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Chapter 17

Delayed Release of Salmon

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INTRODUCTION

The customary time of release for cultured fish from most salmon hatcheries is about the time when wild stocks in the watershed reach the peak of their seaward migration; the exact time of release may vary due to floods, siltation, elevated temperatures, uncontrollable diseases, and even economic problems. It was essentially a need to respond to the declining sports angler harvest in the inner Puget Sound, Washington that led to the development of delayed salmon releases; that is, extending the artificial rearing periods beyond the time of normal release or migration.

The saltwater catch of salmon by the sport fishery in Puget Sound, Washington (Fig. 1) reached a peak in 1957, when anglers harvested 208 000 chinook salmon *(Oncorhynchus tshawytscha)* and 220 000 coho salmon *(O. kisutch)*. Within 12 years, the catch of chinook declined to a quarter of the 1957 peak and coho, to an eighth. This decline occurred despite increased hatchery production, increased numbers of adult fish returning to the hatcheries, and a relatively constant angling pressure. Extensive marking studies in 1967-69 showed that Puget Sound hatchery coho released at the normal time migrated northward and westward into Canadian waters, where commercial trollers caught 10 times more fish west of Vancouver Island (Canada) than anglers did in

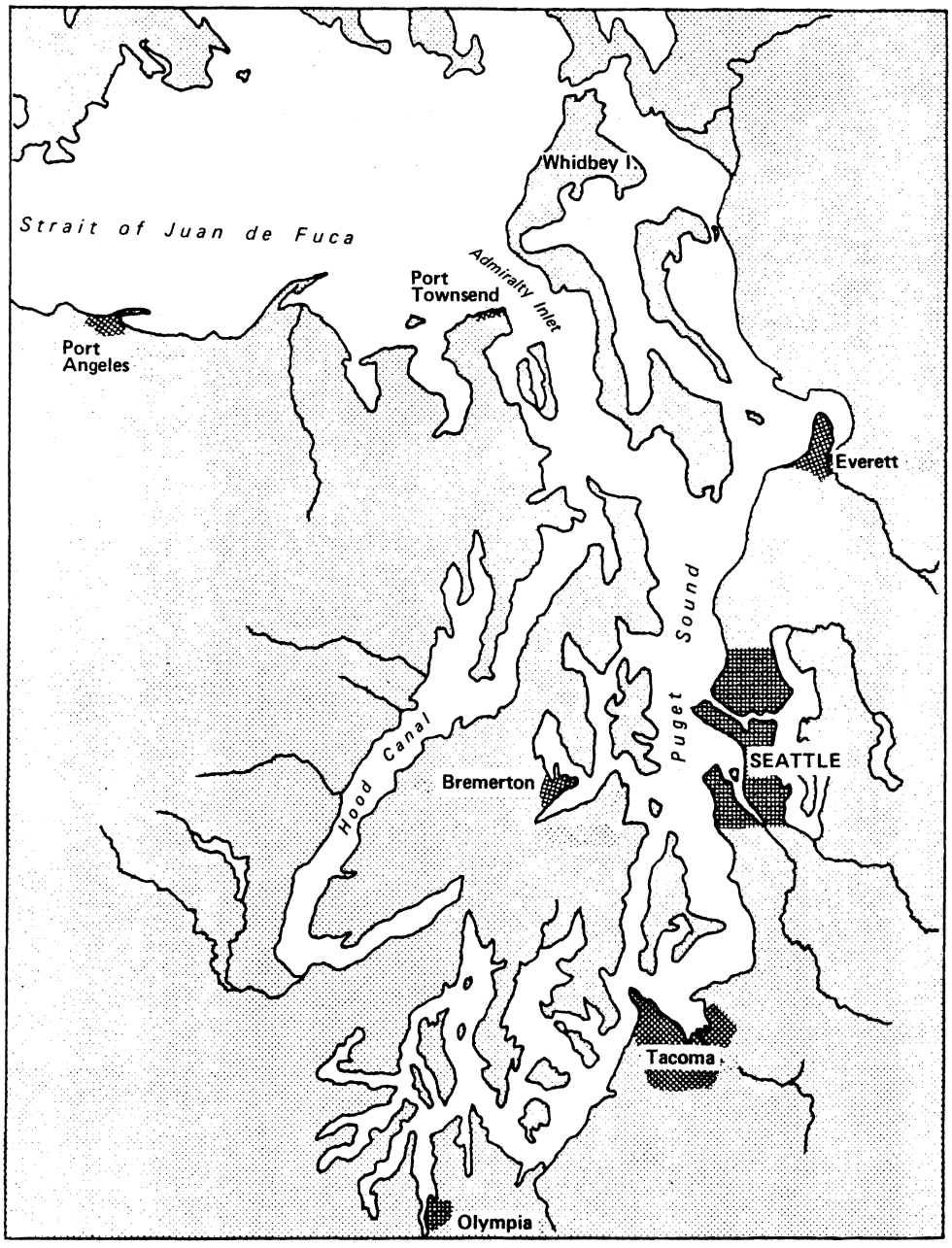
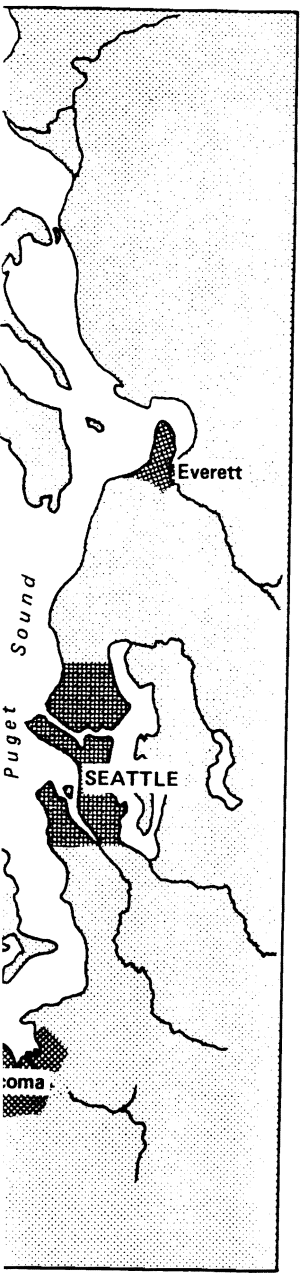


Fig. 1. Region of the most concentrated delayed release programmes in Washington State.



ase programmes in

Puget Sound. Moreover, because hatchery coho were reluctant to feed in Puget Sound as adults, the harvests there were almost entirely by commerical net fisheries. In fact, many coho caught by anglers were taken as immature fish (an accepted management practice in Puget Sound) and were determined to be resident fish, primarily from local wild stocks.

Biologists with the Oregon Department of Fish and Wildlife conducted a controlled growth experiment and found that by simultaneously releasing coho averaging 17 g and 45 g, the latter would contribute at twice the rate of the smaller fish to the coastal fisheries (Johnson, 1970). Washington State Department of Fisheries (WDF) chose to rear coho salmon for an extended time to achieve a greater size at release, rather than control growth or grade out larger fish (Hager and Noble, 1976). In 1971, 57 g coho salmon released from Minter Creek Hatchery contributed 60 times as many fish to the Puget Sound salmon sport fishery as did 23 g coho salmon from a normal April release (Washington State Department of Fisheries, 1971).

Since that pioneering effort, delayed-release studies, sometimes referred to as extended rearing studies, have been applied to other species of Pacific salmon and trout. Their objectives include: altering oceanic migration routes, increasing marine survival, increasing contributions to certain types of fisheries, creating new fishing areas by altering migration routes, and imprinting to new "homing stations". In this chapter, techniques of delaying releases and imprinting salmon and trout are described and a number of studies discussed.

TECHNIQUES EMPLOYED IN DELAYING RELEASES

Freshwater Releases

Extended Fry Rearing

Most delayed release programmes in freshwater concern seaward migrating fish, but National Marine Fisheries Service (NMFS) biologists in Alaska conducted extended rearing experiments with sockeye salmon *(O. nerka)* fry to enhance survival to the migrant smolt stage in Auke Lake, Alaska. The sockeye salmon are normally released as unfed fry. In 1974, however, 11% of the cultured fry released into the lake at 0·38 g smolted at age 1+ and 2% more at age 2+. This

quadrupled the total number of seaward migrants (at age 1 + and 2 +) that survived from hatchery plants (Northwest Fisheries Center *Monthly Report,* July 1976).

Wild chum salmon *(O. keta)* and pink salmon *(O. gorbuscha)* migrate to the sea in the spring as fry, shortly after emergence from the gravel. Hatchery programmes of WDF for pink salmon include freshwater rearing to 1 to 2 g prior to release. Some Japanese hatcheries practise a form of extended rearing of pink fry by ponding and feeding but allowing the fish to migrate freely at any time (Moberly and Lium, 1977). In WDF hatcheries, chum salmon fry are reared to 1·5 g before release, whereas in Japan they delay release until there is a combination of preferred stream and estuarine temperatures as well as a spring plankton bloom in the estuaries (Mathews and Senn, 1975). As prolonged freshwater rearing of chum and pink salmon may reduce oceanic survival, extended rearing must be manipulated carefully to maximise the returns to the fisheries and hatcheries.

Delayed Release of Fall Chinook Salmon

Recoveries. On the Pacific coast of North America, fall chinook salmon are normally released from hatcheries at 3-10 g in their first spring (age 0), which coincides with the early May to mid-June migration of most wild stocks. Size of fall chinook at release affects survival: 0·18% of Washington State's 1971 brood Puget Sound hatchery fall chinook released at 5 g returned to the release sites, whereas 1·5% of the University of Washington hatchery fall chinook released into Puget Sound at 11 g returned to the hatchery.* Differences in diets, environment, disease, genetic stock, and husbandry techniques can influence size at release but, in general, delayed-release fish are larger than average. The most extensive data available for the delayed release of fall chinook salmon from freshwater hatcheries are for the 1971 and 1972 brood years in Washington State, the first years of wide use of the coded-wire tag (Tables I and II; Figs 1 and 2).† The release sites range from northern to southern Puget Sound, and no general rule applies for all results. For example, yearlings released at

*Stephen B. Mathews, Associate Professor, College of Fisheries, University of Washington (Seattle). Data presented at June 23, 1977 meeting of the American Salmon Growers Association.

