A Case History: The Kokanee Stocks of Okanagan Lake

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ABSTRACT

Within a single decade, Okanagan Lake kokanee (*Oncorhynchus nerka*) went from being managed for sport fishery purposes to being a major concern from the perspective of conservation biology. Both shore-spawning and stream-spawning runs have declined dramatically, despite a fishery closure since 1995. Shore spawners are genetically different from stream spawners, and are quite unique in spawning behaviour. The 1998 returns of both stocks were about 1% of the levels of the 1970s, when routine monitoring of spawning began. While the introduction of an exotic species, the opossum shrimp (*Mysis relicta*), is likely the driving force behind the decline, there are a variety of other forces that may have initially masked and more recently aggravated the situation. A long-term (20-year) action plan for the recovery of the kokanee stocks was formulated in 1995. Phase I (1996–2000) of the plan stands on 2 legs: 1) developing a practical means of *Mysis* control; and 2) conserving key habitats. The results of the first 3 years of work on the plan are reviewed, and options for the future discussed. Given intensifying human development pressures in the Okanagan, can we save habitats that are currently empty for future fish?

Key words: kokanee, limnology, *Mysis relicta*, Okanagan, *Oncorhynchus nerka*, opossum shrimp, spawning habitat.

First Nations peoples fished both sockeye and kokanee (*Oncorhynchus nerka*) spawning runs in the Okanagan system long before white pioneers first appeared in the Okanagan Valley, B.C. The early settlers took an abundance of kokanee for granted, and with rakes and washtubs used to take kokanee home by the wagon-load from the beaches and tributaries of Okanagan Lake. Even into the late 1960s, kokanee remained so numerous that no need was seen even for an angling bag limit province-wide. By the late 1970s, concern for Okanagan Lake kokanee stocks began to build, as angler catches climbed and spawner numbers shrank. In the mid-1980s, the British Columbia Environment Ministry began to allocate additional resources to improving the management of the Okanagan Lake kokanee sport fishery, which had an estimated net worth of about $1,000,000 annually (Shepherd 1990).

By 1995, stock conservation concerns had replaced those of fishery management, and Okanagan Lake was closed to fishing for kokanee effective 15 March 1995. That closure is unlikely to be rescinded in the near future, given the bleak population monitoring results to date. Both stream and shore spawner numbers have continued to decline since annual escapement counts began in the early 1970s. In 1998, spawner numbers were down to disastrously low levels of <13,000 adults in total, just 1% of the numbers seen 25–30 years ago (Fig. 1). Annual hydroacoustic (Fig. 2) and trawling (Fig. 3) surveys of younger age classes indicate that, without some significant changes, further declines, rather than recovery, are likely in the coming years.

SELECTED FEATURES OF OKANAGAN LAKE KOKANEE STOCKS

Both stream-spawning and shore-spawning strains of kokanee occurred naturally in the Okanagan Lake system, probably due to glacial wanderings some 10,000 years ago (McPhail and Carveth 1992). Despite this relatively recent arrival in the Okanagan, the 2 strains differ markedly from each other in terms of spawning and incubation lifestyles (Table 1). The stream-spawning kokanee runs are similar to the "standard" sockeye in spawning morphology and behaviour, and can be quite variable in size and age at maturity. In contrast, shore spawners are smaller and less variable in size (Table 1), and are much less pronounced with regard to spawning colouration (Dill 1996) and other secondary sexual maturation features (e.g., dorsal hump, hooked jaws, compression of body).

Okanagan Lake shore spawners are unique among salmon in their spawning behaviour. Rather than rounded gravel, they choose large, angular rocks in shallow (15–100 cm water depth) shoreline areas, presumably to allow water circulation

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Table 1. Selected characteristics of shore-spawning and stream-spawning kokanee in Okanagan Lake (modified from Shepherd and Sebastian 1998).

Characteristic	Shore spawners	Stream spawners
Spawning dates		
Peak	25 Oct–30 Oct	1 Oct–5 Oct
Range	15 Oct–4 Nov	21 Sep–20 Oct
Preferred substrates	• angular riprap • size >5 cm	• rounded gravels • size <5 cm
Spawning behaviour	• no obvious pairing • little defence of redd • school when disturbed • "bright" spent fish common	• pairing • redds defended • hide in cover • spent are "rags" and highly coloured
Nose–fork lengths (1987–97)	236 mm overall mean (216–250 mm range)	265 mm overall mean (229–352 mm range)
ATU[a] - hatch	616 C-days[a]	660 C-days
(range)	(550–682)	(627–693)
- emerge	880 C-days	902–970 C-days
Hatching date	6 Jan–15 Mar	1 Jan–30 Apr
Emergence date	15 Mar–15 Apr	1 Apr–15 Jun

[a] ATU = Accumulated Thermal Units. For this paper, the ATUs were calculated by the cumulative addition of mean daily water temperatures measured in degrees centigrade above freezing (C-days). For example: Eggs spawned on 15 Sep. Mean daily temperature on 16 Sep = 10°C, so ATU = 10 C-days. Mean daily temperature on 17 Sep = 11°C, so ATU = 10 + 11 = 21 C-days. Mean daily temperature on 18 Sep = 8.5°C, so ATU = 10 + 11 + 8.5 = 29.5 C-days. Etc.

