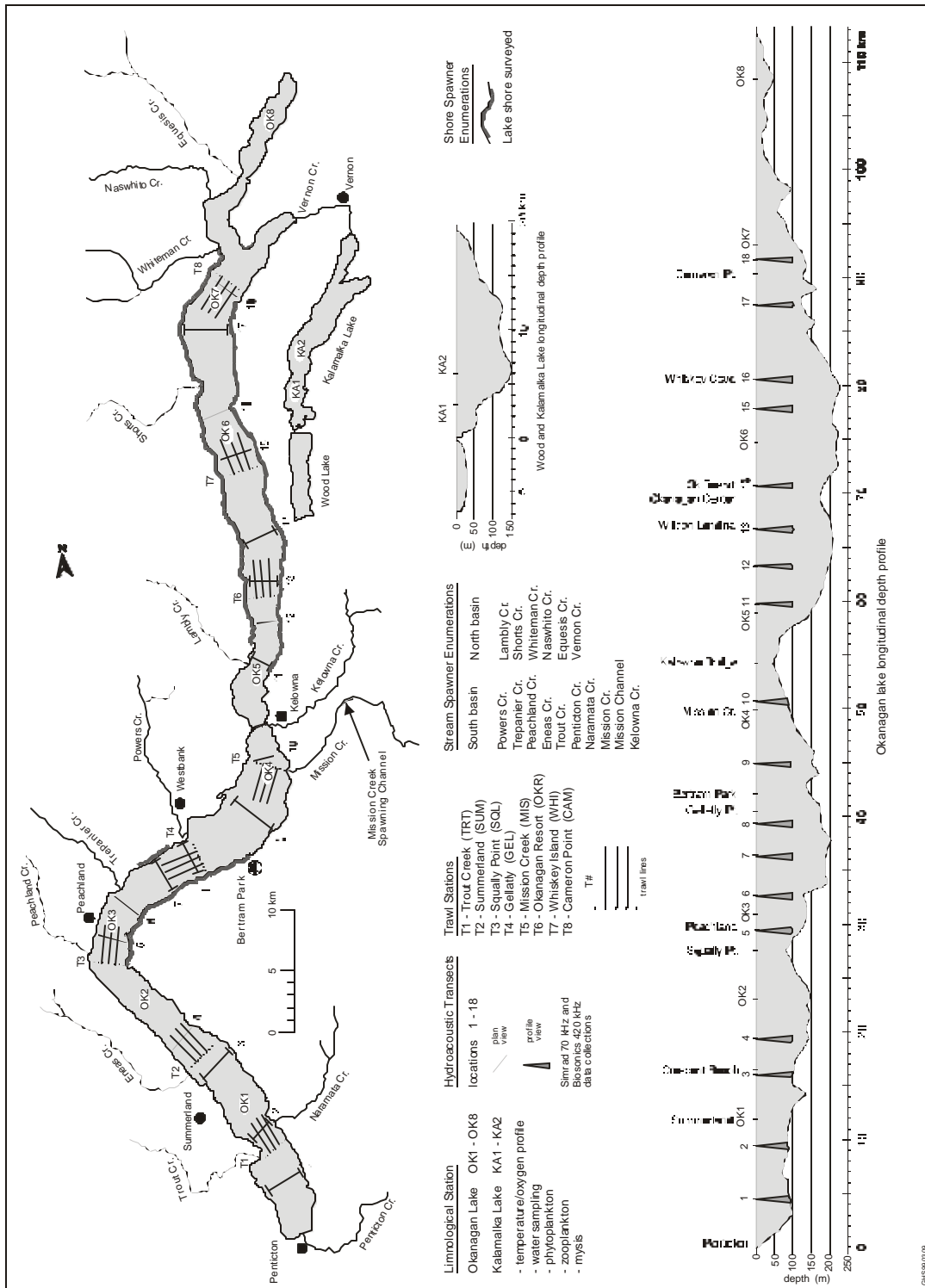
Bertram Park (Reach 22) Spawning Site

This site is located at the northern boundary of the SE quadrant immediately south (4 km) of the City of Kelowna (Map 1). The beach is approximately 75 m long defined by extensions of bedrock at both ends of the beach. The substrate is dominated by angular rocks 15-25 cm in size with pieces of broken bedrock and large flat rock

> 50 cm. Small rounded and angular rocks (< 5 cm) are sparsely interspersed amongst the angular rocks and well above high water there are ample amounts of rounded rocks that have been “tossed” onto the beach by large storm events. More detail on the site and substrate composition can be found in Dill (1996). This site was chosen for this egg study because of its easy access and known use in 2002. Ten days of spawner observations were made in 2002 at this site and a peak count of 2,468 fish was determined on October 25th (Andrusak et al. *in* Andrusak et al 2003).

Paul’s Tomb (Reach 24) Spawning Site

Located in the NE quadrant approximately 3 km north of Kelowna this site consists of a long stretch (2 km) of cobble/angular rock beach with some very large bedrock located at the southern end. Except for the bedrock area the substrate was fairly uniform comprised of angular rock 10-50 cm with smaller rocks (< 10 cm) associated with the immediate shoreline. The bedrock area has pockets of small gravel amongst the larger angular rock and this area is highly preferred by kokanee spawners. Most of the smaller gravels are located in water < 25 cm, hence, this site is of particular interest for investigation of egg development.



Map 1. Okanagan Lake Action Plan sampling stations and key kokanee spawning locations.

METHODS

Water Level Records

Daily lake water levels were obtained from measurements made by the provincial Ministry of Water, Land and Air Protection, Water Management Branch at the Kelowna Highway Bridge.

Water Temperature Recorders

In 2002, the Water Survey of Canada [(WSC) Federal Government Department of Environment] established a permanent water temperature probe located at the Kelowna bridge. This continual recorder will be used as a benchmark reference recorder for all future work on Okanagan Lake; therefore, the Optic Tidbit temperature loggers used in this study were calibrated with the WSC probe.

Kokanee Egg Development and Fry Emergence

This study was initiated after the 2002 spawning event, therefore, eggs were obtained from known “redds” in the substrate at the Bertram Park and Paul’s Tomb sites. The location of egg depositions had earlier been identified by Andrusak et al. (*in* Andrusak et al. 2003).

Shoreline Excavations

To determine egg and alevin mortality associated with lake level drawdown, excavations using a shovel were undertaken along exposed foreshore periodically throughout the incubation period at the Bertram Park and Paul’s Tomb index sites. One meter square areas were excavated at 7 intervals at Bertram Park and 4 intervals at Paul’s Tomb. Excavated areas were located between the water level at peak spawning (marked with rebar at time of spawning) and water level at time of excavation. In all cases, areas were excavated to a depth of 15 cm, the depth of maximum egg deposition identified in previous studies (Dill 1996). Excavated material was sorted in wire mesh baskets and eggs and alevins enumerated. Excavations were completed at both index sites on December 19, 2002, January 16 and March 11, 2003. Timing of excavations was linked to lake level and given the minimal fluctuation in level excavations was kept to a minimum.

