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The Effectiveness of Semi-Natural Rearing of Coho Salmon (*Oncorhynchus kisutch*) at the Nitinat River Hatchery, British Columbia

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Abstract: We compared: 1) rearing mortality, 2) size at release (mean length), 3) jack, male and female sizes, and 4) jack, female, and adult returns of coho salmon (*Oncorhynchus kisutch*) from three consecutive brood years reared at the Nitinat River hatchery using a conventional or a semi-natural rearing method. The semi-natural method included feeding restrictions, shading of the rearing ponds, lower rearing temperature and rearing densities, exposure to a predator and a volitional release. We found no significant effects of brood year or rearing method on rearing mortality; it was significantly lower during the marking to release phase than during the other two phases (eyed-egg to ponding, ponding to marking). Conventionally reared smolts were significantly longer. Conventionally reared males were longer. As a proportion of number of smolts released, semi-natural rearing produced 86% fewer jacks, the same proportion of females and 15% more adults. Adult production trends, described as marine survival rate (returning adults • smolt^{-1}) for Nitinat River Hatchery coho, and as *ln* recruits • female spawner^{-1} for a nearby wild coho population, were similar. Jacking rates were lower in Nitinat River hatchery coho than for the nearby wild coho population. We concluded that the semi-natural rearing methodology produces adult fish more efficiently than the conventional rearing method does, and at 73% of the cost.

Keywords: Hatcheries, production, salmon, semi-natural rearing, survival.

INTRODUCTION

Semi-natural rearing is a strategy used to produce salmon smolts. The original intent was to use enhanced natural rearing areas to reduce the cost of smolt production [1]. Recently, semi-natural rearing has come to mean modifying existing hatchery facilities to provide a more natural rearing setting [2]. The goal is to increase adult return by producing a smolt that resembles more closely a wild one while minimizing negative interactions between wild and hatchery fish.

Considerable effort has been expended to explore the influence of facets of semi-natural rearing (natural food [e.g. 3], cover [e.g. 4], natural substrate [e.g. 5], exercise [e.g. 6], varying rearing period length [7] and predator avoidance training [e.g. 5, 8-10]) on the post-release survival of smolts [11]; most of this research is a product of the Natural Rearing Enhancement System research programme [12-14] of the American National Marine Fisheries Service. Most investigations tested the effect of semi-natural rearing in the hatchery setting [e.g. 3]. Studies that measured post-release survival showed mixed results for freshwater [no effect: 6, 8, 15; positive effect: 5, 10] or smolt-to-adult survival [negative effect: 16; no effect: 15, 17, 18; positive effect: 19] and on jacking rate [no effect: 17; lower for semi-naturally reared fish; 18 (based on our re-analysis of the data)].

Our study evaluated the effectiveness of a semi-natural rearing methodology for coho salmon (*Oncorhynchus kisutch*) at the Canadian Department of Fisheries and Oceans' Nitinat River hatchery, located on the southwest coast of Vancouver Island. Experimental groups were incubated at lower temperatures and densities in ponds with some shade, fed less, fed a natural marine diet (euphausiids), exposed to a predator (*O. clarkii*) and released volitionally at a smaller size. We tested the null hypotheses that there was no significant effect of rearing method on: 1) rearing mortality and 2) return of jacks and adults expressed as returns per smolt.

MATERIALS AND METHODOLOGY

Incubation/Rearing Conditions

All experiments were conducted at the Canadian Department of Fisheries and Oceans' Nitinat River Hatchery which is located on the southwest coast of Vancouver Island. Progeny originated from the same egg takes in each year. Incubation conditions are listed in Table **1**. They were consistent over brood years and only the incubation containers and temperatures differed between conventional and semi-naturally reared fish. Otolith thermal marking [20] was used to distinguish the rearing groups. Table **2** lists early rearing (from ponding to marking) conditions and Table **3** presents information including rearing density and water flows. Late rearing (from marking to release) conditions are listed in Table **4**. Conventionally reared fish were moved to early rearing conditions sooner because the eggs incubated in warmer water; consequently photoperiod and time spent under early and late rearing conditions differed between treatment groups. As shown in Tables **2** and **4**, fish were fed at rates to reach a target size at release; the targets were 20 g

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for conventionally reared fish, which is typical, and 10 g for semi-naturally reared fish, which is the maximum observed size of wild smolts. Semi-naturally reared fish were held in ponds which were shaded to some extent, fed less and released volitionally at a smaller size. Semi-naturally and conventionally reared fish were exposed to river water as of October and March respectively. Semi-natural fish were presented with euphausiids as prey during the last three weeks of rearing; euphausiids were introduced in a subsurface jet of well water. Final rearing densities ranged between 2 and 3.5 times greater for conventionally reared fish and these fish were between 1.6 and 2.3 times heavier at release. Fish were released simultaneously but semi-naturally reared fish left volitionally.