†Most hatchery reared fall chinook salmon in Washington State return as 3, 4, or 5-year old adults.

Table I. Survival and geographic distributions of 1971 brood normal and delayed release fall chinook salmon from Washington State Department of Fisheries hatcheries in Puget Sound, Washington. The data are summarised as percentages estimated from coded-wire tag recoveries in all fisheries sampled. Estimates of sport fishery recoveries in Puget Sound are indicated in ( ). (Data from Washington State Department of Fisheries.)

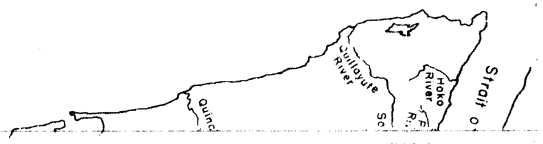
Stock no.	Release site	Stock origin	No. of rearing days	Average weight at release (g)	Date released	No. of tagged fish released	Total recovery[a] (%)	Distributions (%) Alaska	British Columbia	Washington coast	Puget Sound	Oregon coast	Columbia River	Escapement
1-1	Skagit R.	Green R. X	124[b]	3·3	15/6/72	97 117	0·16	0·0	37·3	7·0	50·0(13·3)	0·0	0·0	5·7
1-2	Skagit R.	Skagit R.	149	4·5	11/7/72	66 486	0·10	0·0	29·8	0·0	55·2(3·0)	0·0	0·0	14·9
1-3	Skagit R.	Skagit R.	198	16·2	29/8/72	47 549	0·25	0·0	31·7	2·5	58·3(10·8)	0·0	0·0	7·5
1-4	Skagit R.	Skagit R.	298	34·9	7/12/72	39 622	0·99	0·5	14·7	5·6	72·3(48·2)	0·0	0·0	6·9
1-5	Skagit R.	Skagit R.	425	82·5	11/4/73	37 100	3·04	0·0	30·6	3·7	56·5(29·0)	7·1	0·7	1·3
1-6	Skagit R.	Skagit R.	441	75·7	1/5/73	28 624	5·62	0·0	19·6	3·5	65·5(58·7)	0·0	0·0	11·4
1-7	Minter Ck.	Minter Ck.	386	64·9	12/3/73	20 698	6·55	0·0	3·3	2·7	90·8(75·2)	0·0	0·6	2·7
1-8	Green R.	Green R.	100[b]	4·6	19/5/72	70 749	0·31	0·0	38·9	5·0	43·9(12·2)	0·0	0·0	12·2
1-9	Green R.	Green R.	125	8·4	22/6/72	64 137	0·46	0·0	36·3	3·4	38·4(9·9)	0·0	0·0	21·9
1-10	Green R.	Green R.	302	32·4	15/12/72	28 882	0·03	62·5	0·0	0·0	37·5(0·9)	0·0	0·0	0·0[d]
1-11	Nooksack R.	Nooksack R.	112[b]	4·2	18/5/72	69 806	1·26	0·2	61·5	9·9	24·6(14·6)	1·6	0·0	2·3
1-12	Nooksack R.	Nooksack R.	141	8·3	16/6/72	52 113	6·13	0·0	38·1	5·6	54·7(11·0)	0·0	0·0	1·6
1-13	Nooksack R.	Nooksack R.	182	15·1	27/7/72	31 361	5·44	0·0	34·7	8·0	55·1(8·8)	0·6	0·0	1·8
1-14	Nooksack R.	Nooksack R.	235	30·3	18/9/72	27 501	1·09	0·0	37·1	1·3	56·5(10·0)	1·3	0·0	3·7
1-15	Nooksack R.	Nooksack R.	440	90·8	11/4/73	18 092	6·77	0·0	26·2	1·5	71·6(31·8)	0·2	0·0	0·5
1-16	Capitol L.	Deschutes R.	125[b]	7·0	5/6/72	76 392	0·62	0·0	23·8	11·3	38·6(17·0)	0·0	0·0	26·3
1-17	Capitol L.	Satsop R. X	182	15·1	17/8/72	27 965	1·18	0·0	23·6	5·8	52·1(28·8)	0·0	0·0	18·5
1-18	Eld Inlet[c]	Deschutes R.	195	22·7	30/8/72	19 000	0·71	0·0	65·9	5·2	24·4(20·0)	0·0	0·0	4·4

[a]Estimated from coded-wire tag recoveries in all fisheries sampled in the Pacific Northwest (including Canada and Alaska) plus escapement.
[b]Normal rearing time and release for fall chinook salmon for that hatchery.
[c]Saltwater release site.
[d]There were only eight estimated recoveries from this release.

Table II. Survival and geographic distribution of 1971 brood normal and delayed release fall chinook salmon from Washington State Department of Fisheries (WDF) hatcheries in the Hood Canal-Juan de Fuca (Washington) region. The data are summarised as percentages estimated from coded-wire tag recoveries in all fisheries sampled. Estimates of sport fishery recoveries in Puget Sound are indicated in ( ). (Data from Washington State Department of Fisheries.)

Stock no.	Release site	Stock origin	No. of rearing days	Average weight at release (g)	Date released	No. of tagged fish released	Total recovery[a] (%)	Distributions (%)						
								Alaska	British Columbia	Washington coast	Puget Sound	Oregon coast	Columbia River	Escapement
2-1	Dungeness River	Elwha R.	442	64·9	19/4/73	37 513	0·16	1·7	26·0	4·0	62·8(61·4)	0·6	0·0	4·8
2-2	Hood Canal[c]	Hood Canal	97[b]	3·1	9/5/72	82 757	0·23	0·0	33·7	4·7	50·6(7·4)	0·0	0·0	11·0
2-3	Hood Canal	Hood Canal	91[b]	3·6	23/5/72	46 976	0·13	0·0	52·4	11·1	31·7(11·1)	0·0	0·0	4·8
2-4	Hood Canal	Hood Canal	99[b]	3·6	23/5/72	18 000	0·20	2·8	27·8	44·4	19·4(8·3)	0·0	0·0	5·6
2-5	Hood Canal	Hood Canal	191	20·6	31/8/72	28 684	0·02	0·0	83·3	0·0	0·0	0·0	0·0	16·7[d]
2-6	Hood Canal	Hood Canal	370	50·4	26/2/73	20 083	6·59	0·5	20·3	32·3	28·9(21·3)	3·1	0·2	14·6
2-7	Elwha R.	Elwha R.	369	64·9	31/1/73	10 974	0·49	3·7	50·0	5·6	31·6(16·7)	0·0	0·0	9·3
2-8	Hoko R.	Hood Canal X	146	9·9	11/7/72	31 144	0·13	0·0	100·0	0·0	0·0	0·0	0·0	0·0
2-9	Pysht R.	Elwha R.	146	9·9	11/7/72	30 881	0·35	1·9	53·7	0·0	44·4(13·9)	0·0	0·0	0·0

[a]Estimated from coded-wire tag recoveries in all fisheries sampled in the Pacific Northwest (including Canada and Alaska) plus escapement.
[b]Normal rearing time and release for fall chinook for that hatchery.
[c]WDF hatchery at Hoodsport (Hood Canal) releases its fish directly into the mouth of Finch Creek on this saltwater fjord. Fish can be conditioned in this hatchery with pumped seawater.
[d]There were only six estimated recoveries from this entire group.



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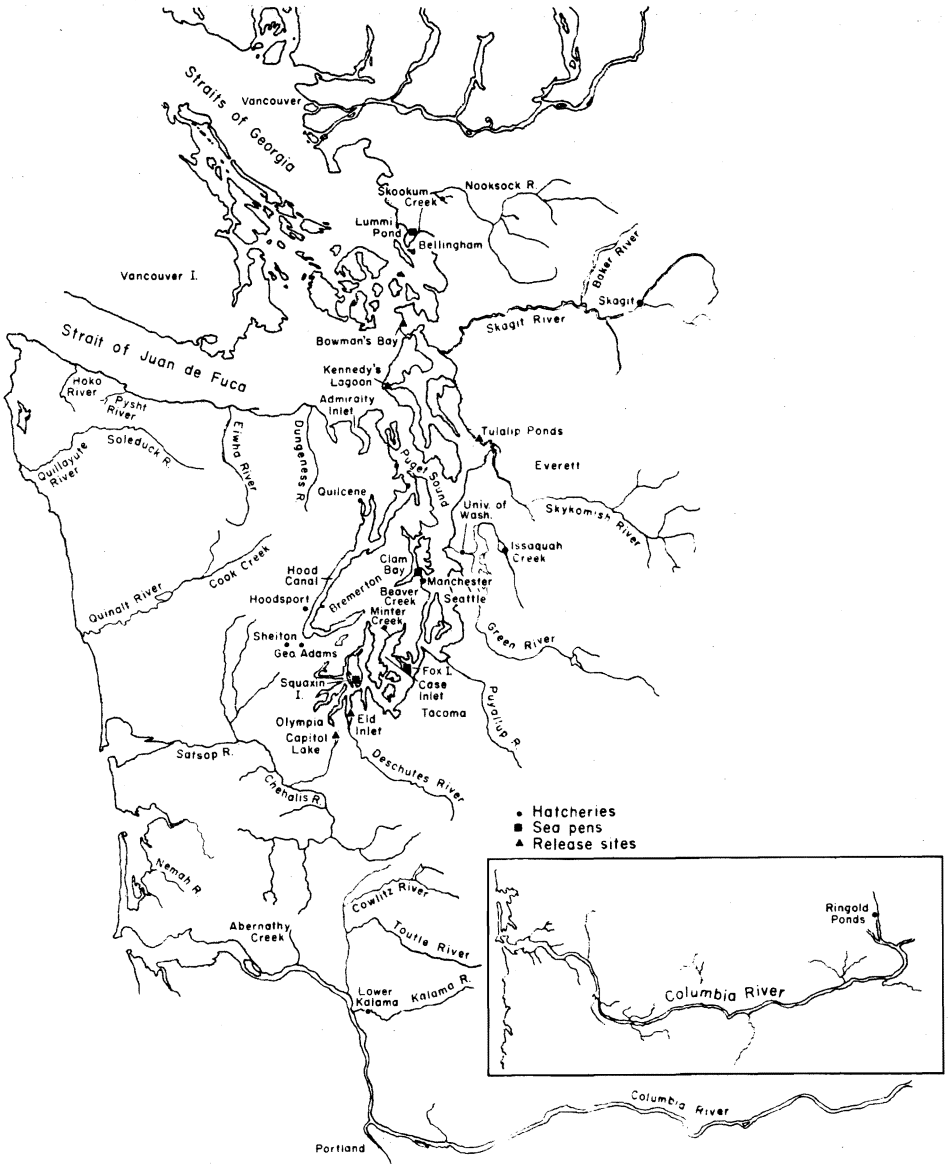

Fig. 2. Composite map showing the delayed-release areas discussed in the text.