All data on excavations was summarized on a per area basis. While the numbers are at best considered qualitative, they do provide insights into the relative impact of water level fluctuation on kokanee eggs and alevins.

Inter-gravel Temperature Monitoring

Intergravel temperature determines the rate of kokanee egg and alevin development. However, there is no knowledge of how intergravel temperature varies with depth over

the course of the shore spawning kokanee incubation period. The shore spawning distribution and abundance work completed to date has identified that kokanee use depth strata preferentially. As water levels change following spawning however, the inter-gravel temperature at each depth strata may change disproportionately, thus affecting kokanee development and emergence timing.

To determine if temperature varies by depth, Optic Tidbit temperature loggers were buried to a depth of 15 cm in high use spawning areas along depth transects at the Bertram Park and Okanagan Centre spawning sites. Four tidbits were placed along depth transects at the mid-depth point of four spawning depth strata: 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm below water level at peak spawning. Tidbit loggers were attached to cinder blocks and set to record temperature at 30 minute intervals starting December 24, 2002 and finishing on April 22, 2003.

Egg and Alevin Development

Information on egg and alevin development relative to accumulated thermal units is required to refine the kokanee sub model component of the Fish Water Management Tools project. As such, two egg capsules (Photo 1) were used to monitor egg and alevin development over the incubation period. Twenty eyed eggs were used to seed each of the capsules on December 19, 2002. Eyed eggs were obtained from excavations of known kokanee spawning areas and placed with spawning gravel in the capsules. The capsules were then buried at a depth of 15 cm in the substrate of the Bertram Park index site, one at the 25-50 cm depth strata and one at the 50-75 cm depth strata (depths from time of peak spawning).

Egg capsules were then excavated six times between December 19, 2002 and March 6, 2003. The number of surviving eggs or alevins was determined and the capsules replaced to following each excavation. Alevins were further broken into one of five categories of development as per Dill (*in* Ashley et al. 1998). Excavations and enumerations were continued until March 6, 2003, at which point all surviving alevins had reached the terminal point of development and were released.

Egg Incubation Baskets

Egg incubation baskets were used to refine the understanding of kokanee egg-to-fry development and swim up timing relative to ATUs to better gauge mortality due to fluctuating water levels. To determine fry swim up timing and gauge egg-to-fry development, 12 egg incubation baskets as per Jeric et al. (1995) were deployed on December 30, 2002, at the mid-depth of the 25-50 cm and 50-75 cm depth strata (6 baskets per strata) at the Bertram Park study site (depths relative to peak spawning water level).

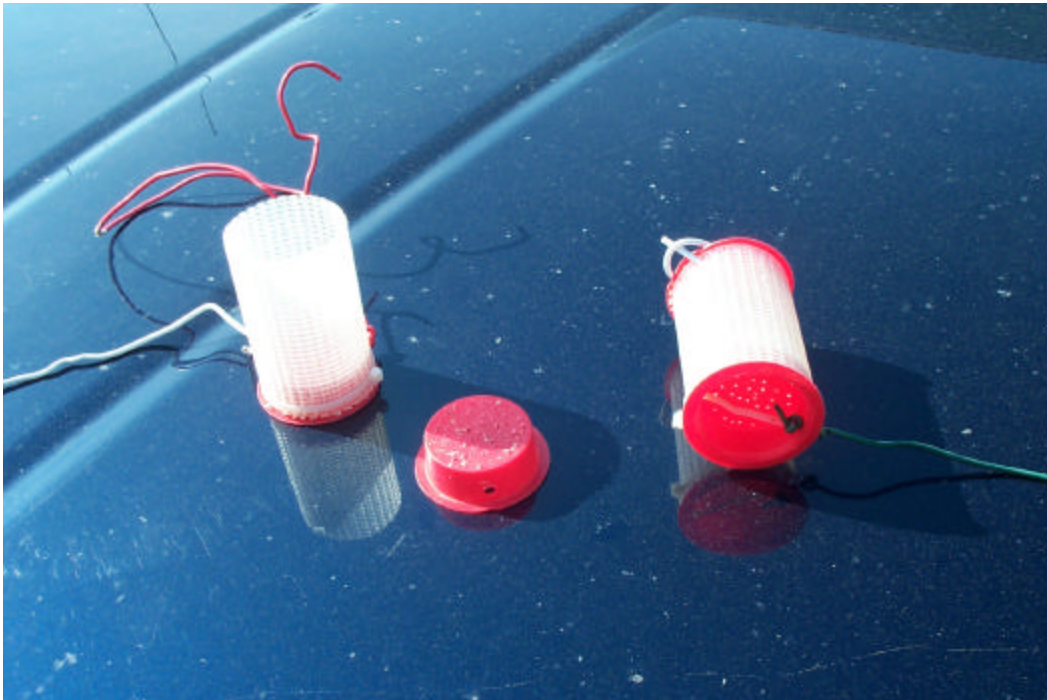


Photo 1.

The baskets used to measure in situ kokanee egg development and fry emergence were a modification of those described by Jeric et al. (1995) and were constructed of 21 cm diameter PVC pipe cut to a length of 24 cm. Six equally spaced panels (20 cm x 9 cm) were cut out using an electric jigsaw leaving a 2 cm wide frame. Polyethylene mesh (2 mm x 2 mm) was used to line the inside of the incubation basket and 2 mm stretched knotless nylon mesh used to form the bottom and top of the basket. The base of the basket was secured using nylon straps whereas the lid was held in place with an elastic band.

The incubation baskets were prepared by first half filling them with gravel collected from the northern portion of the Bertram Park study area. Once partially filled with gravel, 40 eyed eggs excavated from the surrounding area were used to seed each basket following the method of Jeric et al. (1995). Once the baskets were seeded with eyed eggs, they were topped off with gravel and sealed with a 2 mm knotless mesh cover. Holes were excavated to a depth of 30 cm along each of the depth strata and the baskets placed gently in the middle of the hole. The holes were then backfilled with substrate to a level even with that of the surrounding lake bottom. The baskets then were loosely covered with large flat rocks to disguise them from people walking along the beach or headland.

The incubation baskets were left undisturbed at the Bertram Park index site to allow development and hatching of the kokanee egg. Two baskets were removed on February 14, 2003, to confirm development, survival, and gauge when fry emergence

traps were required to be applied to them. Based on results observed at that time, fry traps constructed as per Jeric et al. (1995) were attached to 8 of the remaining 10 egg incubation baskets on February 14, 2003. Fry traps were monitored twice a week thereafter. The number of fry in each trap were enumerated and released. The remaining two baskets were left sealed for removal on March 7 to further confirm development and survival.