Table 1. Incubation conditions for all brood years of coho reared conventionally or semi-naturally at the Nitinat River Hatchery.

Smolt Type	
Conventional	**Semi-Natural**
First incubation (pre-eyed)	
All Females screened for BKD with eggs from each female kept in separate trays	
Marked (hatchery) and unmarked (wild) adults mixed at 1:1 sex ratio	
All eggs surface disinfected	
Ground water used for incubation	
Second incubation (post-eyed)	
All eggs pooled by screen result	
Low positive and negative eggs used for 2002. Negative screened eggs used for all 2003, 2004.	
Incubated in 31.5 x 39.0 x 5.5 cm deep plastic Heath trays with no substrate	90 x 109 x 55 cm deep aluminum boxes with a 12 gauge aluminum 2.4 mm mesh upwelling screen; alevins contained in 15 cm deep plastic saddles
Temperature profile	
Groundwater (7.5° C)	Chilled (3.2° C) and re-circulated groundwater

Fish Sampling

Yearlings were sampled in May before release. A subsample was collected using a dipnet from the conventional or semi-natural rearing pond. Total length (mm) and total mass (g) were measured for between 100 and 199 yearlings for each brood year x rearing method category.

Jacks and adults were sampled when they returned to the hatchery. Jacks were identified by length because, based on historic returns, jacks are always at least 10 cm shorter than mature males and there are no jills. All fish returning to the hatchery were counted and sexed, and subsamples of fin-clipped fish were collected for otolith analysis. Subsampling was at the rate of 20% of the daily return so that collections were distributed over the return migration. The sub-sampling strategy was to collect otoliths from 150 jacks and 250 adults. Total length (mm) and sex were recorded for each fish in a subsample.

Table 2. Early rearing (ponding to marking) methods for all brood years of coho reared conventionally or semi-naturally at the Nitinat River Hatchery. BWD – body weight per day.

Rearing Condition	Fry type	
	Conventional	**Semi-Natural**
Container type	6.92 x 1.51 x 1.22 m deep outdoor aluminum troughs with baffles	2.20 x 1.90 x 0.35 m deep indoor concrete raceways
Ponding	Trays carried to troughs	Fry moved volitionally to concrete raceways
Feeding	Moore Clark "NUTRA"; Fed 1.8 % BWD to 1.5 grams then reduced to 1% BWD to slow growth	Moore Clark "NUTRA"; Fed 1.8% BWD to 0.6 gram then reduced to 1% BWD to slow growth
Marking	Fin-clipped	
Photo-period	Differed as a consequence of earlier metamorphosis (45 – 60 days) of conventionally reared fish	

Statistical Analyses

We tried to use analyses of variance (ANOVA) to test the significance of the effects of brood year and rearing method on rearing mortality, pre-release length, and returning length. A three-way ANOVA without replication was used to test for significant effects of brood year, rearing method and rearing phase on rearing mortality. The tests for effects on size were to be factorial analyses and include all simple and higher-order interactions when possible. Tukey's HSD test would be used to identify which least squares means differed significantly for all ANOVA's. We examined the studentized residuals and leverage coefficients to test for outliers before accepting the results of the tests. Statistically significant outliers were defined as data where the studentized residuals| were greater than 2.5 and the leverage coefficients were greater than 4 divided by the sample size [21]. Studentized residuals for the analysis of the effects of brood year, rearing method, sex and all possible interactions on adult length were not normally distributed before or after log-transforming length. We were able to test the effects of brood year and rearing method on returning female size using a two-way analysis of variance without replication. However, there was no instance when un-transformed or log-transformed male lengths, and one- or two-way analyses of variance, generated normally distributed studentized residuals. Therefore, we used the Kruskal-Wallis test, accompanied by the Steel-Dwass method for non-parametric all-pairs comparisons of maximum rank sums, to evaluate the effect of brood year on male length, and the Wilcoxon test to evaluate the effect of rearing method on length. The Kruskal-Wallis test was also used to compare ranks of marine survival rate and *ln* recruits•female spawner^{-1}, blocked by return year.

