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Documentation of Unaccounted-for Losses of Chinook Salmon from Saltwater Cages

JOHN R. MORING

U.S. Fish and Wildlife Service
Maine Cooperative Fish and Wildlife Research Unit
Department of Zoology
University of Maine
Orono, Maine 04469, USA

Abstract.—"Shrinkage," or unaccounted-for losses of fish during cage rearing, is widely acknowledged among fish culturists who rear salmonid fishes, but the extent of such losses has not been documented. Over 60,000 chinook salmon (*Oncorhynchus tshawytscha*) were reared in floating cages at four locations in Puget Sound, Washington, and were hand-counted at the beginning and end of 200+ d of rearing. Average unexplained losses were 8–38% for individual locations (three to four cages each) and 2.5–46.5% for individual cages. When cage netting remains intact, unexplained losses are probably the result of decomposition of carcasses (particularly during disease outbreaks); scavenging by birds, mammals, and fishes; and to a lesser extent, escapes. The economic consequences of losing fish can be important in terms of lost harvest and increased food costs, resulting in true food conversions 10–68% higher than anticipated.

It is widely known among commercial fish culturists that when fishes are held within nets in a body of water, a certain portion of fish assumed to be in cages disappears. Though this unexplained loss of fishes has been recognized for decades (Institute of Fisheries Economics 1971; Kennedy 1975; Secretan 1979), it has never been accurately documented. Even today, commercial fish culturists continue to lose important numbers of salmonid fishes from cages in salt water, estimated to range from 10% to as much as 30% (Lindsay 1980; Coche 1983; Leet et al. 1986; Hansen et al. 1987; Mills 1988; C. Mahnken, National Marine Fisheries Service, personal communication). Such losses are generally not discovered until a cage is emptied at the time of harvest or grading. Accurate documentation of the extent of such losses and the relationship of such losses to feed conversion (weight of feed fed/weight gain by fish) and rearing densities has not been made.

Fish disappear even when there are no tears in the netting, the cages are covered, and daily inspections of cages are made. In a public or commercial operation, this loss can have economic importance—not only because of lost fish ("shrinkage") but also because food provided for these "phantom" fish often falls through the bottom netting and is wasted, such that assumed feeding rates and food conversions thus are both inflated.

I conducted a 2-year study of the rearing of chinook salmon (*Oncorhynchus tshawytscha*) in floating cages to address two questions: How important are unaccounted-for losses of cultured stock? and, How do actual food conversions compare with predicted conversions based on the actual fish fed and the fish assumed to be present and needing food? Although the study was conducted over a decade ago, no documentation of this type has been provided in the interim and this information has direct application to current salmonid cage operations.

Chinook salmon (Finch Creek stock) obtained from Hoodsport (Washington) State Fish Hatchery were held in cages at the Big Beef Creek Research Station and later transferred to floating cages at four sites in Puget Sound (three in 1971 and three in 1972): Clam Bay (central Sound), Squaxin Island (southern Sound), Big Beef Creek (a brackish-water pond near Hood Canal), and Friday Harbor (San Juan Islands).

Fish were reared in either three or four cages at each site in each year (total pens: 12 in 1971–1972 and 11 in 1972–1973). Cages were cubical, 2.4 m per side, with an effective rearing volume of 12.7 m^3/cage. Netting was 6.4-mm-square mesh, and cage shape was maintained with square 2.4-m frames of weighted polyvinyl choride. A net was placed over each cage to control bird predation. Cages used today in commercial operations are similar to those used in the study except that commercial cages are somewhat larger and have netting extending higher above the water line (0.7 m) to decrease predation by otters.

Chinook salmon were individually counted into cages at the beginning of the culture period (11–20 July 1971 and 22 May–8 June 1972); fish averaged 12.3–12.8 g in 1971 and 4.8–5.8 g in 1972. Fish were normally fed Oregon Moist Pellets four times a day at 1–4.5% of assumed fish biomass in the cages. Fish growth was monitored by biweekly sampling in spring through fall and monthly sampling in winter. Based on the samples, changes in feeding rates were made for all cages at all sites on the same days. Cages were inspected daily, and dead fish were removed. At termination of the study, remaining chinook salmon were again hand-counted.

Chinook salmon disappeared from every cage during the 214–260 d of rearing, even though there were no tears in the netting (Table 1). As might be expected, the proportion of unaccounted-for losses varied widely but nearly all losses were important. Average percentage losses by site were: Clam Bay, 17.5 in 1971–1972 and 37.9 in 1972–1973; Squaxin Island, 18.0 in 1971–1972 and 19.7 in 1972–1973; Big Beef Creek, 8.4 in 1971–1972; Friday Harbor, 28.7 in 1972–1973.

The initial number of chinook salmon stocked, minus known deaths, known escapement during biweekly or monthly sampling, and intentional removals was used to calculate the feeding rate for each cage. Because this net number included unexplained fish loss, actual food conversion was always higher than anticipated (Table 2). Food conversions were higher than those encountered in most hatchery and commercial situations, possibly due to our experimental design. Feeding rates were not adjusted for environmental conditions at each site but were adjusted at all sites by date in order to eliminate location as a variable; most fish culturists adjust feeding rates according to local conditions (e.g., water temperature). Similarly, the

TABLE 1.—Percentages of missing chinook salmon from floating cages at sites in Puget Sound, Washington, 1971-1973.