Fry traps were modified from the design presented by Jeric et al. (1995). A one-liter nalgene bottle was used as the body of the trap, with an inverted powder funnel fixed to the mouth of the bottle. This was then attached to the egg incubation basket by a 2 mm knotless nylon mesh cone fixed the nalgene bottle with a nylon strap and to the basket with elastic bands. Floatation was provided to the fry trap by capturing a small volume of air in the trap bottle as it was being inverted and attached to the egg incubation basket.

Free Standing Fry Traps

To correlate fry swim up timing from the egg incubation baskets with that of un-manipulated Bertram Park kokanee eggs, four additional free standing fry traps developed as per Chotkowski et al. (2002) were deployed over known kokanee spawning areas at Bertram Park. One trap was deployed on February 14, 2003, the remainder on February 21, 2003. Free standing fry traps were checked concurrently with those attached to the egg incubation baskets.

Fry traps were deployed in the 50-75 cm depth strata to provide sufficient depth for them to properly function. Locations were selected for trap deployment based on observations of where large numbers of kokanee had been seen spawning by the field crew during the shore spawner enumeration component of the project.

RESULTS

Lake Surface Water Temperatures

The Tidbit logger data obtained from the Bertram Park site was plotted against the WSC recorder data as shown in Figure 1a. There were very small variations between the two recorders ($R^2=0.99$) (Fig. 1b); a similar result was evident when Tidbit temperature data from Okanagan Landing was compared to the WSC data (data on file). As noted by Andrusak et al. (2002) there are subtle differences in surface water temperatures between the S.E., N.E. and N.W. quadrants of the lake, therefore, kokanee egg incubation investigations should use data from recordings at the specific study site(s). The differences in the 2002-2003 temperature data from the Bertram Park Tidbit logger and the WSC probe were small but over the incubation period the disparity was nearly 100 ATUs. Using the WSC probe data (which tended to record higher temperatures than the Tidbit recorder) could result in the FWMTP model predicting alevin development well in advance of actual development. The FWMTP model should use site specific temperature data until the WSC probe is calibrated to reflect differences between probes as well as real differences that occur between various parts of the lake.

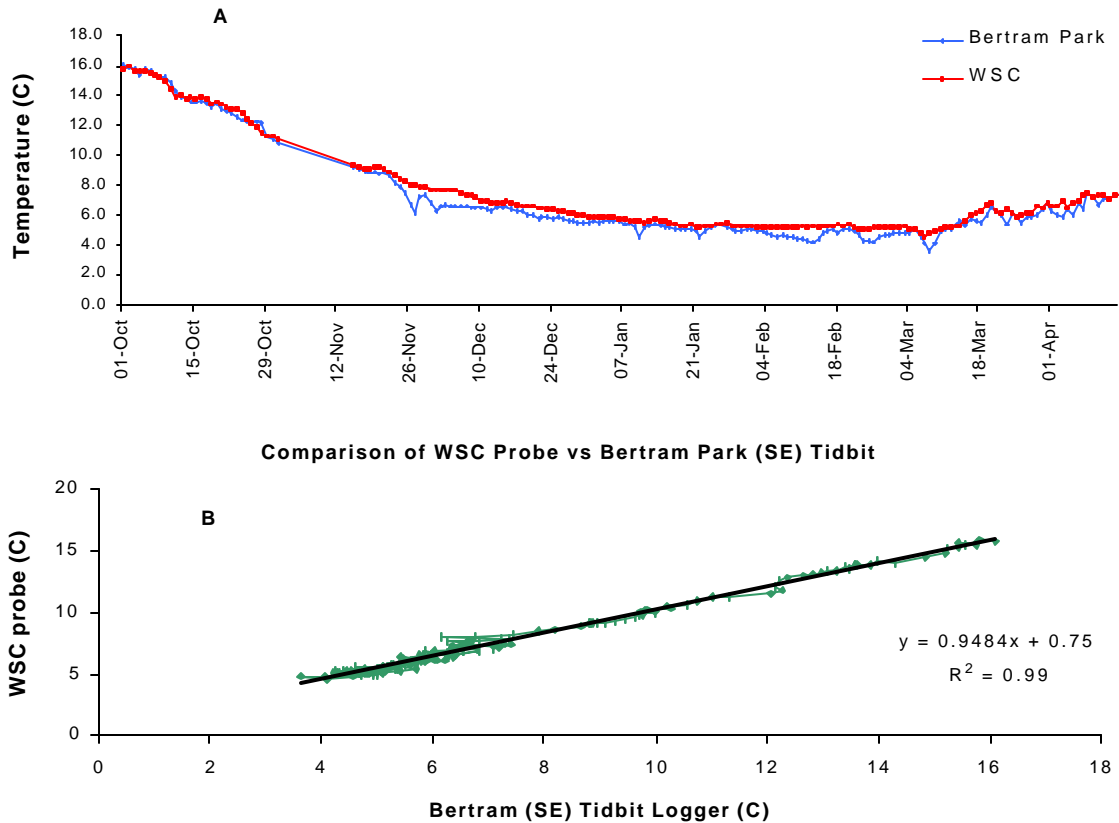


Figure 1a,b. Comparison of temperatures recorded by a Tidbit logger located at Bertram Park vs. temperatures recorded by the WSC probe located at the Kelowna Bridge October 2002-April 2003. R2 value of 0.99 also obtained in comparison with logger located at Okanagan Landing (data on file).

A water temperature logger was located at Bertram Park site in advance of the 2002 spawning event anticipating that kokanee would utilize this site. Mean daily water surface temperatures were computed from hourly water temperatures recorded at Bertram Park from October 1, 2002 to April 20, 2003 (Fig. 2). During the period when most spawning occurred the highest temperature was slightly over 13°C (October 20th) while the lowest temperature was 10.7°C (November 1st). These temperatures were on average over 1°C higher than those recorded in 2001 (Andrusak and Jantz 2002). During the incubation period surface water temperatures gradually declined from about 10°C to a low of 3.7°C in early March and then increased gradually to over 6°C by early April.