Table 3. Rearing densities, water flow, rearing periods and release characteristics for all brood years of coho reared conventionally or semi-naturally at the Nitinat River Hatchery.

Factor	Brood Year					
	2002		2003		2004	
	Conventional	Semi-natural	Conventional	Semi-natural	Conventional	Semi-natural
No. fry Ponded	249,271	123,734	175,475	115,090	112,999	112,339
Max. early rearing flows ($kg \bullet l^{-1} \bullet min^{-1}$)	0.5	0.1 – 0.3	0.5	0.1 – 0.3	0.5	0.1 – 0.3
Max. early rearing density ($kg \bullet m^{-3}$)	14	6.5	12	6	12	6
Early rearing period (D/M)	12/02 to 02/06	08/04 to 11-18/08	28/01 to 02/05	10/04 to 12-17/08	24/01 to 07/06	30/03 to 27/06-08/07
Max. final rearing flows ($kg \bullet l^{-1} \bullet min^{-1}$)	0.5					
Max. final rearing density ($kg \bullet m^{-3}$)	7	2	12	6	12	6
Late rearing period (D/M/Y)	02/06/03 to 05/05/04	11-18/08/03 to 09/05/04	02/05/04 to 04/05/05	12-17/08/04 to 04/05/05	07/06/05 to 08/05/06	12-17/08/05 to 09/05/06
No. smolts released	220,000	101,726	172,214	97,387	94,663	99,486
Mean release mass (g)	21	9.1	15.4	9.8	15.1	7.7
Release dates (D/M)	05/05	09/05	04/05	04/05	05/05	05/05
Release conditions	Fish flushed into a channel which was transitional to the river	Hatchery water level reduced and fish left volitionally over five days	Fish flushed into a channel which was transitional to the river	Hatchery water level reduced and fish left volitionally over five days	Fish flushed into a channel which was transitional to the river	Hatchery water level reduced and fish left volitionally over five days

Table 4. Late rearing (marking to release) methods for all brood years of coho reared conventionally or semi-naturally at the Nitinat River Hatchery.

Condition	Smolt Type	
	Conventional	**Semi-Natural**
Container type	80.5 x 3 m increasing to 5 x 0.8 m deep plastic-lined dugout pond	
Ponding	Piped from marking room to final rearing room	
Feeding and growth	• Food (Moore Clark" Nutra") modulated to produce 20-22 g smolts at release; ration of 1.8% BWD with feeding frequency decreasing in fall and winter to weekly and increasing in spring to daily at 1.8% BWD	• Food (Moore Clark" Nutra") modulated to produce 9-10 g smolts at release; ration of 1.8% BWD with feeding frequency decreasing in fall and winter to weekly and increasing in spring to daily at 1.8% BWD
		• "BUG LIGHT" added to pond to introduce insects
		• Euphausiids introduced during last three weeks of rearing in a subsurface jet of well water
Water	Ground water until March and then river water	Ground water until October and then river water
Predators	Kingfishers	Kingfishers, cutthroat trout
Habitat enhancement	None	Shade cloth that blocked 80% of the light covering 40% of the ponds

The Cochran-Mantel-Haenszel test was used to evaluate if the proportions of returning jacks, females or adults were independent of rearing method over the three brood years. Exploitation rates during the study period were estimated as 5% (C. Lynch, DFO, Vancouver, B. C., *pers. comm*.) so we accepted the number of fish returning to the hatchery as total return. The statistics that we used in the analyses were number of fish returning and number of fish released.

RESULTS

Rearing/Pre-Release

We found that there was no significant effect of rearing method on incubation mortality and that conventionally reared fish were longer. Rearing mortalities by brood year, period and rearing method are presented in Table **5**. Mortality did not differ significantly over brood years, or

Table 5. Rearing mortality (proportion) of coho reared conventionally or semi-naturally at the Nitinat River Hatchery by brood year, rearing method and rearing period. EP – eyed egg to ponding, PM – ponding to marking, MR – marking to release.

	Rearing Methodology					
	Conventional			Semi-Natural		
	Rearing Period			Rearing Period		
Brood year	EP	PM	MR	EP	PM	MR
2002	0.033	0.038	0.008	0.023	0.035	0.007
2003	0.084	0.028	0.019	0.074	0.036	0.005
2004	0.047	0.09	0.026	0.05	0.05	0.019

between rearing methods, but it was significantly lower (p=0.0056) during the Marking to Release rearing period. Pre-release length of conventionally reared fish (least squares mean length=116 mm) was significantly (p=1.8e-170) greater than for semi-naturally reared fish (least squares mean length=91 mm).