to the eggs via wave action without shifting the substrate. Shore spawners have abandoned the standard salmon strategy of an approximate 2-week period of spawner pairing, male defence of the female against other males, and female defence of her redd until death. Instead, schools of adults move onto the shoreline in the morning, and females drop out of the schools to investigate the substrate. Once a female finds a suitable spot, she will circle and clean the selected area using

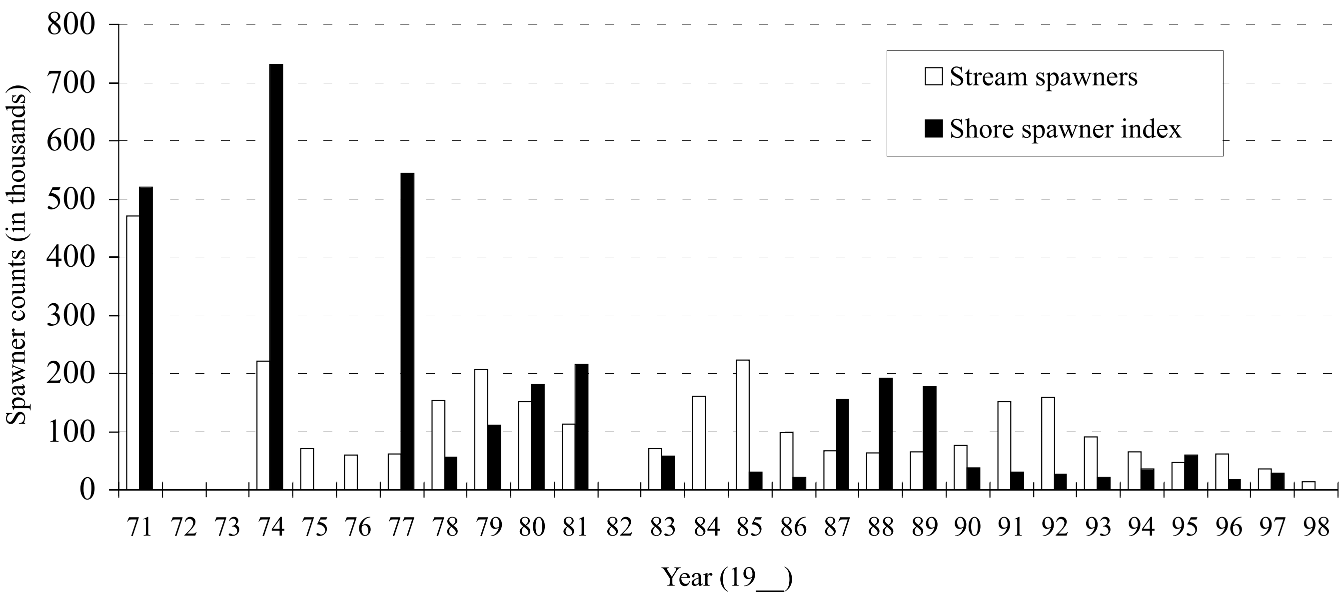

Figure 1. Okanagan Lake kokanee spawner enumerations, 1971–98.