[a]Estimated from coded-wire tag recoveries in all fisheries sampled in the Pacific Northwest (including Canada and Alaska) plus escapement.
[b]Normal rearing time and release for fall chinook for that hatchery.
[c]WDF hatchery at Hoodsport (Hood Canal) releases its fish directly into the mouth of Finch Creek on this saltwater fjord. Fish can be conditioned in this hatchery with pumped seawater.
[d]There were only six estimated recoveries from this entire group.

the Skagit River Hatchery yielded 35 times the total recoveries of a normal release. Recoveries of fish from the same procedure at the Nooksack River Hatchery, however, yielded only 5 times those of normal releases (Table I). Similarly, extending the rearing from a normal 112 days to 141 days at the Nooksack River Hatchery produced a fivefold gain in recovery, but a similar procedure at the Skagit River Hatchery produced no benefits at all (Table I). In the Juan de Fuca and Hood Canal (Washington) regions (Figs 1 and 2), a spring release of yearling fall chinook from the Hoodsport Hatchery produced 33 times the normal total recovery, but a later summer delayed release of 0-age fish resulted in a tenfold decline (Table II). This could be due to seasonal abiotic factors in the release area, where surface temperatures can exceed 20°C, and dissolved oxygen concentrations become marginal.

Recovery patterns are reversed for serial delayed releases in the coastal Nemah River (Table III), where an early August release in the first year produced a fourfold recovery compared to a slightly delayed mid-May release. Genetic experiments with exotic strains complicated results from this region, as with stock 3-9 (Table III), yearling chinook salmon from a lower Columbia River stock hybridised with a southern coastal Oregon stock, which produced an unusual 9·19% recovery when released from a coastal Washington stream (Fig. 2). Differences in genetic stock and size of fall chinook are apparent in delayed-release experiments on the Columbia River (Table IV). There were benefits in rearing fall chinook from Kalama River Hatchery to a larger size in distant (Ringold, Wash.) spring-fed ponds before transporting them back to the hatchery for a delayed June release in the Kalama River (stocks 4-5 versus 4-6). Fourfold increases could be gained by releasing larger fish of the Ringold pond stock in late September from the Kalama River Hatchery (4-10) than of the native stock of the Kalama River Hatchery (4-7); midwinter delayed release (4-3) at the Toutle River Hatchery produced four times the recoveries of mid-fall releases (4-2), whereas midwinter releases from the Kalama River Hatchery (4-8) showed no benefits at all.

Migrations. Recoveries of coded-wire tagged salmon in commercial fishery samples from California to Alaska as well as the Washington State salmon sport fishery are revealing migratory patterns for both chinook and coho salmon. Fall chinook do not appear in the coastal sport fishery until age-2 nor in the commercial fisheries until almost

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Table III. Survival and geographic distribution of 1971 brood normal and delayed release fall chinook salmon from Washington State Department of Fisheries hatcheries in the coastal (Washington) region. The data are summarised as percentages estimated from coded-wire tag recoveries in all fisheries sampled. Estimates of sport fishery recoveries in Puget Sound are indicated in ( ). (Data from Washington State Department of Fisheries.)

Stock no.	Release site	Stock origin	No. of rearing days	Average weight at release (g)	Date released	No. of tagged fish released	Total recovery[a] (%)	Distributions (%)						
								Alaska	British Columbia	Washington coast	Puget Sound	Oregon coast	Columbia River	Escapement
3-1	Nemah R.	Nemah R.	117[b]	5·3	17/5/72	33 718	0·86	15·0	41·8	21·9	0·3(0·3)	1·0	0·0	20·2
3-2	Nemah R.	Nemah R.	144	7·6	17/6/72	55 787	1·40	12·9	44·0	18·0	2·6(2·6)	0·4	0·0	21·9
3-3	Nemah R.	Nemah R.	192	14·2	3/8/72	32 248	3·73	11·5	33·1	26·4	0·6(0·6)	0·2	0·0	28·3
3-4	Nemah R.	Abernathy R.	137[b]	5·3	17/5/72	66 616	0·35	0·0	37·2	54·7	4·2(3·8)	0·0	0·0	3·8
3-5	Nemah R.	Abermathy R.	155	7·6	17/6/72	43 354	0·22	2·1	14·5	64·9	12·4(12·4)	0·0	0·0	6·2
3-6	Satsop R.	Nemah R. X Deschutes	376	75·7	13/3/73	41 972	1·83	1·2	44·9	33·1	6·3(6·3)	0·0	0·0	3·0
3-7	Soleduck R.	Nemah R. X Cook Ck.	98[b]	4·6	28/6/72	97 954	0·24	21·9	42·0	19·7	0·0	0·0	0·0	16·3
3-8	Soleduck R.	Cowlitz R. X	260	30·3	21/9/72	42 463	2·39	12·4	45·1	10·2	16·3(16·3)	0·8	0·0	15·5
3-9	Soleduck R.	Umpqua R.	496	141·9	8/5/73	26 819	9·19	5·9	57·3	14·6	4·5(4·5)	1·6	0·0	16·1
3-10	Soleduck R.	Quillayute R.	423	141·9	8/5/73	23 028	2·25	18·0	68·3	9·3	4·4(4·4)	0·0	0·0	0·2

[a]Estimated from coded-wire tag recoveries in all fisheries sampled in the Pacific Northwest (including Canada and Alaska) plus escapement.
[b]Normal rearing time and release for fall chinook salmon for that hatchery.

Table IV. Survival and geographic distribution of 1971 brood delayed release fall chinook salmon from Washington State Department of Fisheries hatcheries in the middle and lower Columbia River (Washington) region. The data are summarised as percentages estimated from coded-wire tag recoveries in all fisheries sampled. Estimates of sport fishery recoveries in Puget Sound are indicated in ( ). (Data from Washington State Department of Fisheries.)

Stock no.	Release site	Stock origin	No. of rearing days	Average weight at release (g)	Date released	No. of tagged fish released	Total recovery[a] (%)	Distribution (%)						
								Alaska	British Columbia	Washington coast	Puget Sound	Oregon coast	Columbia River	Escapement
MIDDLE COLUMBIA RIVER														
4-1	Columbia R.[b]	Lower Kalama R.	150	23·9	29/6/72	46 127	3·66	0·1	10·2	55·1	1·9(1·9)	5·7	26·8	0·1
LOWER COLUMBIA RIVER														
4-2	Toutle R.	Toutle R.	209	18·9	20/10/72	38 200	1·08	0·5	47·7	25·3	0·0	0·0	18·4	7·9
4-3	Toutle R.	Toutle R.	316	26·7	15/1/73	25 517	4·12	1·9	49·1	28·0	5·3(5·0)	0·3	8·9	6·7
4-4	Toutle R.	Toutle R.	394	56·8	10/4/73	21 376	12·06	0·3	38·2	39·9	2·4(2·4)	2·0	8·8	8·5
4-5	Lower Kalama R.	Lower Kalama R.	150[c]	23·9	29/6/72	38 198	1·96	0·1	16·2	61·3	2·0(2·0	4·7	8·5	7·1
4-6	Lower Kalama R.	Lower Kalama R.	157	7·0	30/6/72	68 030	0·97	1·1	52·0	23·1	5·3(5·3)	0·9	14·7	3·0
4-7	Lower Kalama R.	Lower Kalama R.	233	18·9	21/9/72	39 762	1·58	0·0	49·9	33·0	4·3(4·3)	0·6	8·4	3·6
4-8	Lower Kalama R.	Lower Kalama R.	306	32·4	4/12/72	20 190	0·88	0·0	38·4	25·5	14·7(6·8)	0·0	18·6	2·9
4-9	Lower Kalama R.	Lower Kalama R.	424	78·3	1/4/73	20 088	8·77	0·3	35·6	46·5	2·6(2·6)	1·0	10·4	3·8
4-10	Lower Kalama R.	Ringold	250	64·8	21/9/72	17 566	6·85	0·2	21·9	57·5	2·9(2·9)	1·0	5·9	10·5

[a]Estimated from coded-wire tag recoveries in all fisheries sampled in the Pacific Northwest (including Canada and Alaska) plus escapement.
[b]Initial rearing at Lower Kalama hatchery; transported up the Columbia River to Ringold Pond for extended rearing and release.
[c]Reared at Ringold Pond and transported back to the Lower Kalama for release.