Returns

There was a significant effect of brood year on jack length, significant effects of brood year and rearing method on the length of males, and a significant effect of brood year on the length of returning females (Table **6**). Median jack length was affected significantly (p=7.28e-6) by brood year; it was lower in 2005 (least squares mean=259 mm) than in 2004 (least squares mean=286 mm) and 2006 (least square mean=288 mm). Males were significantly (p=9e-10) smaller in the 2007 return year (median length=481 mm) than in 2005 (median length=530 mm) and 2006 (median length=520 mm). Male coho originating from conventional rearing were significantly (p=0.0035) longer (median length=515 mm) than semi-naturally reared males (median length=494 mm). There was a significant effect (p=9.11e-51) of brood year on female length; least squares mean lengths differed significantly among all return years (560 mm in 2005, 588 mm in 2006, and 513 mm in 2007).

Jack production was significantly lower, female production the same, and adult production significantly greater for semi-naturally reared fish (Table **7**). Based on odds ratios, jack production for semi-naturally reared fish was 14% (p=3.92e-63) of that for conventionally reared ones, female production was equal (105%) and adult return was 15% greater (p=4.30e-39).

Fig. (**1**) shows that variations in marine survival rates for the Hatchery fish, estimated as the proportion of smolts returning as adults, were comparable to changes in *ln* recruits•female spawner^{-1} (S. Baillie, Fisheries and Oceans Canada, Nanaimo, B. C. *pers. comm.*) for coho from Carnation Creek, located about 50 km from the Hatchery. There was no significant difference (p=0.67) in rank sums of marine survival rate and *ln* recruits per female spawner blocked by brood year.

Fig. (**2**) shows that jacking rate, estimated as the proportion of jacks to jack and adult return for a given brood year, were lower than those for Carnation Creek fish (S. Baillie, Fisheries and Oceans Canada, Nanaimo, B. C. *pers. comm.*). Semi-natural and conventional rearing produced 0.008 (p=0) and 0.07 (p=0) the proportion jacks that Carnation Creek wild coho did for the 2002-04 brood years.

DISCUSSION

The results of our study show that the semi-natural rearing methodology generates a significantly greater return of adult fish than conventional rearing does and we found no significant effects of rearing conditions on pre-release survival. Only one study [16] reported a negative effect of semi-natural rearing on smolt-to-adult survival, and it appears that

Table 6. Median length of returning fish reared conventionally or semi-naturally at the Nitinat River Hatchery.

Brood Year	Source	Median Length (mm)		
		Jack	Male	Female
2002	Conventional	290	520	555
2002	Semi-natural	285	534	562
2003	Conventional	260	530	590
2003	Semi-natural	240	500	580
2004	Conventional	295	487	521
2004	Semi-natural	286	474	474

Table 7. Number of returning conventionally or semi-naturally reared coho sampled at the Nitinat River Hatchery by brood year, maturity and sex. Number of fish is estimated as $n_{sampled}$ • sampling rate^{-1}.

Brood year	Source	n			Sampling rate		Number of fish		
		Jack	Male	Female	Jack	Adult	Jacks	Males	Females
2002	Conventional	157	71	50	0.28	0.02	560	3550	2500
2002	Semi-natural	7	43	26	0.28	0.02	25	2150	1300
2003	Conventional	43	84	82	0.72	0.57	60	147	144
2003	Semi-natural	5	69	70	0.72	0.57	7	121	123
2004	Conventional	55	113	115	0.44	0.22	125	514	523
2004	Semi-natural	14	196	136	0.44	0.22	32	891	618