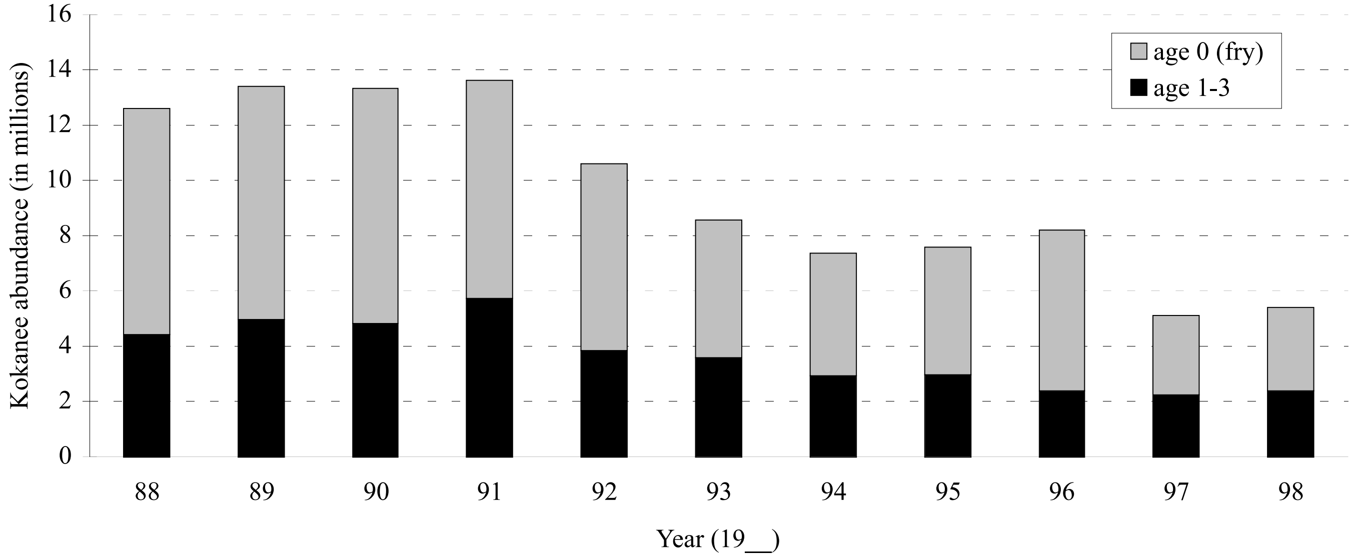

Figure 2. Index of kokanee abundance in Okanagan Lake based on hydroacoustic surveys, 1988–98 (data from D. Sebastian, British Columbia Ministry of Fisheries, Victoria, BC).

the typical salmonid tail-digging action. This behaviour draws males to the site, and they press into a "cluster" (Dill 1996) over the crevice that has been cleaned by the female. The female then passes through the cluster of males, and the combined group releases eggs and sperm to settle into the crevices. Spawner numbers peak around noon, and the spawning sites are generally abandoned by evening (Dill 1996).

Recent genetic studies using a variety of methods (Taylor

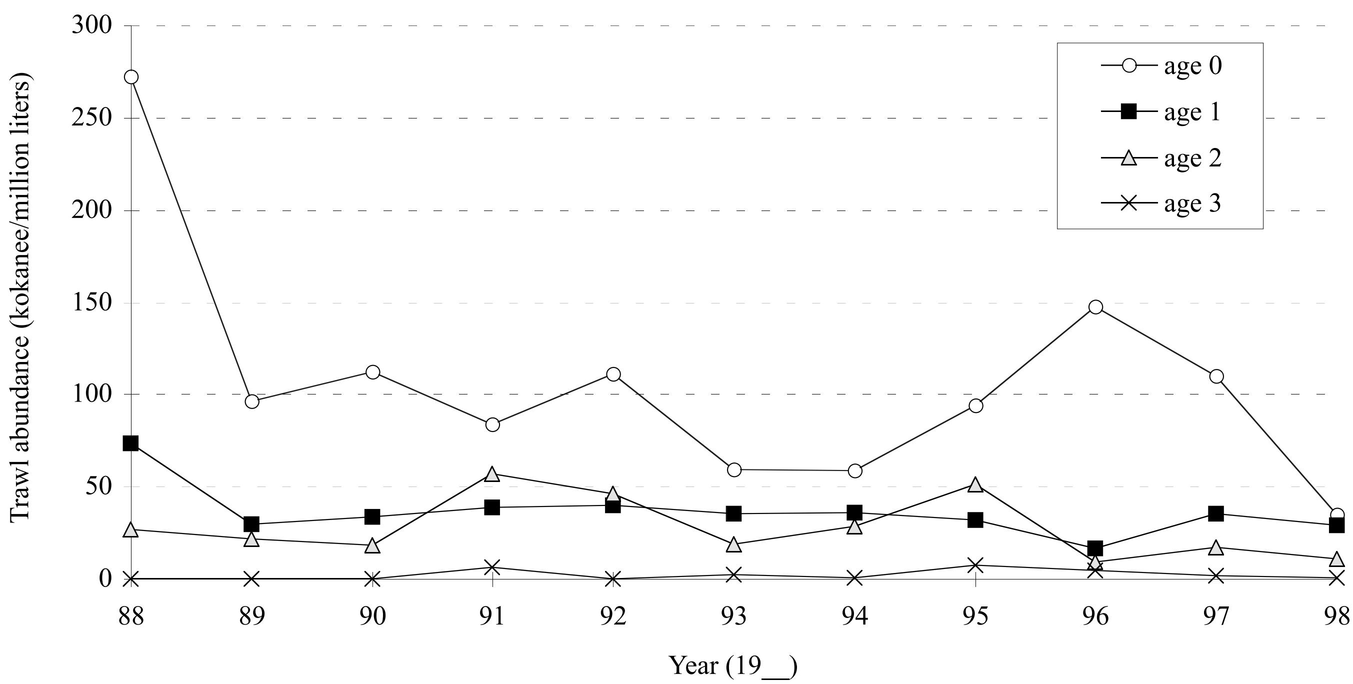

Figure 3. Index of kokanee abundance by age for Okanagan Lake based on trawl surveys, 1988–98 (data from D. Sebastian, British Columbia Ministry of Fisheries, Victoria, BC).

and Pollard 1998) suggest that the stream- and shore-spawning ecotypes of Okanagan Lake kokanee are closely related to each other and have a common ancestry. However, the results to date also indicate that gene flow is restricted between these 2 ecotypes, and improved microsatellite-assay techniques may allow strain identification and separation.