4-9	Lower Kalama R.	424	78·3	1/4/73	20 088	8·77	0·3	35·6	46·5	2·6(2·6)	1·0	10·4	3·8
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[c]Reared at Ringold Pond and transported back to the Lower Kalama for release.

age-3, because of restrictions in net mesh size and strict regulations in the offshore troll fishery (Wahle and Vreeland, 1978). However, in Puget Sound (where there is no commercial troll fishery) sport anglers may keep chinook over 50-cm fork length—a size that is reached the winter after their second year. Puget Sound has a mild climate and is protected from oceanic storms. Consequently, small-boat anglers are able to catch many feeding chinook salmon during an intensive winter sports fishery. Any increase in fish residency increases the potential catch per angler day. If fishing remains persistently good, the rate of exploitation may be increased as more anglers are attracted into the fishery.

Migrational patterns of fall chinook salmon vary with geographical origin. Lander (1970) reported that contributions of fall chinook from Columbia River hatcheries to Alaska fisheries (from 1961-1964 brood year marking studies) were very low, as were those from the 1971 brood for some of the coastal stocks (Table III). The highest contributions to Alaskan fisheries of the latter stocks (3-7; 21·9%) came from a normal release, whereas the lowest had some extended rearing. In 75% of the delayed-release groups from coastal hatcheries, the recoveries from Washington coastal waters and Puget Sound were high. Contributions of 1971 brood fall chinook to the Oregon coastal fishery from any of the Washington State hatchery releases listed were negligible (Tables I-IV).

All Puget Sound recoveries from coastal releases (Table III) and most of the Puget Sound recoveries from Columbia River releases (Table IV) were from the sport fishery. Evidently large numbers of these fish turn into Puget Sound to feed as immature fish and leave before the late summer commercial net fishery begins.

Some delayed releases of coastal hatchery stocks (Table III, stocks 3-5 and 3-8) were of definite benefit to the Puget Sound sport fishery, even though they were of mixed origin. In comparison with normal releases, delayed releases of fall chinook salmon in the Hood Canal-Juan de Fuca region (Table II) were responsible for higher percentages of recovery in the Puget sound sport fishery (2-1, 2-6, and 2-7) as were delayed releases from Puget Sound hatcheries (Table I). Although some delayed release groups had a relatively poor showing in the Puget sound sport fishery (1-2, 1-3, 1-9, 1-10, 1-13, and 1-14), several of these releases had a very good showing.

Large numbers of chinook salmon that originate in Washington are

caught in the Canadian commercial fishery off the British Columbia Coast. This includes a high percentage of recoveries of normal releases from Puget Sound hatcheries (Table I; 1-1, 1-8, 1-11; 3 out of 4) and some of the delayed releases (1-9, 1-12, 1-13, 1-14, and 1-18; 5 out of 14). Delaying the release of chinook salmon from hatcheries in other regions of Washington has an inconsistent effect on migration to Canadian waters. Although some shifts in the population movements occur, they are not *en masse*, and it would appear that the schools break up—some to residualise and others not. What determines this is not known.

Delayed Release of Coho Salmon

Recoveries. Coho salmon are normally released from Pacific Northwest hatcheries in the spring as yearlings (age 1+). This coincides with normal migration time and age of most wild stocks, except for some colder Canadian and Alaskan waters, where coho may smolt at age 2 or even 3. They normally spend one winter at sea, and return as adults the following fall. Normal migrations lead these fish into the food rich coastal waters from northern California to Alaska.

However, some coho salmon spend their entire sea life inside Puget Sound. This resident group originally came from native wild stocks and contributed heavily to the important Puget Sound salmon sport fishery, at an average size at maturity smaller than ocean-run fish. Mathews and Buckley (1974) estimated that the natural mortality of these resident coho during their last winter in the sea was 48%. This high figure would justify a size limit lower than that for chinook and, indeed, there is no size limit on coho at this time inside Puget Sound. However, Buckley and Haw (1978) concluded that catches were declining from 1949 to 1967 due to decreases in the numbers of resident coho and that delaying the release of hatchery stocks (especially in the southern part of Puget Sound) might induce residency. In 1969, two groups of coho were marked and released at Minter Creek Hatchery (southern Puget Sound)—one at the normal time and another after extended rearing. The delayed-release group contributed 21 times more to the Puget sound recreational fishery, 3 times more to the ocean sport fishery, and 32 times more to the Washington commercial troll fleet than the group released at the normal time. The tests were expanded with the 1970 brood coho, releases of marked fish were made in May (control), June, July, and August. The June release had the greatest

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total contributions to Washington's fisheries (11·8%), but the recovery of the August release (9·3% total) was 3·8 times higher than the June release in the Puget Sound sport fishery. Using the May group as a control, the comparative benefits of the delayed releases to sports angling in all Washington waters were: June 7·5:1; July, 10·9:1; August, 16·0:1.

The coded wire tag was the major technical break-through that enabled subsequent expansion of experiments by the WDF biologists at the Minter Creek Hatchery and other WDF hatcheries (Tables V and VI) and confirmed that delayed releases could increase the total recovery but that the time of release and size at release were usually critical. Excessive extended rearing in fresh water may have contributed to the lower survival of stocks 5-4 and 5-10 (Table V), and 6-3 (Table VI), and was probably related to declining photoperiod (Hoar, 1976).

Tagged 1972 brood coho salmon were released from the Toutle River (Tributary to the Columbia River) Hatchery at intervals from early March until the end of June (Table VI). The earliest releases (No. 6-9) had the lowest recovery (of 5-11, Table V), and releasing larger fish gave greater benefits after the photoperiod started increasing (No. 6-12 and 6-15). The greatest recoveries came from normal sized smolts released at the beginning of June (6-16), and larger fish at the end of June (6-17). Thus, an 8·7% extension in rearing time over the normal release (6-13) produced 1·9 times more fish, and a 16·2% extension in rearing time produced 3·9 times more fish.

Migrations. Coho salmon in the Puget Sound, Admiralty Inlet, Hood Canal, and Juan de Fuca region can appear in the Washington sport fishery early because there is no size limit, unlike the coastal commercial troll and sport fisheries (which moreover are closed during the winter and early spring months). As the seasons progress, recruitment into the coastal fisheries accelerates, whereas increasing fish size and improving weather attract more Puget Sound anglers and recruitment here also increases. All fisheries peak in late summer and early fall as the rapidly maturing fish migrate toward their release areas. Late in the season the commercial drift gill-netters and purse-seiners enter the fisheries.

Migratory patterns differ between normal and delayed releases of coho salmon (Table V and VI). The percentage of the total recovery of the normal release from the Skykomish River Hatchery (No. 5-3) was

Table V. Survival and geographic distribution of 1971 brood normal and delayed release coho salmon from Washington State Department of Fisheries hatcheries in Puget Sound and Hood Canal (Admiralty Inlet), Washington. The data are summarised as percentages estimated from coded-wire tag recoveries in all fisheries samples. Estimates of sport fishery recoveries in Puget Sound are indicated in ( ). (Data from Washington State Department of Fisheries.)

Stock no.	Release site	Stock origin	No. of rearing days	Average weight at release (g)	Date released	No. of tagged fish released	Total recovery[a] (%)	Distribution (%)					
								Calif-fornia	British Columbia	Washington coast	Puget Sound	Oregon coast	Escape-ment
5-1	Skagit R.	Baker R.	359	18·9	1/5/73	39 886	3·11[b]	0·0	38·3	23·0	8·8(4·2)	1·9	28·1
5-2	Skagit R.	Skagit R.	488	45·4	30/7/73	19 998	2·77	0·0	26·0	20·0	23·8(11·5)	5·1	25·1
5-3	Skykomish R.	Skykomish R.	385	22·7	1/5/73	17 499	8·40[c]	0·0	40·0	22·8	17·0(1·0)	4·4	15·7
5-4	Skykomish R.	Skykomish R.	474	42·0	29/7/73	17 882	4·59	0·0	33·2	25·4	25·7(13·7)	3·3	12·5
5-5	Tulalip Ponds	Skykomish R.	—	28·4	15/6/73	18 700	6·28	0·0	44·7	16·9	33·1(3·5)	5·4	0·0
5-6	Green R.	Green R.	400	22·7	23/4/73	18 280	13·29[c]	0·0	35·4	17·2	12·9(3·4)	3·3	31·1
5-7	Puyallup R.	Green R.	470	37·8	5/7/73	20 000	7·53	0·0	21·0	9·3	35·8(13·9)	1·7	32·4
5-8	Minter Ck.	Minter Ck.	386	25·2	16/4/73	17 173	15·61[c]	0·7	27·2	17·2	29·2(4·6)	2·9	22·8
5-9	Minter Ck.	Minter Ck.	435-509	—	Jun-Aug	21 545	14·69[d]	0·0	27·6	15·6	32·2(4·2)	3·6	20·9
5-10	Minter Ck.	Minter Ck.	509	113·5	16/8/73	5 207	7·86	0·0	9·3	1·7	42·6(24·7)	0·0	46·4
5-11	Geo. Adams	Geo. Adams	366	18·2	1/3/73	30 182	1·97[e]	0·0	45·2	20·9	15·6(4·5)	9·0	9·3
5-12	Hoodsport	Hoodsport	515	56·8	31/7/73	26 325	4·76	0·0	11·5	9·3	18·1(12·8)	1·2	59·8

[a]Estimated from coded-wire tag recoveries in all fisheries sampled in the Pacific Northwest (including Canada and Alaska) plus escapement.
[b]Approximately normal release for that hatchery, but the stock is one that returns exceptionally early.
[c]Normal rearing time and release for coho salmon for that hatchery.
[d]Volitional releases from the hatchery pond.
[e]An example of a stock released earlier than normal and slightly smaller than those from a normal release.

5-10	Minter Ck.	Minter Ck.	509	113·5	16/8/73	5 207	7·86	0·0	9·3	1·7	42·6(24·7)	0·0	40·4
5-11	Geo. Adams	Geo. Adams	366	18·2	1/3/73	30 182	1·97[c]	0·0	45·2	20·9	15·6(4·5)	9·0	9·3
5-12	Hoodsport	Hoodsport	515	56·8	31/7/73	26 325	4·76	0·0	11·5	9·3	18·1(12·8)	1·2	59·8

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[e]An example of a stock released earlier than normal and slightly smaller than those from a normal release.