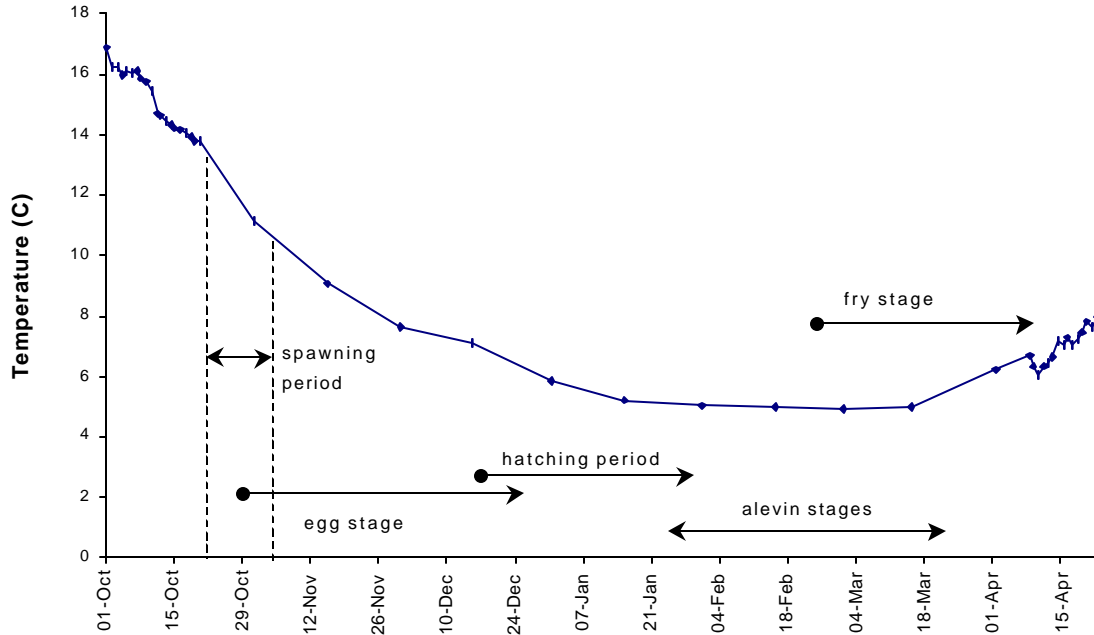


Figure 2. Mean daily surface water temperature (°C) recorded at Bertram Park, Okanagan Lake, October 2002 to April 2003. Note: kokanee shore spawning illustrated from October 20 to November 1, 2002 and range of developmental stages approximated from study results.

It is known that subsurface, intergravel water temperatures can vary considerably from surface water temperatures. Influence of warmer groundwater temperatures in the winter months during kokanee egg incubation could greatly influence the rate of egg and alevin development and emergence. Variable water levels may also influence intergravel temperatures and further confound the rate of egg development. Lower water levels may raise or cool the intergravel temperature around the most shallow deposited kokanee eggs, thereby affecting development and have consequences for managing the timing of lake drawdown to minimize kokanee impacts.

During this study four Tidbit temperature loggers were buried along depth transects of the study site. Loggers were buried 15 cm deep in the substrate at mid point of depth intervals 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm. The recorders were placed in the gravel December 20th and retrieved April 22nd. The logger located at the 12.5 cm depth was vandalized and data lost. Some subtle differences were observed between the sub-surface and surface temperatures illustrated in Figure 3a. During early incubation the surface waters were warmer than sub surface but in December-February the sub-surface temperatures were slightly warmer than the surface temperatures. However, by March-April surface temperatures became increasingly warmer. The comparable total ATUs for each depth were very similar and virtually indistinguishable

as shown in Figure 3b. The 75-100 cm logger shows that eggs would have accumulated slightly more ATUs earlier than the surface temperature logger but by mid April the surface temperature ATUs were slightly higher (1%) compared to the recorder at the 75-100 cm depth interval and 2.3% higher than the recorder placed at the 25-50 cm depth. The differences would probably be greater if the entire incubation period were monitored, i.e., surface water temperatures recorded from late October (egg deposition) to December would most likely be higher than sub-surface temperatures.

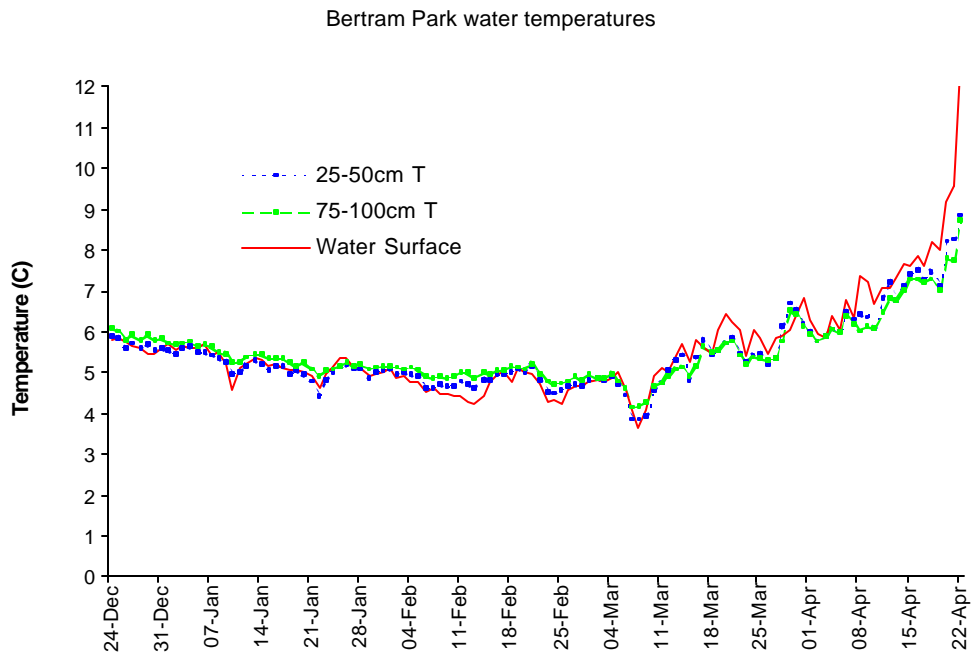


Figure 3a. Surface and sub-surface water temperatures recorded at the Bertram Park study site December 24, 2002 to April 22, 2003. Subsurface temperatures recorded by Tidbit recorders buried at depths of 15 cm in the substrate at water depths of 25-50 and 75-100 cm.