In the simpler days of dealing with just fisheries management concerns, stream-spawning stocks received the most attention, as it appeared that shore spawners contributed less to angler catches due to their smaller size at maturity (Shepherd 1990). Times, of course, have changed, and the first priority of the British Columbia Fisheries Program is now "the protection, maintenance and rehabilitation of native fish and their habitat to ensure ecosystem sustainability and biodiversity" (B.C. Fisheries Branch 1996). The unique biology of the shore-spawning kokanee of Okanagan Lake only adds to the argument for its protection and preservation together with the stream spawners.

WHY HAVE OKANAGAN LAKE KOKANEE STOCKS DECLINED?

So what has brought the Okanagan Lake kokanee runs to their knees, and what are we doing about it? The simultaneous decline of both the stream- and shore-spawning stocks without a compensatory increase in growth rates suggests that the primary problem has to do with a reduction in the lake's carrying capacity for kokanee (Ashley and Shepherd 1996). The primary cause of this reduction was hypothesized to be the introduction of the opossum shrimp, *Mysis relicta* (Shepherd 1996). Ironically, the introduction of *Mysis* into Okanagan Lake in 1966 was done with the intention of boosting the size of kokanee, based on a decade of experience with the introduction of *Mysis* into Kootenay Lake. As it turned out, *Mysis* were able to avoid predation by kokanee in the main basins of both lakes by sounding into the dark depths during the day. By virtue of their sheer numbers, together with their habit of coming up to feed all through the night on the same zooplankton species preferred by kokanee, *Mysis* instead became a formidable competitor. Conservative estimates of the current abundance of *Mysis* in Okanagan Lake are in excess of 62 x 10^9 animals, or 1,250 metric tonnes. That biomass is equivalent to well over 6 x 10^6 catchable-size (200 g) kokanee! Recent surveys revealed that dramatic autumn declines of *Mysis* in Armstrong Arm of Okanagan Lake were associated with significant increases in cladocerans, which are preferred prey of both kokanee and *Mysis* (McEachern 1999*a*). This response indicates that mysids may be controlling the abundance of other plankters important to kokanee.

Unfortunately, the Okanagan Lake kokanee stocks also face a number of other problems aside from *Mysis*, which complicate recovery efforts. Some parallels perhaps can be drawn between the Okanagan situation and the modelling exercise of Nickelson and Lawson (1998) for Oregon coho. In the case of Oregon coho, populations in reaches with poor incubation/rearing habitats became extinct during periods of low marine (for Okanagan kokanee, substitute in-lake?) survival; their probability of persistence increased with habitat quality.

Factors in the Decline of Stream-Spawning Stocks

The majority of the problems facing Okanagan kokanee stream-spawning stocks are associated with escalating human development pressures, set in a water-scarce situation. Of the 46 named tributaries to Okanagan Lake, most have seasonally ephemeral flows, and only 17 are known to support Okanagan Lake salmonid stocks. Of those known salmonid-producing streams, only 9 are currently utilized by kokanee. Humans were also attracted to the few year-round streams in this semi-arid region. Major irrigation developments began in the early 1900s, with detrimental consequences for fish; by the 1950s, >90% of the historic spawning areas in the main valley tributaries had been lost (Galbraith and Taylor 1969). Low summer-autumn flows further restrict the fish production potential of the remaining habitat in most of the tributaries to about half of optimum (Wild Stone Resources 1992).

For Mission Creek, the largest tributary to Okanagan Lake and historically the major kokanee producer of the Okanagan Lake tributaries, the situation is even worse. Up to 1983, Mission Creek carried an average of 85% of the lake's total returns of stream spawners; since then, the contribution of this stream has dropped disproportionately to an average of just over 50% (and <25% in 1998) of the total stream spawner returns. A host of perturbations of human origin probably factor in this decline, including upstream forestry and agricultural practices. In the lower reaches, urban encroachment has choked and channelled the floodplain; the dyking and dredging associated with the flood protection program has detrimentally impacted spawning habitat by siltation, scouring and outright removal of gravel.

Factors in the Decline of Shore-Spawning Stocks

Shore spawners have also been impacted by increasing human activities along the foreshore. Construction of piers and boat launches, retaining walls, breakwaters, and sand traps can change wave energy patterns and cause siltation of spawning habitats. Fines and other contaminants can also find their way to the foreshore as a result of a variety of upland activities. It is likely no accident that the reaches of Okanagan Lake most heavily utilized by shore spawners in recent years are areas that remain relatively free of foreshore development. But shore spawner numbers are down even in pristine stretches. While much of this decline is blamed on *Mysis*, it is probable that drops in lake levels for flood protection purposes resulted in incubation losses of up to 50% in some years (Fig. 4; Shepherd and Sebastian 1998).

Other Factors in the Decline of Kokanee Stocks

In addition, there are other, larger forces at work in Okanagan Lake. A major program to control phosphorus discharges from sewage systems has operated in the Okanagan for almost 3 decades (Forty 1996), and levels of phosphorus declined steadily in Okanagan Lake from 1982 to 1994 (Bryan 1996). Decreasing nutrient loading would be expected to reduce the productive capacity of the lake for both *Mysis* and kokanee, and there are some indications that this is happening (Figs. 5 and 6; McEachern 1999*a*).