Table VI. Survival and geographic distribution of 1972 brood normal and delayed release coho salmon from Washington State Department of Fisheries hatcheries in Puget Sound, coastal Washington, and the Columbia River regions. The data are summarised as percentages estimated from coded-wire tag recoveries in all fisheries sampled. Estimates of sport fishery recoveries in Puget Sound are indicated in ( ). (Data from Washington State department of Fisheries.)

Stock no.	Release site	Stock origin	No. of rearing days	Average weight at release (g)	Date released	No. of tagged fish released	Total recovery[a] (%)	Distribution (%)						
								Californ-ia	British Columbia	Washington coast	Puget Sound	Oregon coast	Columbia River	Escape-ment
6-1	Skagit R.	Baker R.	377	20·6	15/5/74	41·022	6·80[b]	0·7	17·5	19·0	17·6(2·1)	1·7	0·0	43·5
6-2	Skagit R.	Skagit R.	385	25·2	15/5/74	31 923	6·28[c]	0·0	23·3	16·4	36·0(2·4)	1·2	0·0	23·1
6-3	Skagit R.	Skagit R.	450	25·2	1/8/74	20 743	3·64	0·0	14·4	10·4	24·8(6·6)	4·8	0·0	45·5
6-4	Puyallup R.	Puyallup R.	386	22·7	30/4/74	30 205	9·40[c]	0·0	24·7	19·5	50·0(4·3)	0·9	0·0	4·6
6-5	Puyallup R.	Puyallup R.	—	37·8	20/7/74	20 400	11·62	0·0	19·4	14·3	53·6(13·7)	3·0	0·0	9·9
6-6	Green R.	Green R.	487	32·4	31/7/74	20 221	7·41	0·0	18·6	15·0	49·8(26·7)	0·7	0·0	15·9
6-7	Nemah R.	Nemah R.	415	22·7	2/5/74	29 690	2·99[b]	3·5	2·6	41·3	0·0	37·1	0·0	15·5
6-8	Nemah R.	Nemah R.	477	30·3	2/7/74	18 589	5·78	6·5	1·9	30·4	0·5(0·3)	42·9	0·0	17·9
6-9	Toutle R.	Toutle R.	296	22·7	1/3/74	52 220	3·47[d]	10·3	0·3	22·7	0·0	41·1	1·3	24·4
6-10	Toutle R.	Toutle R.	327	15·1	1/4/74	49 050	3·72[e]	13·2	0·5	19·0	0·0	37·5	2·4	27·3
6-11	Toutle R.	Toutle R.	327	22·7	1/4/74	42 000	4·25[f]	15·7	0·0	20·1	0·0	39·5	0·0	24·7
6-12	Toutle R.	Toutle R.	327	32·4	1/4/74	31 668	4·94[d]	12·1	0·7	14·6	0·0	46·9	0·8	24·9
6-13	Toutle R.	Toutle R.	357	21·6	1/5/74	42 756	4·17[c]	14·3	0·1	28·3	0·0	32·3	1·1	23·9
6-14	Toutle R.	Toutle R.	357	15·1	1/5/74	41 820	4·11[g]	8·8	0·2	18·0	0·2(0·2)	37·3	4·5	31·0
6-15	Toutle R.	Toutle R.	357	32·4	1/5/74	30 944	6·40[h]	7·1	0·5	18·1	0·0	43·8	3·1	27·1
6-16	Toutle R.	Toutle R.	388	22·7	1/6/74	41 340	8·11[i]	12·2	0·4	22·0	0·0	40·4	5·0	19·8
6-17	Toutle R.	Toutle R.	415	37·8	27/6/74	31 068	16·21	7·6	0·5	26·0	0·0	40·5	4·0	21·3

[a]Estimated from coded-wire tag recoveries in all fisheries sampled in the Pacific Northwest (including Canada and Alaska) plus escapement.
[b]Approximately normal release for that hatchery, but the stock is one that returns exceptionally early.
[c]Normal rearing time and release for coho salmon for that hatchery.
[d]An early release of large fish (normal smolt size).
[e]An early release of small fish.
[f]An early release of fish of normal (smolt) sized fish.
[g]A release of small fish at the normal time.
[h]A release of large fish at the normal time.
[i]A delayed (late) release of normal (smolt) sized fish.

1·8 times that of the delayed release (No. 5-4). However, the proportion of recoveries of the delayed release in the Puget Sound sport fishery was 13·7 times that of the normal release and less in Canada and Oregon. A chronological examination of the Puget Sound sport fishery recoveries in 1974 reveals how these shifts occurred (Fig. 3). Some of the delayed-release group probably never left Puget Sound, but the controls contributed more heavily to the British Columbia troll fishery than fish in the delayed-release group that migrated out of Puget Sound; 19·1% of the delayed-release and 24·9% of the normal release recoveries came from fisheries off southwestern Vancouver Island (Canada), and 1·1% and 7·3% (respectively) came from fisheries off

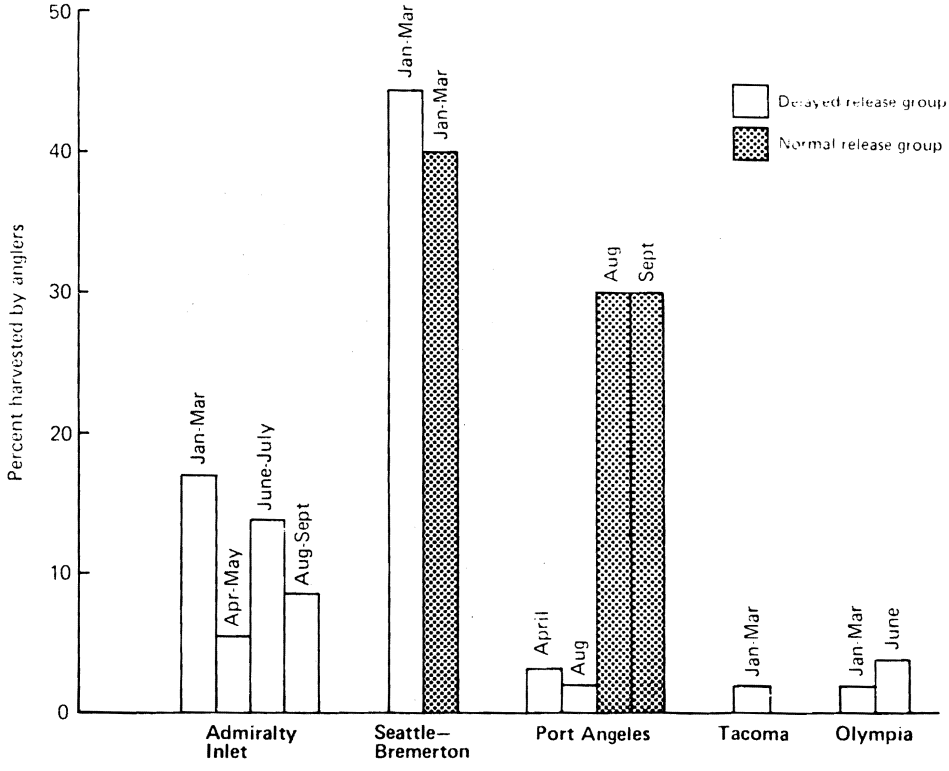

Fig. 3. Estimated 1974 recoveries in the Puget Sound sport fishery of normal and delayed release fish of the 1971 brood release (5-4) Skykomish River Hatchery coho. The time of the recoveries and the percentages of the estimated 1974 Puget Sound angler harvest *(above)* are shown in relation to the geographical reporting areas, and their distances from the estuary *(right)*.

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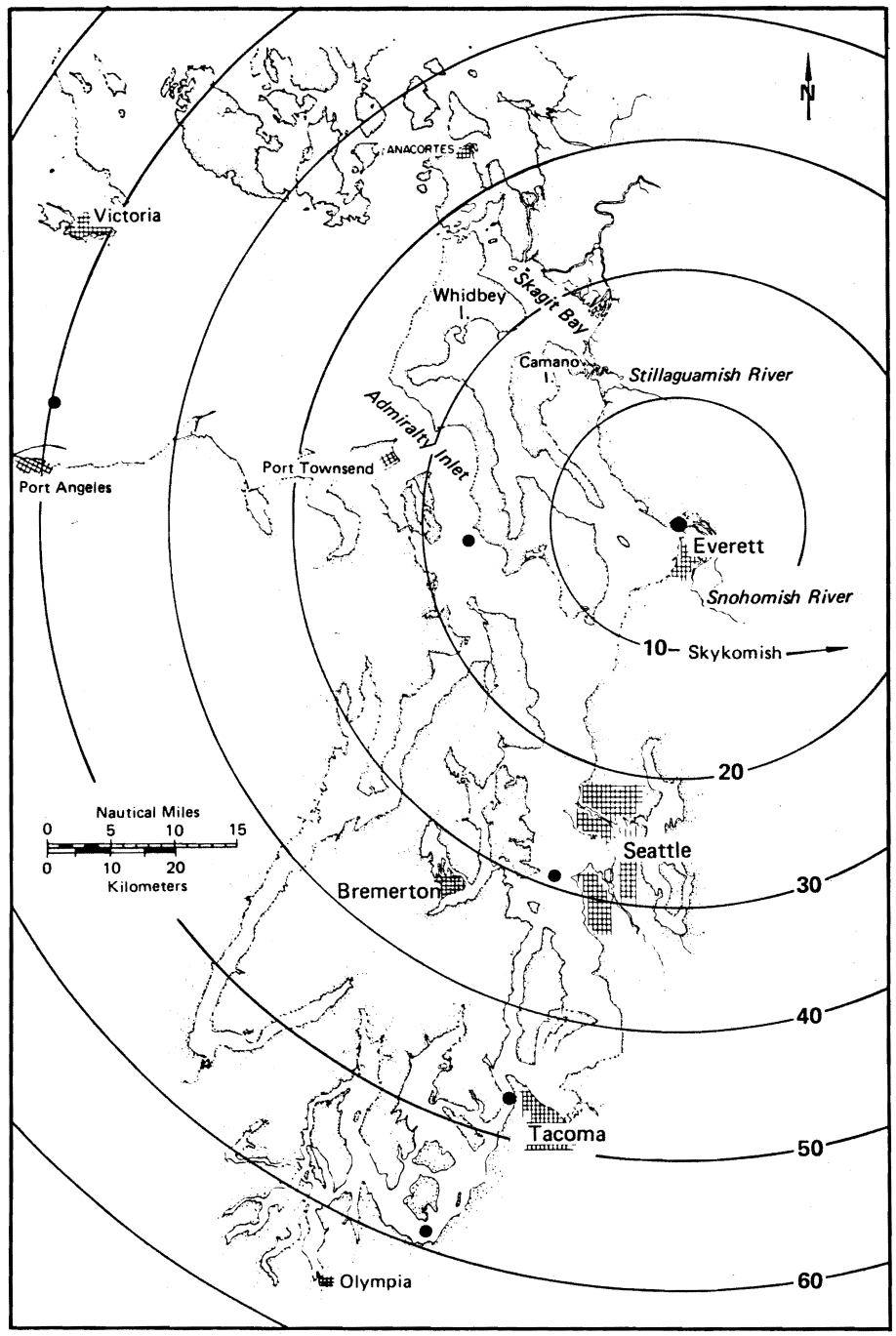