Season and site	Cage	Rearing period (d)	Number of fish: Original number	Number of fish: Unaccounted-for (%)
1971–1972				
Clam Bay	A-1	214	1,743	5.3
Clam Bay	A-2	214	1,743	19.2
Clam Bay	A-3	214	1,742	27.0
Clam Bay	A-4	214	1,737	20.7
Squaxin Island	9	246	1,728	5.1
Squaxin Island	10	246	1,732	2.5
Squaxin Island	11	246	1,729	17.1
Squaxin Island	12	246	1,737	46.5
Big Beef Creek	E-1	228	2,119	8.9
Big Beef Creek	E-2	228	2,117	8.5
Big Beef Creek	E-3	228	2,120	10.1
Big Beef Creek	E-4	228	2,120	7.2
1972–1973				
Clam Bay	A-1	256	3,747	37.7
Clam Bay	A-2	256	3,721	39.7
Clam Bay	A-3	256	3,721	31.8
Clam Bay	A-4	256	3,745	41.6
Squaxin Island	10	260	4,013	20.7
Squaxin Island	11	260	3,965	28.4
Squaxin Island	14	260	4,005	16.5
Squaxin Island	15	260	3,985	12.9
Friday Harbor	1	249	3,432	31.0
Friday Harbor	2	249	3,418	23.4
Friday Harbor	3	249	3,447	32.0

assumed rearing densities were always overestimated; actual densities were 1.5–7.6 kg/m^3 lower.

When fish disappear from a cage, escapement either through a hole in the netting or over the top of the cage is suspected. No holes were found in the netting (knotless 10.9-kg-test Ace netting, 6-mm mesh), and each cage extended out of the water 0.4 m and was covered with netting; thus, there was little opportunity for chinook salmon to escape.

Decomposition of dead chinook salmon is a likely contributing factor to unexplained losses. Cages were examined daily for dead fish, but decomposition sometimes is rapid. Carcasses can disappear from nets in less than a day, and some fish predators, such as spiny dogfish (*Squalus acanthias*), are known to prey on dead salmon through cage netting (C. Mahnken, National Marine Fisheries Service, personal communication). Such decomposition and predation can be high during outbreaks of vibriosis, and there is a relation between known losses to *Vibrio* outbreaks and unaccounted-for losses during rearing ($r = 0.52$; average losses to *Vibrio* at the sites I monitored

TABLE 2.—Assumed and actual food conversions and fish-rearing densities for chinook salmon in floating cages in Puget Sound, Washington, 1971–1973. Values are averages for four pens at each site, except for Friday Harbor, where three pens were used in 1972–1973.

Site	Food conversion			Rearing density (kg/m^3)		
	Assumed	Actual	Difference (%)	Assumed	Actual	Difference (%)
1971-1972						
Clam Bay	3.11	3.87	24	16.4	13.5	21
Squaxin Island	2.67	3.33	25	21.9	17.9	22
Big Beef Creek	2.66	2.92	10	18.4	16.9	9
1972-1973						
Clam Bay	2.40	4.03	68	21.5	13.9	55
Squaxin Island	2.23	2.85	28	33.0	26.2	26
Friday Harbor	2.88	3.98	38	16.4	12.3	33

were 1–3% in 1971–1972 and 11–19% in 1972–1973).

Although some species of small fish were occasionally encountered in pens, they have little effect as scavengers or as food items (Moring and Moring 1975). However, predators were known to play a role in the disappearance of fish. Birds attacked chinook salmon through the top netting and through the outside nets below the surface of two of the four pens in Clam Bay in January 1971. Although the overhead netting remained intact, when fish were individually examined at the time of release, 13 and 51% of the fish in the two pens showed scars from bird attacks, and 21 and 27%, respectively, of the fish in these two cages were missing compared to 5 and 19% in the two cages to which birds were not attracted. However, it was previously reported (Moring 1982) that when fish in the 21 cages without bird attacks are combined, bird scars were found on less than 0.2% of the 14,885 chinook salmon examined.

Other animals known to prey on salmonids in cages include gulls (Laridae), great blue herons (*Ardea herodias*), and otters (*Lutra* spp.). Otters occasionally were observed attacking chinook salmon in cages at the four sites. Otters and mink (*Mustela vison*) have attacked coho salmon (*Oncorhynchus kisutch*) in cages in British Columbia, Canada (Kennedy et al. 1975). Gray seals (*Halichoerus grypus*) have attacked caged Atlantic salmon (*Salmo salar*) in Maine. Currently, otters are the major predator of Pacific and Atlantic salmon at experimental and commercial cage sites in Clam Bay, despite the use of boards nailed around the perimeter of each cage and predator nets draped down the rails. Attacks by sea lions (*Eumetopias jubatus*) are rapidly increasing; these animals chew on netting beneath the surface to feed on fishes (Mahnken, personal communication). Other unlikely sources of losses are escapement of small fish through net meshes and intraspecies cannibalism. Despite a long history of commercial cage culture of salmonids in the USA, important unexplained losses continue to occur. The results of this study indicate that these losses can affect assumed rearing densities and food conversions. These losses appear to be a consequence of escapement, decomposition, and predation, particularly during outbreaks of disease.

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