These in-lake declines have led some to suggest that a nutrient enrichment program should be considered for Okanagan Lake. Indeed, such a program has operated on Kootenay Lake for 6 years, with encouraging short-term boosts in kokanee production (Ashley et al. 1997). This strategy has not been pursued to date for Okanagan Lake, for at least 2 reasons. One reason is that the implementation of a nutrient addition program on the heels of major public investment in a long-term nutrient removal program obviously would appear to be inconsistent, and certainly is controversial from the socioeconomic perspective (Ashley and Shepherd 1996). A second and more technical concern is whether a nutrient enrichment program will work biologically in the longer term. While the results of the Kootenay fertilization experiment have favoured kokanee to date, it is pointed out that the total phosphorus target levels of 0.004–0.010 mg/L for Kootenay Lake (Ashley et al. 1997) are similar to or even less than the levels of total phosphorus presently in Okanagan Lake (McEachern 1999*b*), and spring total phosphorus levels have almost doubled in the 1995–98 period (V. Jensen, Pollution Prevention Branch, Penticton, unpubl. data.). Given that Okanagan Lake has kokanee productivity problems at these higher phosphorus levels, there is concern as to the long-term benefits of nutrient additions. However if kokanee numbers continue to drop, this may be a short-term approach worth considering to stave off extinction.

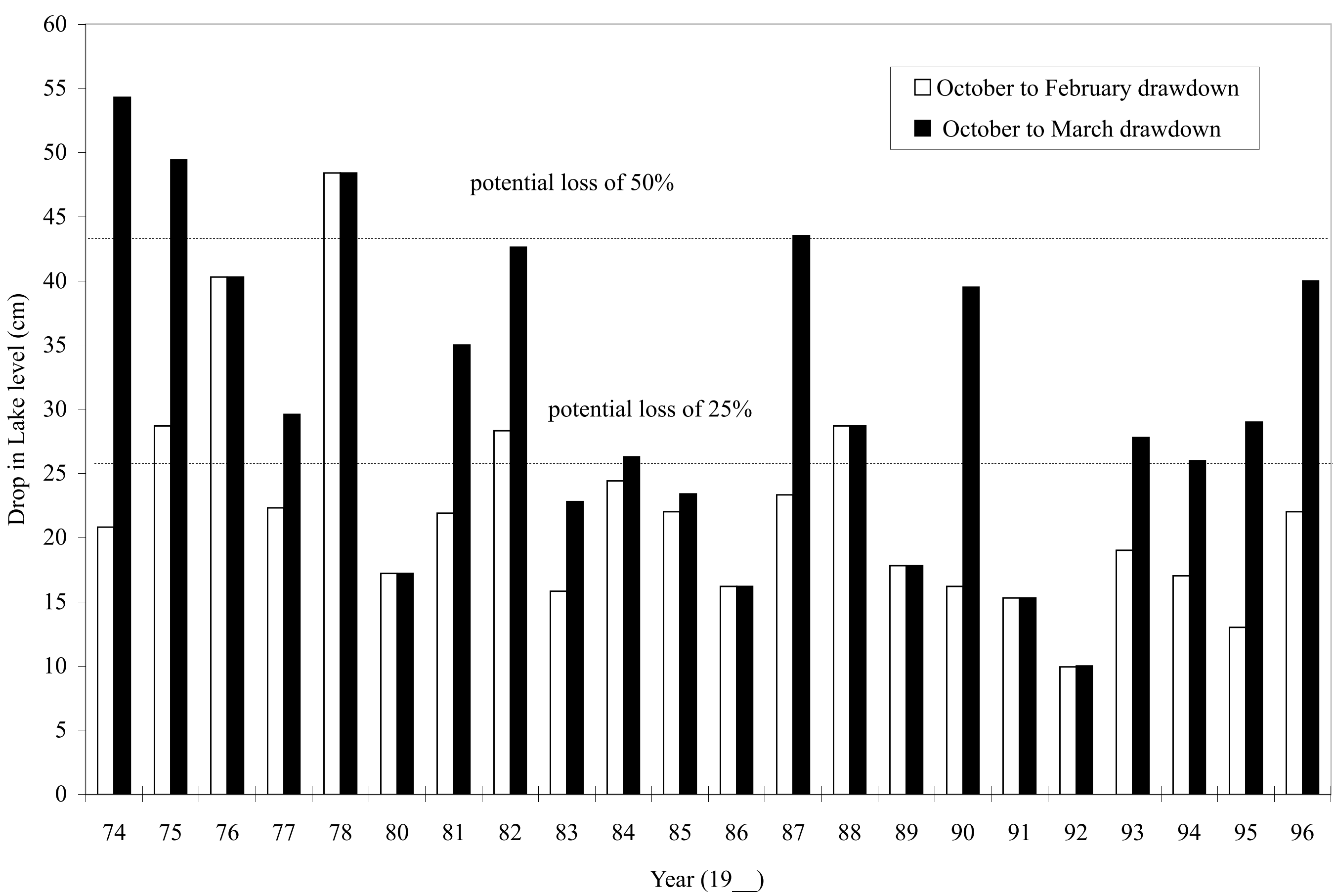

Figure 4. Predicted shore-spawning kokanee embryo losses due to drawdown of Okanagan Lake.