northwestern Vancouver Island (from unpublished WDF data not included in the tables).

Shifts in the distributions of other delayed-release stocks from the 1971 brood WDF hatchery coho also favoured the Puget Sound sport fisherman as "resident" coho and did not contribute as heavily to the northern Canadian fisheries (Table V; 5-2, 5-7, 5-10, and 5-12) as did the normal release groups (5-3, 5-6, and 5-8).

The delayed releases of the 1972 brood from the Skagit River Hatchery (Table VI, No. 6-3) contributed only 2·8 times more than the controls (6-2) to the Puget Sound sport fishery; the percentage distributions to the Canadian and U.S. commercial fisheries (except Oregon) was down, but the percentage of escapement was almost double the control. The average fork length of the delayed release escapement was 53 cm and of the control, 63 cm. This size disparity would favour heavy exploitation of the control fish by the intense, selective commercial gill-net fishery. Other 1972 brood delayed-release coho from WDF hatcheries in Puget Sound produced proportionately better populations, including resident fish (6-5 and 6-6).

As with most Columbia River hatcheries, very few of the 1972 brood Toutle River coho salmon (No. 6-9 through 6-17) were recovered in the Canadian fisheries or in Puget Sound. The major 1975 recoveries were from the Washington, Oregon, and California coastal fisheries; in the latter, major exploitation was from the commercial troll fleet. In coastal sport fisheries, 0-1% were recovered in California, 5·4 to 11·3% in Oregon, and 7·2 to 17·9% in Washington (from unpublished WDF data not included in the tables). As the range of total Washington coastal recoveries was only 14·6% (No. 6-12) to 28·3% (No. 6-13), these Toutle River Hatchery release groups contributed heavily to the coastal sport fishery. Although the contributions to the Washington coastal sport fishery of the control (No. 6-13; 16·5%) and those of the late June delayed release (No. 6-17; 17·9%) differed little, the latter contributed almost 4 times as many fish to the sport fishery as the controls—an impressive figure.

Saltwater Releases

Floating Net-pens

Floating net-pens for the culture of Pacific salmon were adapted from Japanese and Norwegian techniques for rearing rainbow trout *(Salmo gairdneri)* and Atlantic salmon *(S. salar)* in the sea. In 1969, the NMFS

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sea. In 1969, the NMFS

studied the feasibility of culturing coho and chinook salmon for market in net-pens in Clam Bay, Puget Sound, near the town of Manchester. During the course of a large pilot farm study, many excess coho and chinook salmon were made available for delayed saltwater release to study distributions and contributions to the sport fishery.

University of Washington and WDF biologists tagged 800 yearling chinook salmon weighing an average of 150 g with Carlin dangler tags and released them in Clam Bay and Case Inlet in southern Puget Sound. Within a year, the total contributions to the Puget Sound sport fishery were approximately 10%, with Case Inlet fish contributing heavily in southern Puget Sound and Clam Bay releases almost exclusively to middle Puget Sound (Haw and Bergman, 1972). After 17 months, 12·5% of the chinook were recovered from the Clam Bay release group and 14·3% from the Case Inlet group. Hundreds of coho salmon were tagged by WDF with the same external tag and released in the same areas with similar results. Coho salmon that escaped from the pilot farm net-pens in the winter of 1971-72 were in excellent condition and weighed from 200 to 400 g. Their caudal fins were rounded (presumably from the effects of high-density rearing). This distinguishing feature became well known to Puget Sound anglers, and their movements could be traced by the reports of heavy sport fishery catches of "round-tailed" coho. The total releases from this pilot farm, including excess potential brood fish, were approximately 10 metric tons and had a large impact on the local sport fishery.

These early successes in sport fishery enhancement through net-pen culture resulted in more organised studies, not all of which were encouraging. For example, over 70 000 yearling Minter Creek Hatchery coho salmon were released by NMFS and WDF biologists from floating net-pens in Clam Bay on 2 July, 1971, at an average weight of 45 g (Novotny, 1975), but recoveries in the Puget Sound sport fishery were approximately one-fifth those of a simultaneous delayed release of the same stock directly from the hatchery. Inventories in net-pen culture have always been a problem; the estimate of the number of fish released on 2 July, 1971, was probably too high—but not high enough to produce the difference in recoveries observed. Subsequent studies of releases of net-pen cultured chinook salmon at NMFS's Manchester facility on Clam Bay indicated that sport fishery recoveries could indeed be very poor. Moring (1973) estimated a contribution of only 0·1% from a 1973 release of 1971 brood fall

chinook in Clam Bay. Releases of 1971 brood fall chinook in early 1973 from a net-pen rearing density study in Clam Bay contributed a meagre 0·3% to the resident sport fishery, and this failure was attributed to repeated epizootics of furunculosis and vibriosis during the saltwater culture stages (Novotny, 1978). In late August, 1974, NMFS released 95 externally tagged net-pen culture 1972 brood coho in Clam Bay. The average weight at releases was 554 g, and mortalities from tagging were expected to be low. Sport anglers returned 13·7% of the tags within three months after release, all from central Puget Sound (Fig. 4). The total recovery was 20% (including recaptures in a trap at the head of Clam Bay), but nothing further was seen of this tagged group after December, 1974.

The 1971 brood fall chinook salmon reared at the WDF Hoodsport Hatchery in Hood Canal (Fig. 5) were transported by truck and transfer barge to the floating net-pens near Squaxin Island (Fig. 6). Four groups bearing coded-wire tags were released in 1972 and 1973, including one that had been fed a dry, pelleted ration (instead of Oregon moist pellets) for part of the rearing period (Table VII). The percentage of recovery was not high for any group, but spring releases of yearling fish increased overall survival by as much as 29:1 over fish released the previous summer and improved the contributions to the Puget Sound sport fishery by at least 4:1. Similarly, through co-operative sportsmen's projects, the WDF reared 1971 brood Samish coho for delayed release in sea-pens off Whidbey Island in 1973, and 1972 brood Minter Creek coho for delayed release in sea-pens in Seattle's Elliot Bay. One group of 4850 marked coho averaging 45 g was released off Whidbey on 29 May, 1973, and another group of 4850 ($\bar{x}$ = 91 g) on 1 August, 1973. The total recovery of the first group was 3·9%, with 18·1% of the catch taken by the Puget Sound sports fishery. The total recovery of the August release was 12·4%, but only 4·6% of the catch was taken by Puget Sound anglers. On 4 August, 1974, 11 035 coho averaging 99 g were released in Elliot Bay, and the total recovery was a spectacular 28·3%. However, only 9·6% of this was taken by the Puget Sound sports fishery (from unpublished WDF data not included in the tables).

Since that time, WDF established a station at Fox Island (Fig. 5) for extended rearing and releasing of coho and chinook salmon. At least 250 000 coho and/or chinook salmon are reared in net-pens each year in Puget Sound for delayed release.