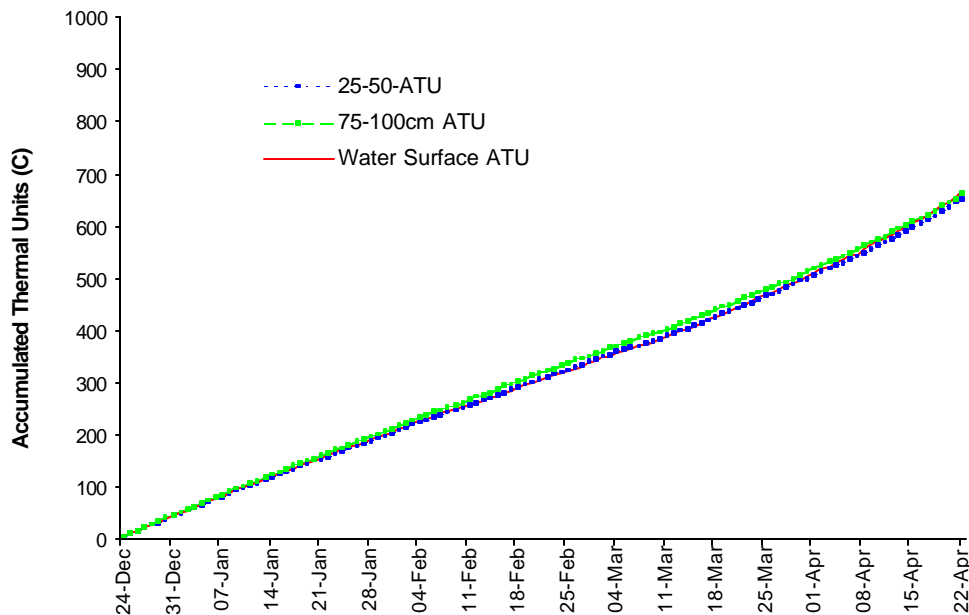


Figure 3b. Cumulative thermal units (ATUs) experienced by eggs deposited 15 cm in the substrate at the surface, 25-50 cm and 75-100 cm water depths at Bertram Park site December 24, 2002 to April 15, 2003.

Lake Levels

Okanagan Lake is regulated by means of a low-level dam located at the outlet of the lake near Penticton, BC. Lake levels can fluctuate to a maximum of 1.3 m but the annual variation is usually <1 m. The 2002-2003 drawdown regime for the lake was optimal for shore spawning kokanee. Figure 4 shows that the lake level was deliberately dropped just prior to spawning and then held fairly constant until the end of February. From October 20th to April 1 2003, the lake was lowered a total of 12.5 cm with only a slightly greater drop occurring during early March.

Gravel Excavation Observations

Initial excavations along the shoreline at Bertram Park and Paul's Tomb on December 15th provided some insight into where kokanee eggs were deposited and the stage of development. Eggs were readily found at the Bertram Park and Paul's Tomb sites at locations where spawning had been observed during late October. The majority of eggs had developed to the eyed stage although a few had begun to hatch, i.e., stage 1 development. Of particular interest were eggs found in water < 2 cm depth as well as viable eggs in wetted gravels above the lake surface. Evidently wave action had thrown smaller gravel(s) and kokanee eggs onto the beach where they remained alive due to subsurface water and constant wave action.

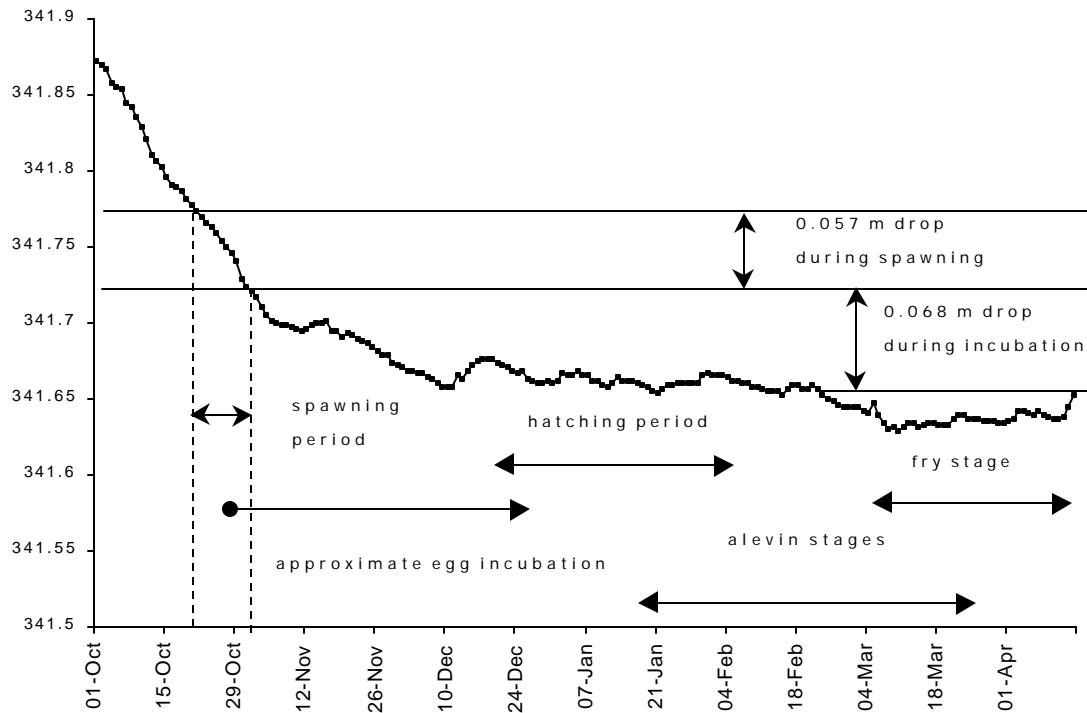


Figure 4. Drawdown pattern (m) on Okanagan Lake for 2002-2003 from October 1st through to April 14th. Generalized range of spawning, incubation, and emergence periods are also illustrated. Lake level dropped approximately 12.5 cm from initial spawning to fry swim up stage.

Gravel excavations were conducted throughout the incubation period at Bertram and Paul's Tomb sites in an attempt to quantify the numbers of eggs or alevins impacted by lake level drawdown. During December, January and March multiple 1 m² plots were excavated along the old and new water level/shoreline interface to a depth of 15 cm. Results of these excavations are summarized in Table 1. Since spawning is known to be patchy (i.e., not uniform) along the beaches the data cannot be quantified but do suggest that some eggs/alevins are impacted even during a year when lake level drawdown was quite minimal (12.5 cm). No eggs/alevins observed during the March 11th excavations suggests that development had advanced to late stage alevins or fry that were able to avoid desiccation and or excavation.

Table 1. Numbers of eggs and alevins affected by water level drawdown at Bertram Park and Paul's Tomb by date and excavation site.

Bertram Site	Dec-19	Jan-16	Mar-11	Paul's Tomb Site	Dec-19	Jan-16	Mar-11
1	43	18	0	1	0	1	0
2	0	4	0	2	7	8	0
3	0	3	0	3	3	7	0
4	0	5	0	4	12	21	0
5	2	4	0				
6	0	1	0				
7	0	0	0				
Average	6.4	5.0	0	Average	5.5	9.3	0

Accumulated Thermal Units (ATU)

Results of the egg capsule experiment are shown in Table 2. Eggs placed in the two capsules in December were all eyed by January 16th the majority had hatched and were primarily at stage 1 development. By mid February most were at stages 3 and 4, and by March 6th all the survivors were at the swim up fry stage. Of the 40 eggs placed in the two capsules 16 survived to the fry stage or 40% from eyed egg-to-fry.