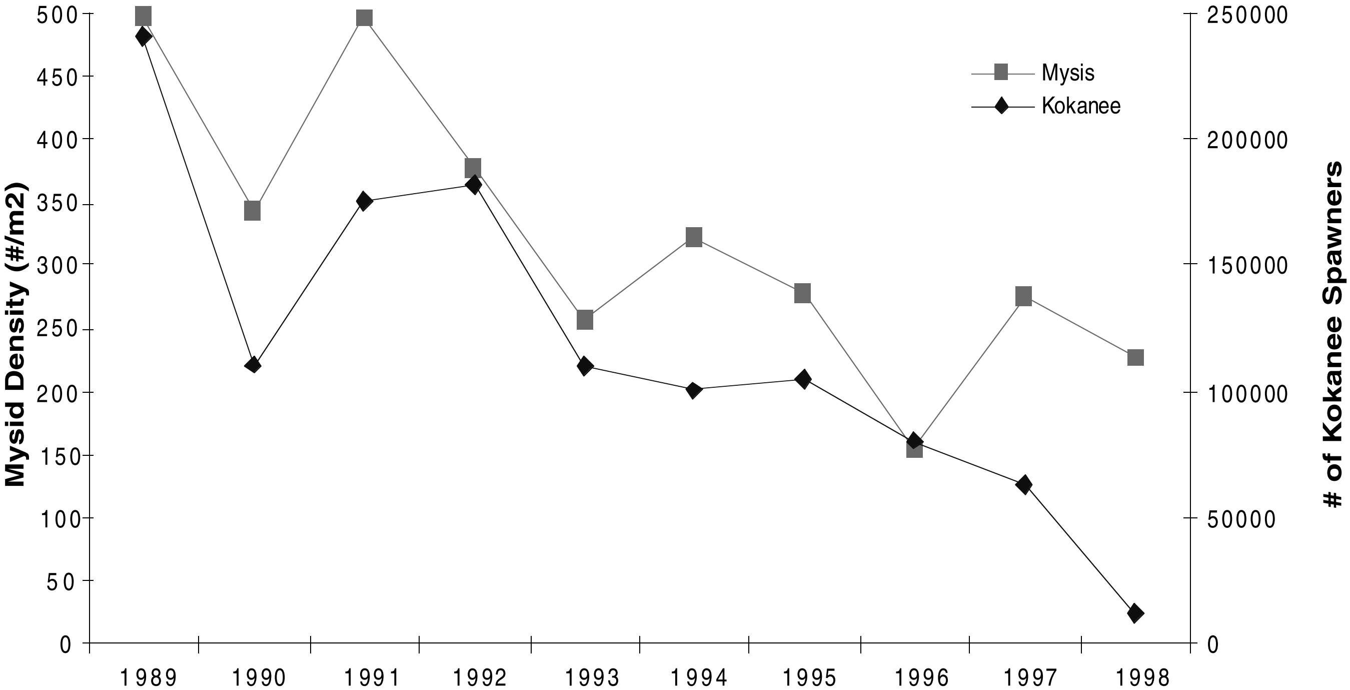

Figure 5. Trends in fall mysid abundance (vertical hauls) as compared with trends in numbers of kokanee spawners (fall counts) from 1989 through 1998, inclusive, in Okanagan Lake (from McEachern 1999*a*).