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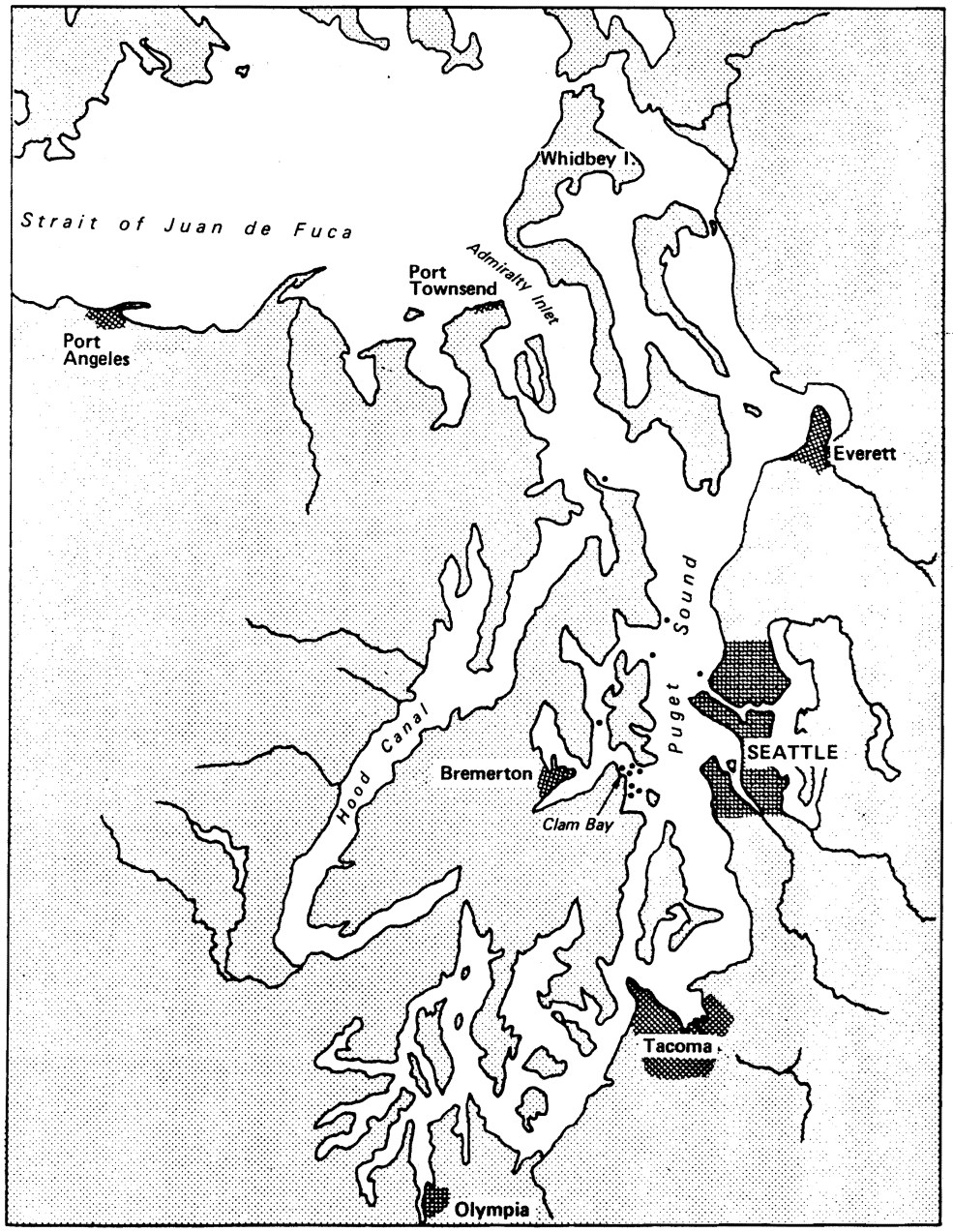


Fig. 4. Sport fishery recoveries (•) of coho salmon of age-group 1+ that were released from sea-pens in Clam Bay.

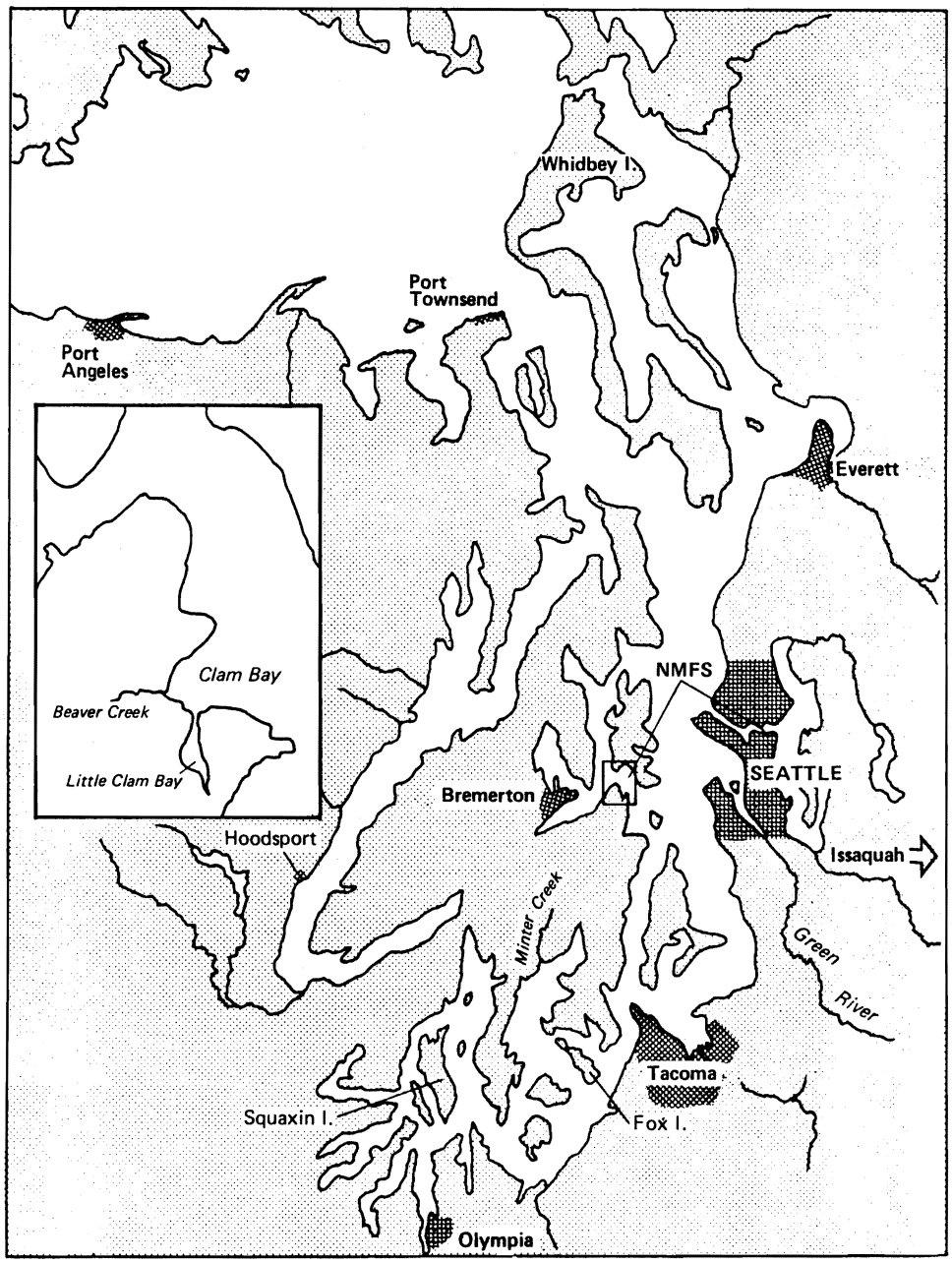
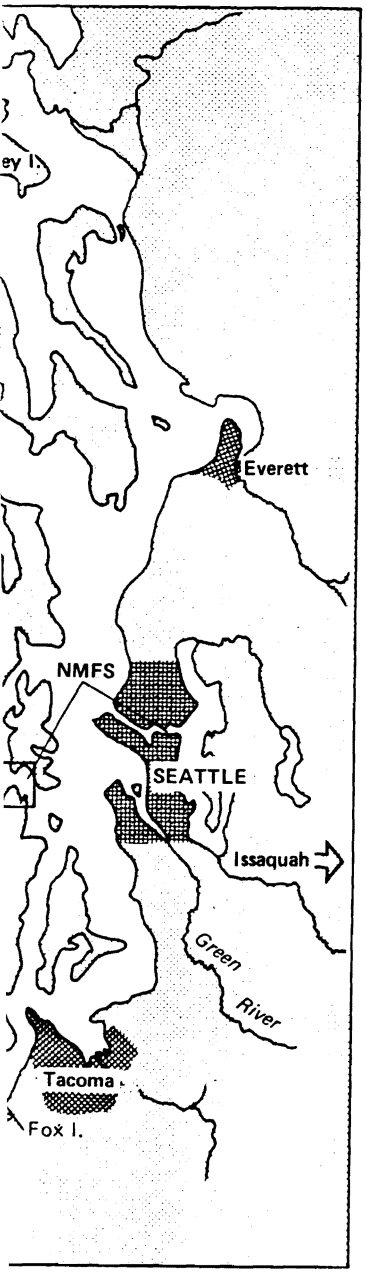


Fig. 5. Locations of the major saltwater delayed release sites in south and central Puget Sound (Squaxin Island, Fox Island, and Clam Bay); the major Washington Department of Fisheries hatcheries that supply production quantities of coho and chinook salmon smolts for transfer to seawater systems (Minter Creek, Hoodsport, Green River, and Issaquah); and, the National Marine Fisheries Service, NOAA, freshwater laboratory in Seattle.



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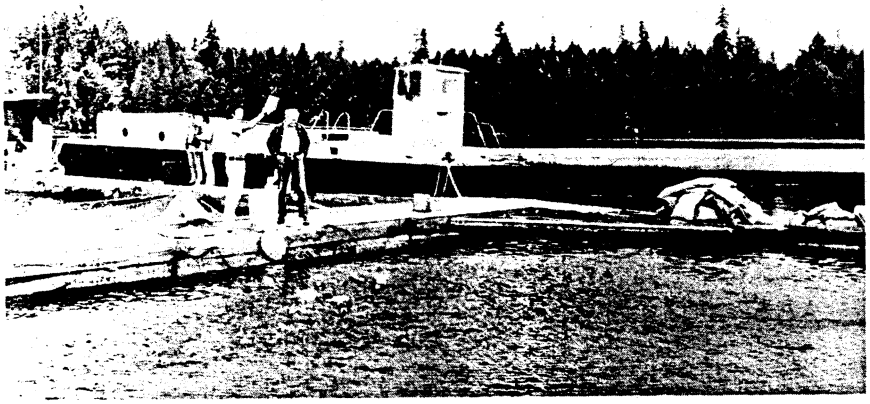

Fig. 6(a). Feeding chinook salmon in floating net-pens near Squaxin Island, southern Puget Sound (Washington). Both coho and chinook salmon were reared in these pens for delayed release by the Squaxin Indians on contract for the Washington State Department of Fisheries.

Fig. 6(b). Aerial view of the Squaxin Island floating net-pens that were used in co-operative programmes of delayed sea release for coho and chinook salmon.