Table 2. Percentage of survivors by development stage for kokanee eggs placed in the two egg capsules at Bertram Park site December 2002-March 2003.

Date	Survivors	Percentage of Survivors by Development Stage				
		Eyed egg	Stage 1	Stage 2	Stage 3	Stage 4
Dec 19	40	95%	5%			
Dec 30	40	65%	35%			
Jan 16	32	3%	70%	27%		
Jan30	24	3%	34%	63%		
Feb 14	18			61%	34%	
Feb 18	16			45%	32%	5%
March 6	16					23%

Surface water temperatures recorded at Bertram Park (Fig. 5) for the beginning of spawning (October 20th), peak of spawning (October 24th) and the end of spawning (November 1st) were used to determine probable ATUs experienced by the eggs in the capsules (Fig. 6). (Note: since the actual stage of egg development for those placed in the capsule was unknown only a range of ATUs can be expressed). Since all the surviving eggs had become swim up fry by March 6th, development to the fry stage must have occurred between 800-900 ATUs. Based on previous work on Okanagan Lake shore spawners and the 2001-2002 temperature regime at Bertram Park, Andrusak et al. (2002) had estimated the ATUs required to free swim up stage was 760-950.

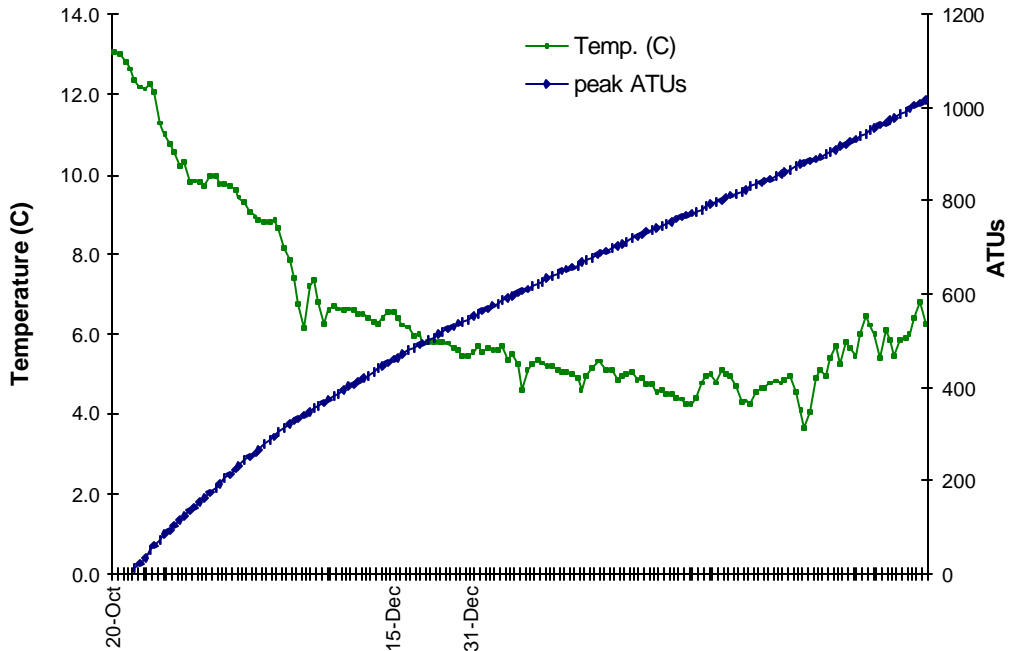


Figure 5. Surface water temperatures at Bertram Park October 20, 2002 to April 1, 2003, and the ATUs experienced by kokanee eggs deposited in the substrate.

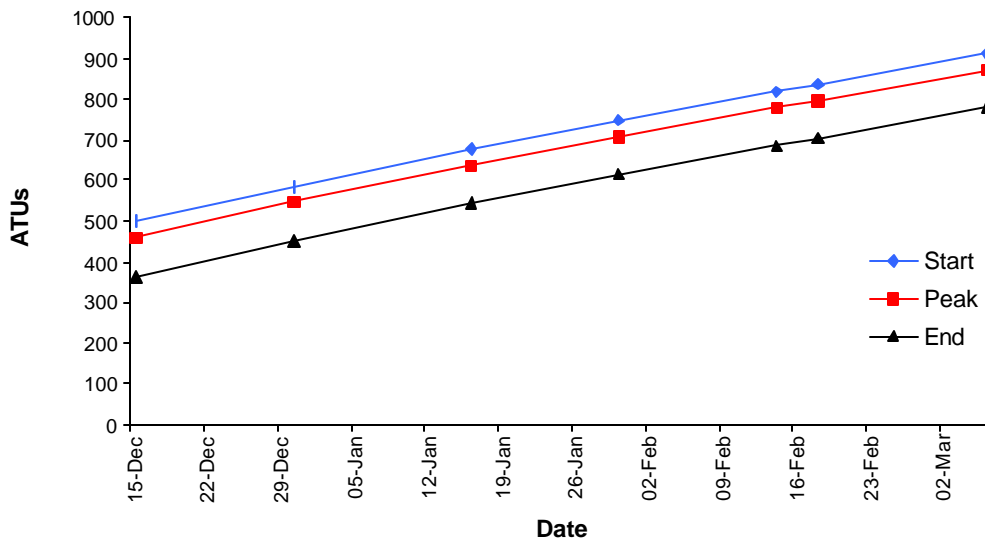


Figure 6. Cumulative thermal units experienced by kokanee eggs incubating in the egg capsules placed at the Bertram Park site December 15 to March 6, 2003. The three lines represent egg development from eggs deposited at the actual beginning, peak and end of spawning.

Okanagan Lake shore spawning kokanee literature was reviewed and ATU requirements for shore spawning kokanee egg-to-fry development has been summarized (Table 2). Results from the 2002 brood are also shown to illustrate differences amongst the various studies. This present study indicates that hatching occurred much earlier during 2002-03 than previously believed and development to the free swimming stage took place similar to what Dill (1996; 1998) reported but considerably earlier than most other studies.

Table 2. Summary of kokanee egg-to-fry development data from studies involving Okanagan Lake shore spawning kokanee.