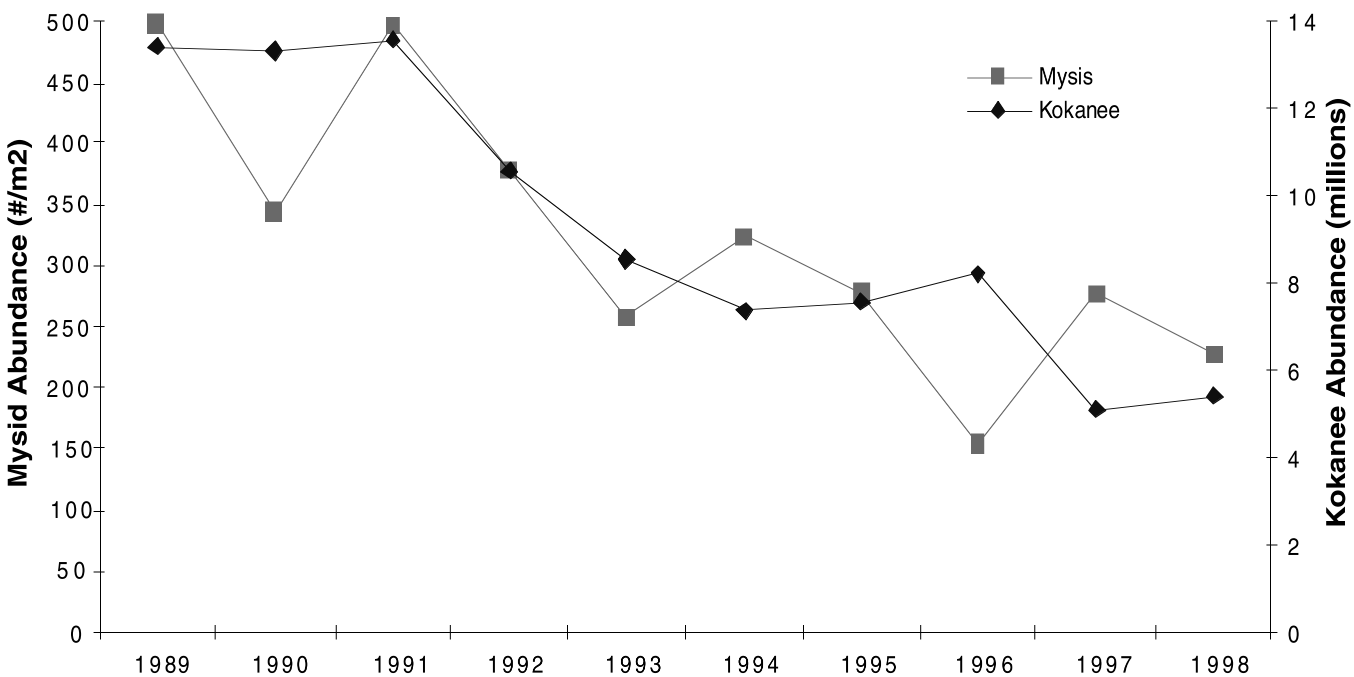

Figure 6. Trends in fall mysid abundance (vertical hauls) as compared with trends in kokanee abundance (hydroacoustic surveys) from 1989 through 1998, inclusive, in Okanagan Lake (from McEachern 1999*a*).

DEVELOPMENT OF THE OKANAGAN LAKE ACTION PLAN

In response to these declines, the British Columbia Ministry of Environment, Lands and Parks hosted an Okanagan Lake workshop in 1995, out of which developed a 20-year action plan to "rebuild and maintain the biodiversity of kokanee stocks (and other indigenous fish species) in Okanagan Lake" (Ashley and Shepherd 1996). The action plan was divided into 4 5-year phases, moving from conservation of remaining fish stocks and habitat, and collection of key information, through development and implementation of innovative resource management and restoration techniques. Action points identified for each phase were grouped into 6 general categories:

1. Priority Remedial Measures – actions to be undertaken as soon as possible to preserve the remaining kokanee stocks of Okanagan Lake.
2. Sustained Monitoring Program – aspects of Okanagan Lake ecology to be monitored on a regular and continuing basis in order to determine success or failure of initiatives.
3. Functional Studies – collection of data to fill critical information gaps leading to improved resource management.
4. Comparative Analyses – collection of information from other stocks, lakes, and time frames that by comparison may provide insights into the Okanagan Lake situation.
5. Large-scale Experiments – to explore the effects of various management options on the ecology of Okanagan Lake.
6. Long-term Applied Research – to examine feasibility of untested techniques that may offer significant benefits if successful.

Workshop participants agreed that some options should not be pursued at this time, including nutrient additions, hatchery stocking, and introductions of new species.

HIGHLIGHTS OF ACTION PLAN ACTIVITIES TO DATE

With the financial support of the Habitat Conservation Trust Fund, phase 1 of the action plan began in 1996, and will continue through to 2000. Many of the results discussed above were products of the phase 1 package. However for phase 1, emphasis was placed on: 1) the conservation of key fish habitats; and 2) the development of a practical means of *Mysis* control. Some highlights of the first 3 years work on Phase 1 include:

- improved database and understanding of the seasonal limnology (including *Mysis*) of Okanagan Lake, as well as Kalamalka and Wood lakes (adjacent "controls");
- better knowledge of kokanee shore spawner behaviour and habitat preferences;
- assessment of potential identification techniques for kokanee shore and stream stocks;
- production and distribution of fish habitat protection information packages to more than 5,000 water licensees and owners of waterfront properties, to encourage stewardship;
- increased profile and assistance of Fisheries staff in fish habitat protection cases;
- investigation into improving the rule curve used to draw down Okanagan Lake;
- feasibility of restoration of mainstem and off-channel habitats in Trout, Mission, Peachland and Trepanier creeks;
- assessment of sonic "thumpers" to selectively destroy *Mysis*, "bubble pumps" to entrain and loft *Mysis* into the upper water column, and pheromones to attract and trap *Mysis*;
- test fishing to evaluate feasibility and impacts of commercial harvest of *Mysis*.

IN CLOSING…

Humans continue to be attracted to the Okanagan, and development pressures are rising. Given these growing pressures, it will be a challenge to conserve both stream and foreshore habitats (especially those that are currently empty of fish due to other reasons) for the use of future fish. However, it is encouraging that many members of the public see the presence of kokanee as symbolic of ecosystem health, and an enhanced sense of public stewardship undoubtedly will be key in the perpetuation of Okanagan Lake kokanee stocks.