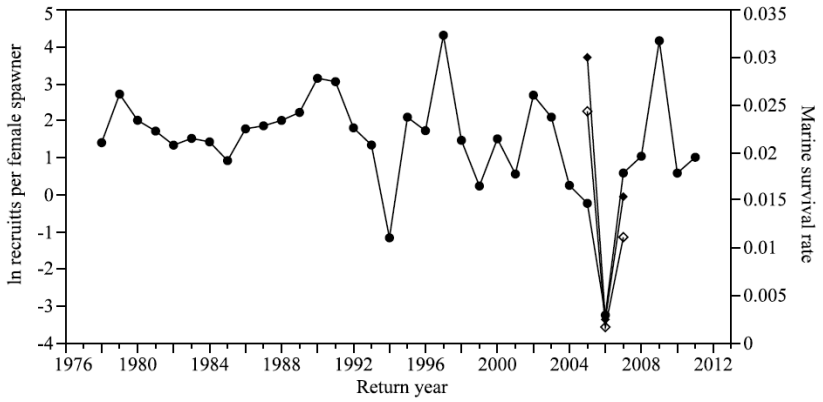

Fig (1). Comparison of marine survival rates (adult return • smolt^{-1}) for Nitinat River Hatchery conventionally (open diamond) and semi-naturally (filled diamond) reared coho and *ln* recruits per female spawner (filled circle) for Carnation Creek wild coho.

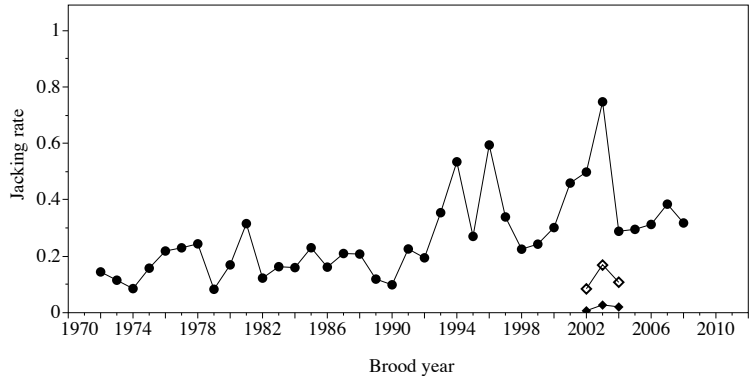

Fig (2). Time series of jacking rates for conventionally (open diamond) and semi-naturally (filled diamond) reared Nitinat River Hatchery coho and for Carnation Creek wild coho (filled circle).

semi-natural rearing provides an option to at least maintain or, in the case of this report, improve adult production, and at a lower cost. It is important to note that testing of the effectiveness of hatchery augmentation has to be comprehensive and consider marine influences as well. It is conceivable that the poor survival rate for the 2003 brood year could have been attributed to a unique aspect of the rearing methodology for those fish. However, the synchronous dramatic decline in *ln* recruits•female spawner^{-1} for Carnation Creek coho suggests that the poor return was likely a consequence of a common marine effect. (R. Tanasichuk (*unpubl. res.*) found in an analysis that included early marine prey, competitor and predator abundances, that most of the variation (74%) in *ln* recruits • female spawner^{-1} for Carnation Creek coho is accounted for by female parental abundance; the observation for the 2003 brood year was a significant outlier to the regression). It is also noteworthy that the variations in survival rate for the hatchery fish vary comparably with adult production for Carnation Creek coho; this suggests that Nitinat River Hatchery coho are not at a survival disadvantage.

A number of authors [2, 17, 18] have noted that the benefits of semi-natural rearing do not offset the loss in adult yield as a consequence of lower rearing density; however, we suggest there are important positive implications of the

semi-natural rearing method for production and enhancement hatcheries. For production hatcheries, the benefit is a reduction in the cost of producing an adult fish [see 2], and it appears that rudimentary changes to the rearing facilities could offset the loss of production resulting from lower rearing densities. We calculated that the cost of semi-natural smolt production are 73% of the cost of smolt production using conventional rearing methods (Table **8**). The positive implication for enhancement strategy would be producing a smolt that would be similar phenotypically to a wild fish.

Table 8. Cost comparison ($) for raising 100,000 fry.

Allocated Costs	Rearing Method	
	Production	Semi-Natural
	Fish Food	
Commercial Pellets	4256.48	2423.48
Krill	0.00	500.00
	Water Pumping	
Incubation	3470.69	1785.89
River water rearing	1275.26	1233.79
Chiller	0.00	497.66
Shade cloth	0.00	167.00
Sum	9002.43	6607.82

CONCLUSIONS

We found that semi-natural rearing strategies generate more adult production than conventional rearing at about 73% the cost. Our results emphasize the importance of considering marine effects when evaluating the efficacy of hatchery enhancement experiments. Finally, semi-natural rearing appears to have the potential to create community-based salmon enhancement opportunities as eluded to in [18].

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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