Development Stage	Date Peak Spawning	Date 50% Development or Range	Field (f), Derived (d) or Hatchery (h)	ATUs (centigrade)	Reference
Fertilized Egg	Oct-24		f	0	Andrusak et al. 2002
	Oct 20		f	0	2002-2003 study
Hatch-Emergence			h	559-691	Smith 1978
	N/A	Jan 6-Feb 16	d	576	Matthews and Bull 1981
	N/A	Early March	f		Dill 1996
	N/A	Mid March	f	580	Dill 1997
	N/A	Jan 23-March 26	f		Dill 1998
		February 19	f		Harris 1984
			h	560-620	Pers. comm., G. Gale 2002
		Early March Late December	f f		Andrusak et al. 2002 2002-2003 study
Swim up fry	N/A	N/A	d	880	Smith 1978
	N/A	N/A	d	750	Smith 1978
	N/A	March 17-April 15	d	884	Matthews and Bull 1981
	Oct-18	Mar-18	f	828	Dill 1996
	Oct-27	May-17	d	917	Dill 1997
	Oct-18	Mar-23	f	939	Dill 1998
			h	970	Pers. comm., G. Gale 2002
		Feb. 1-March 31 March 6	d f	760-950 873	Andrusak et al. 2002 2002-2003 study

Fry Emergence Experiment

Twelve egg baskets were placed in the substrate at the Bertram Park site on December 30th. Forty (40) eggs were placed in each basket. In anticipation of fry emergence commencing, fry traps were deployed on eight of the baskets on February 14th. On that date, two baskets were removed to assess stage of egg development while two baskets were left with covers attached to confirm development at a later date. The excavated egg incubation baskets indicated that alevin development had progressed to the point where swim up was imminent for some late stage alevins (Photo 2). Due to the stage of development identified in the egg incubation baskets, it was decided to install fry traps.



Photo 2.

Following some initial problems with keeping the fry traps attached to the incubation baskets, the traps appeared to function well. However, due to a combination of vandalism and a major storm event from March 4-6th only three baskets with fry traps were considered intact. Fry were captured by the traps February 23, 25, 28 and March 4th with the storm event disrupting the experiment March 5-6th (Fig. 7). Fry emergence was increasing just prior to the storm. Three baskets (with fry traps) considered intact were examined March 7, 11, 14, 18 and 20th. Three fry were captured on March 20th. It is reasonable to conclude that peak fry emergence occurred March 4-20th, with the week of March 4-11th probably the peak period of fry emergence.

While much of this experiment failed due to vandalism of some of the fry traps and major storm disrupting most of the baskets, some information can be extracted from this years result. From the three baskets considered undisturbed, a total of 25 fry were captured from the 120 (planted) eggs for 21% survival rate. This survival rate cannot be considered as an estimate of egg-to-fry survival since natural mortality prior to the time the eggs were placed in the baskets was not accounted for, i.e., the egg-to-fry survival rate was < 21%.

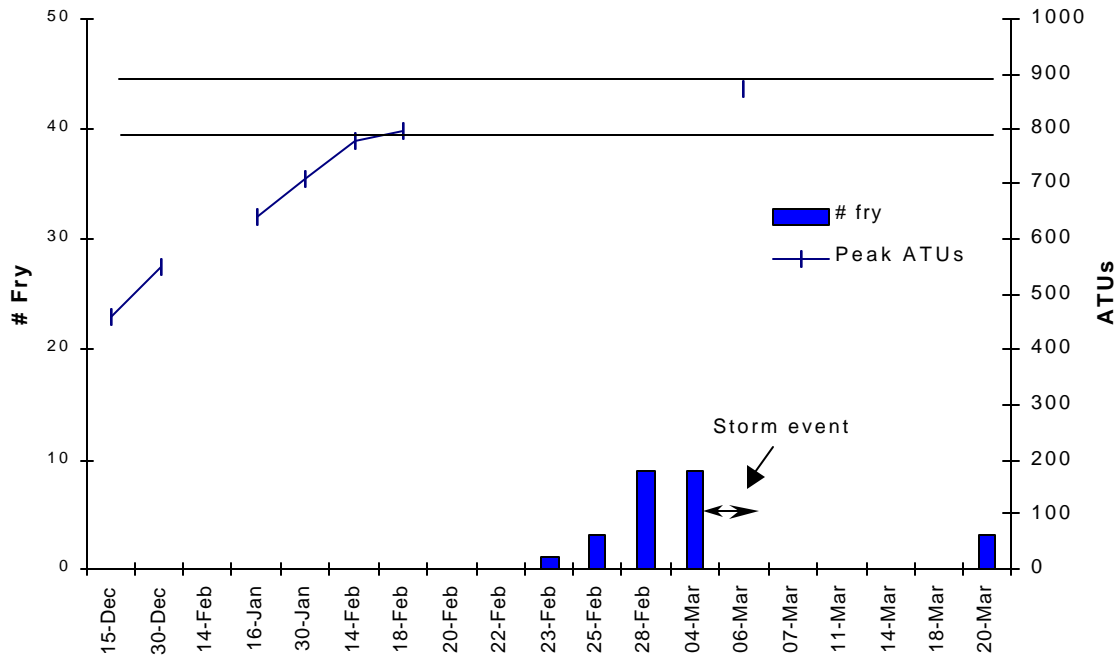


Figure 7. Cumulative thermal units experienced by kokanee eggs in the experimental capsules and the number of swim up fry captured in the experimental baskets during February to March 2003. Note: storm event March 4-6 dislodged most baskets with only 3 considered intact.

DISCUSSION

Results from this study offer some additional insight into the biology and life history of Okanagan Lake shore spawning kokanee. Timing, relative numbers and depth at which spawning occurs has been previously documented as well as depth of egg deposition within the substrate (Dill 1998; Andrusak et al. *in* Andrusak et al. 2003). As part of the FWMTP work the relationship between recent lake level drawdowns and depth of spawning has been analyzed to provide water managers with more accurate information on what are the preferred drawdown scenarios for the shore spawners. Over the last three decades there has been a considerable amount of fisheries concerns expressed about the drawdown pattern. Halsey and Lea (1973) estimated that 30% of the 1972 brood was lost due to lake drawdown during the egg incubation period. Matthews and Bull (1981) estimated an 11% loss of the 1980 brood due to early drawdown that stranded incubating eggs. Most of the 1981 spawners had utilized substrate in 10-30 cm of water and the deposited eggs were quite vulnerable to any appreciable drawdown (Harris 1984). Dill (*in* Ashley et al. 1998) felt that the 1996 brood also experienced up to a 50% loss due to dewatering of eggs and early stage alevins. Andrusak and Jantz (2002) felt there was little or no impact of lake level drawdown on the 2002 brood.