LITERATURE CITED

Ashley, K., and B. Shepherd. 1996. Okanagan Lake workshop report and action plan. B.C. Minist. Environ., Lands and Parks, Vancouver, BC. Fish. Proj. Rep. RD 45. Unpubl. rep. 120pp.

_____, L. C. Thompson, P. Warburton, Y-R. Yang, F. R. Pick, P. B. Hamilton, D. C. Lasenby, K. E. Smokorowski, L. McEachern, D. Sebastian, and G. Scholten. 1997. Kootenay Lake fertilization experiment: year 4 (1995/96) report. B.C. Minist. Environ., Lands and Parks, Fish. Branch, Vancouver, BC. Fish. Proj. Rep. RD 58. Unpubl. rep. 206pp.

British Columbia Fisheries Branch. 1996. Conserving our fish resources: 1996-2000 Fisheries Program strategic plan. B.C. Minist. Environ., Fish. Branch, Victoria, BC. 35pp.

Bryan, J. 1996. Review of Okanagan Lake physical and chemical limnology. Pp. 44–56 *in* K. Ashley, and B. Shepherd. Okanagan Lake workshop report and action plan. B.C. Minist. Environ., Lands and Parks, Vancouver, BC. Fish. Proj. Rep. RD 45. Unpubl. rep.

Dill, P. A. 1996. A study of shore-spawning kokanee salmon

(*Oncorhynchus nerka*) at Bertram Creek Park, Okanagan Lake, B.C., 1992 -1996. B.C. Minist. Environ., Penticton, BC. Unpubl. rep. 23pp.

Forty, T. 1996. Liquid waste management: the Okanagan experience. Pp. 71–81 *in* K. Ashley, and B. Shepherd. Okanagan Lake workshop report and action plan. B.C. Minist. Environ., Lands and Parks, Vancouver, BC. Fish. Proj. Rep. RD 45. Unpubl. rep.

Galbraith, D. M., and G. D. Taylor. 1969. Fish habitat survey: Okanagan tributary streams, 1969 [2 vols.]. B.C. Fish and Wildl. Branch, Victoria, BC. Unpubl. rep. 190pp.

McEachern, L. 1999*a*. Trends in abundance of *Mysis relicta* over the past decade in Okanagan Lake: implications of seasonal variation in Armstrong Arm. Draft for Okanagan Lake action plan year 3 (1998-99) report (in press). Unpubl. rep. 14pp.

_____. 1999*b*. Trends in physical and chemical limnology: seasonal variation in zooplankton communities of Okanagan Lake and Kalamalka Lake, 1996 through 1998. Draft for Okanagan Lake action plan year 3 (1998-99) report (in press). Unpubl. rep. 14pp.

McPhail, J. D., and R. Carveth. 1992. A foundation for conservation: the nature and origin of the freshwater fish fauna of British Columbia. B.C. Minist. Environ., Habitat Conserv. Fund, Dep. Zool., Univ. B.C., Vancouver, BC. Unpubl. rep. 39pp.

Nickelson, T. E., and P. W. Lawson. 1998. Population variability of coho salmon, *Oncorhynchus kisutch*, in Oregon coastal basins: application of a habitat-based life cycle model. Can. J. Fish. and Aquatic Sci. 55:2283–2392.

Shepherd, B. G. 1990. Okanagan Lake management plan 1990 - 1995. B.C. Minist. Environ., Lands and Parks, Penticton, BC. Unpubl. draft tech. rep. 87pp.

_____. 1996. Okanagan Lake fisheries concerns and management. Pp. 25–35 *in* K. Ashley, and B. Shepherd. Okanagan Lake workshop report and action plan. B.C. Minist. Environ., Lands and Parks, Vancouver, BC. Fish. Proj. Rep. RD 45. Unpubl. rep.

_____, and D. C. Sebastian. 1998. Investigation of the impacts of regulating water levels on Okanagan Lake kokanee shore-spawning stocks. Pp. 40–49 *in* Ashley et al. Okanagan Lake action plan, year 1 (1996-97) and year 2 (1997-98) report. B.C. Minist. Fish., Fish. Manage. Branch, Vancouver, BC. Fish. Proj. Rep. RD 73. Unpubl. rep.

Taylor, E. B., and S. Pollard. 1998. Divergence among populations of kokanee in Okanagan Lake. Pp. 290–307 *in* Ashley, K., B. Shepherd, D. Sebastian, L. Thompson, L. Vidmanic, P. Ward, H. A. Yassien, L. McEachern, R. Nordin, D. Lasenby, J. Quirt, J. D. Whall, P. Dill, E. Taylor, S. Pollard, C. Wong, J. den Dulk, and G. Scholten. Okanagan Lake action plan, year 1 (1996-97) and year 2 (1997-98) report. B.C. Minist. Fish., Fish. Manage. Branch, Vancouver, BC. Fish. Proj. Rep. RD 73. Unpubl. rep. 396pp.

Wild Stone Resources. 1992. Okanagan tributaries plan overview Pp. 1–10 *in* Okanagan Lake tributaries plan [7 vols.]. Planning and Assessment Branch, S. Inter. Region, B.C. Environ., Kamloops, BC. Unpubl. rep.