Ward and Yassien (*in* Andrusak et al. 2000) investigated the historical records on lake level regulation and suggested there was considerably more flexibility in the timing and extent of drawdown than previously thought. Consequently, in recent years, an *ad hoc* committee has been established to review the annual drawdown pattern and weekly updates are conducted on the watershed inflows/outflows (pers. comm., S. Matthews, Penticton, Ministry of Water, Land and Air Protection, Fisheries Biologist). This committee is now being provided with far more information through the FWMTP studies which are aimed at development of a real time modeling tool to aid water and fishery managers to minimize flooding as well as impacts to kokanee and sockeye.

The key difference between the operating regimes today (especially 2001-2003) compared to the past is that the lake level is now set lower in early October so that spawning occurs after the lake has been partially drafted for winter conditions. Since some drawdown does occur between October and March there is some flexibility as to when this must take place so it is critically important to define exactly when the eggs have hatched and the alevins have become mobile enough to avoid desiccation due to drawdown. Similar to 2001-2002 (Andrusak and Jantz 2002) the lake level for 2002-2003 was drawn down in early October (Fig. 4) in advance of peak spawning activity and then held relatively constant until late February. The total drop from October 1 to February 28th was only 12.5 cm. This drawdown regime appeared to be ideal for kokanee since very few fish spawned at water depth < 25 cm (Andrusak et al. *in* Andrusak et al 2003). However, results from this study indicate that despite a near perfect drawdown condition some viable eggs were found in very shallow water (< 2 cm) including some “above” the water line (see discussion below).

The inter-gravel water temperature data indicates that some slight differences exist between surface and intergravel temperatures (Figs 3a,b). The inter-gravel temperatures were slightly warmer through the winter months but surface temperatures were somewhat warmer in the fall and spring months. Predicting fry emergence time based solely on surface water temperatures as in all previous studies on Okanagan Lake could lead to predictions of a later fry emergence time than actual. This could occur because most of the ATUs accumulate during the late fall-winter months when surface temperatures are lower than the intergravel temperatures.

Despite the problems encountered in this study with the egg baskets and fry emergence traps there was some good information obtained on timing of alevin and free swimming fry development. Dill (1996) had trapped free swimming fry at the Bertram Park site during March and early April in 1996. However, in 1997 Dill (*in* Ashley et al. 1998) indicated that fry emergence could have been as late as May. Such a wide disparity in fry emergence time led Andrusak et al. (2002) to excavate spawning sites to directly observe egg development and conduct an analysis of ATUs to improve on the prediction of fry emergence. They determined that fry emergence probably occurred in late February 2002 at a range of ATUs from about 750-950. Their analysis also indicated that free swimming fry should typically be present by early March. The 2003 egg capsule data (Table 2) suggests that between 800-900 ATUs (Fig. 6) were required to develop eggs to free swimming fry. The fry trapping results tend to confirm this with apparent peaking of fry emergence in early March (Fig. 7).

In both 2001-2002 and 2002-2003, the water level of Okanagan Lake was held fairly constant from October to January and drawn down less than 21 cm (2002) and only 12.5 cm (2003) from the time of peak spawning to well beyond when the fry were fully formed in the swim up stage. Since very few fish actually spawned in < 25 cm water it has been concluded that there was little chance that any eggs were affected by drawdown especially since most eggs were deposited to an average depth of 15 cm into the substrate (Dill *in* Ashley et al. 1998; Andrusak and Jantz 2002). The gravel excavations conducted in late 2002 tend to support this general view but the observation that viable eggs were found at water depths < 2 cm including some “above” the water line signal reason for caution. The role of wind and action in dislodging eggs deposited in the substrate should not be dismissed, i.e., even though live eggs are generally found in the substrate an unknown percentage appear to become dislodged and are present in very shallow water, including some well above the waterline.

In this study, some fry were captured in the emergence traps as early as late February. These results and those from 2002 (Andrusak and Jantz 2002) help to explain the presence of kokanee fry found in commercial mysid trawl nets (S. Matthews, Penticton, Ministry of Water, Land and Air Protection, Fisheries Biologist, pers. comm.) in March 2001 and 2002. Kokanee fry do not emerge from the streams until late April (Webster 2002) so the fry captured in the mysid trawl nets must have been of shore spawner origin. It is possible that very early emergent kokanee fry observed at the beginning of 2002 and 2003 may not contribute to the subsequent parental generation. Conventional wisdom suggests that for optimum survival, kokanee fry emergence to the lake should

be timed to coincide with the spring zooplankton bloom. It appears that the early emergent fry from the shore spawners are moving into the lake well in advance of the spring zooplankton bloom (see Wilson and Vidmanic *in* Andrusak et al. 2002), thus their survival may be poor. A study of the reasons for the difference in fry emergence strategy between shore and stream spawners in Okanagan Lake is worthy of consideration.

Improvements to the Okanagan Lake winter drawdown, especially in 2001 and 2002-2003 appear to have been highly beneficial for shore spawning kokanee. Most spawning occurs at water depths > 25 cm with eggs deposited a further 15 cm into the substrate. This means there has been a reasonable margin of safety for most kokanee eggs since total lake drawdown during the last two years (during the egg incubation period) has been < 21 cm. One confounding factor identified in this study was the presence of live eggs in very shallow water evidently displaced there by wave and wind action.

The egg basket and fry emergent experiment was not completely successful owing to problems of vandalism, a major storm event and problems with basket design. Despite these problems some good information was obtained and will provide better definition for the FWMTP model. With some slight modification to the baskets and fry traps good data should be obtained in 2003-2004.

RECOMMENDATIONS

1. Monitor the 2003 shore spawning brood to determine egg development relative to lake levels and water temperatures.
2. Monitor inter-gravel and surface water temperatures at Bertram Park and Paul's Tomb and again compare with the WSC probe data.
3. Develop a correction factor for the WSC probe data to ensure the information used in the FWMTP accurately predicts kokanee development.
4. Repeat the egg basket and fry emergent trap experiments after modifying the traps to account for heavy windstorm events and design flaws. The pattern and extent of fry emergence requires greater definition.
5. Capture mature fish on site and use fertilized eggs in the egg capsules to monitor the entire egg incubation process. This work should lead to an estimate of egg-to-fry survival rate.
6. Determine the fecundity of the shore spawners by gill netting fish in the weeks prior to predicted spawning initialization.
7. Reduce lake level to 341.7-341.9 m commencing October 1st to avoid spawning in the drawdown zone.
8. Conduct shore spawner estimates again in 2003 to determine percent composition within the 1 m vertical depth zone presently utilized by most spawners and predict mortality associated with water level drawdown.
9. Place some egg baskets or equivalent device(s) at the water-shoreline interface to capture eggs displaced by wind-wave action.
10. Analyze the results of egg and alevin development in 2004-2005 and contrast with the predictions of the FWMTP to determine accuracy and precision of the model.
11. Support a university based research project to investigate the advantages and disadvantages of early fry emergence from shore spawning kokanee compared to the stream spawning population.

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