Table VII. Estimated recoveries and distributions of 1971 brood fall chinook salmon reared at Hoodsport Hatchery and Squaxin Island sea-pens (delayed release from net-pens). Data are based on estimates from coded-wire tag recoveries in all fisheries but does not include late data for 5-year old fish from Oregon or Canada.[a] (Data from Washington State Department of Fisheries.)

					Distribution of estimated recoveries (%)					
Group	Release date	Weight at release (g)	Number of tagged fish	Total estimated recovery (%)	Puget Sound sport	Puget Sound net	Washington coastal sport	Washington coastal troll	British Columbia commercial	Escapement
1	5/8/72	16·2	33 467	0·14	19·5	43·5	0	19·6	8·7	8·7
2	18/10/72	54·0	6 048	0·31	0	0	0	0	100·0	0
3[b]	6/4/73	174·6	2 800	4·10	84·5	10·3	0	0	4·3	0·9
4	17/4/73	181·6	4 850	2·80	81·0	1·5	6·6	5·1	2·2	8·7

[a]From Washington State Department of Fisheries data.
[b]Partial use of pelleted dry salmon diets during seawater culture.

4	17/4/73	181·6	4 850	2·80	81·0	1·5	6·6	0	5·1	4·3	2·2	0·9	8·7

[a]From Washington State Department of Fisheries data.
[b]Partial use of pelleted dry salmon diets during seawater culture.

The anadromous cutthroat trout *(Salmo clarki)* is another popular game fish in the Pacific Northwest (Washington, 1977), especially in the sheltered waters of Hood Canal. However, in 1972 only 0·1% of the hatchery smolts that were planted in Hood Canal streams were harvested by anglers in marine waters of the canal (Hisata, 1973).

In 1973, several hundred sea-run cutthroat were transported from the Washington State Department of Game (WDG) Shelton Hatchery as yearling spring smolts to net-pens in Clam Bay, cultured in seawater through spring and summer, tagged externally, transported by truck, and released into Hood Canal. The harvest by saltwater anglers was approximately 9%. Research by WDG biologists at NMFS's Manchester facility now includes culturing of thousands of cutthroat trout from a number of genetic strains to examine differential survival in Hood Canal after delayed release (Johnston and Mercer, 1976).

The projects that focused on delayed releases of salmonids from net-pens at the Manchester facility stimulated similar research on delayed releases in other regions, including California. Since 1974, over 28 000 externally tagged (from 2400 to 7600 per group) coho and chinook salmon have been released from net-pens at Tiburon on San Francisco Bay to determine whether they could contribute more heavily to the California sport fishery. The average tag recovery for coho inside San Francisco Bay (including adults returning from the ocean) was 52·0% of the total number recovered and for chinook, only 5·7%. However, the total recovery of five lots of tagged coho in all fisheries was 0·04 to 0·90% (average 0·55%) of the number released, whereas the total recovery of the first group of delayed release fall chinook was an impressive 4·0% of the number released (personal communication, Dan Ralph, National Marine Fisheries Service, Tiburon, California).

In northern Puget Sound, the Lummi Indian aquaculture project cultures coho salmon in net-pens in a 300-hectare shallow, diked tidal pond (Fig. 7). The fish imprint to, and exit through, the dike outlet into Lummi Bay, which is a northerly juncture of Puget Sound and the Strait of Georgia (Fig. 2).

Three groups of coded-wire tagged coho, reared at the Lummi's Skookum Creek Hatchery on the tributary to the Nooksack River were released in 1975 (personal communication, Steve Seymour, Manager, Fish Culture Program, Lummi Indian Tribal Enterprise, Marietta, Washington). The treatments were: (1) direct release (control group) from the hatchery; (2) a simultaneous release of a group reared for 45

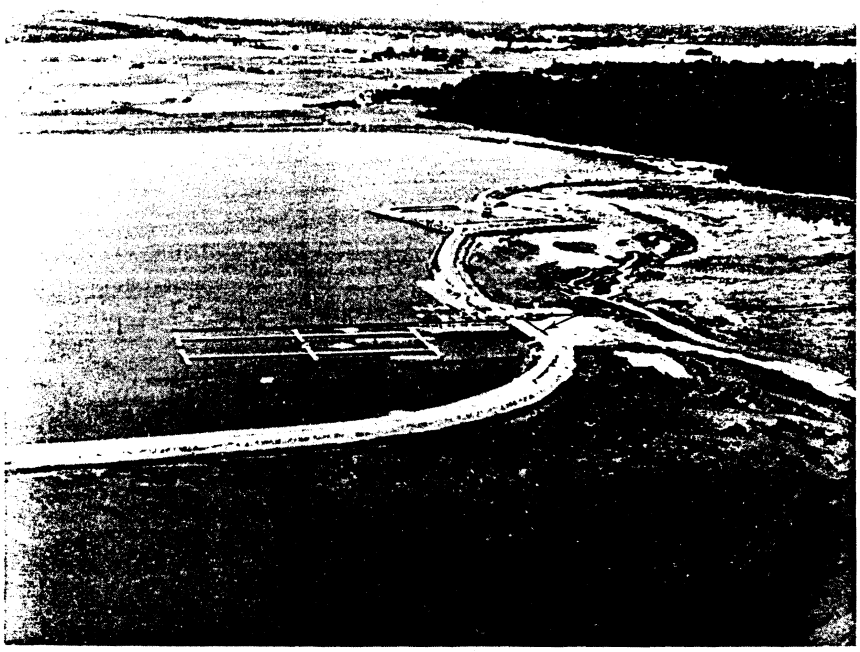

Fig. 7. Aerial view of the Lummi Indian diked-tidal pond in northern Puget Sound. Its outlet is indicated by the arrow. (Photo courtesy of Lummi Indian Tribal Enterprises.)

days in seawater; and (3) a delayed release after 6 days of seawater rearing (Table VIII). Weights at release for all groups were similar despite a 33-day interval between the first and last releases. In comparison to the control group, rearing for 45 days in seawater reduced the total recoveries by a factor of 3·5, and shifted the contributions toward the Canadian fisheries. The delayed release after only 6 days of seawater rearing approached the high recovery level of the control group and shifted contributions in favour of U.S. fisheries.

At Little Port Walter in southeastern Alaska, NMFS biologists culture salmon in both floating net-pens and unique floating raceways (Northwest Fisheries Center *Monthly Report*, April 1977). Freshwater layers allow the use of varying salinities. In one experiment, pink salmon fry were marked and cultured for serial releases (Northwest Fisheries Center *Monthly Report*, Nov. 1977). Marine survivals, based on the number of marked fry released, suggest a growth and survival pattern for Little Port Walter delayed-release pink salmon (Table IX)

Table VIII. A comparison of the estimated contributions of three groups of coho salmon released from the Lummi aquaculture project (northern Puget Sound) in 1975. The fish were from the 1973 Quilcene Hatchery (northern Hood Canal) brood year and are arranged by chronological release.[a]

				Distributions of estimated recoveries (%)						
Test	Release date	Size at release (g)	Estimated total recovery (%)	Puget Sound sport	Puget Sound net	Washington Coastal sport	Washington Coastal troll	British Columbia commercial	Oregon coastal	Escape-ment
45 days seawater rearing	30/5/75	25·2	5·3	0·9	22·1	6·8	14·0	46·5	4·4	5·3
Hatchery release	3/6/75	23·9	18·4	1·0	29·2	8·3	14·3	39·8	3·0	4·4
Delayed release with 6 days seawater rearing	3/7/75	25·2	17·0	2·2	31·1	7·0	20·4	31·2	2·5	5·6

[a]Data provided by Steve Seymour, Manager, Fish Culture Program, Lummi Indian Tribal Enterprises, Marietta, Washington.

Table IX. Results of serial releases of marked cultured 1974 brood pink salmon fry (15 000/group) from the National Marine Fisheries Service, NOAA, Little Port Walter, Alaska station.

Culturing time (days)	$\bar{x}$ weight at release (g)	Estimated marine survival (%)	$\bar{x}$ weight of returning males (kg)
0	0·23	2·7	2·36
30	0·27	3·9	2·01
60	0·55	4·6	2·01
90	1·95	3·8	1·65

which is similar to that of delayed-release coho salmon in Puget Sound; i.e., delaying the release frequently increases survival, but returning adults are smaller.

Diked Tidal Lagoons

In 1960, culturing salmon in marine lagoons was proposed as part of a plan to expand the salmon production of Washington State with a minimum of additional capital investment (Moore *et al.*, 1960). The plan included diking many natural saltwater lagoons in the Sound. Young salmon were to be transferred from freshwater hatcheries to the lagoons, where they could forage on natural foods until they migrated or until they were released. Salo (1963) proposed a similar scheme for salmon and steelhead (the anadromous form of rainbow trout) at Big Lagoon in northern California. However, by the mid-1960s, most of the lagoon rearing programmes were abandoned for a variety of reasons, including predation, disease, and lack of natural foods. DeWitt (1969) concluded that natural food production in lagoons had been overestimated and that supplemental feeding was necessary.

In 1974, WDF reactivated the rearing site at Little Clam Bay, an 11-hectare diked, tidal lagoon that discharges directly into the bay (Figs. 5 and 8). Water exchange between the bay and lagoon is regulated by flapper valves in the dike and is dependent on the extremity of the tides (2-5 m). A rotary screen prevents fish from escaping.

Early in February, 1974, yearling coho (14·2 g) at the WDF Green River Hatchery were injected with a *Vibrio anguillarum* vaccine and tagged with the coded-wire tag. A non-vaccinated control group was also tagged, and on February 14th, the two tagged lots plus a large

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ıarine %)	$\bar{x}$ weight of returning males (kg)
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Fig. 8. Little Clam Bay, a diked-tidal lagoon near Manchester, Washington. *(Upper)* The 11 ha lagoon; *(lower)* the discharge pipe below the dike on a low tide. Note the floating net-pens of a commercial salmon farm in the background.

non-tagged population were trucked to the lagoon at Little Clam Bay and released. The process was repeated in early April, and on April 10th the remaining tagged and untagged yearling coho (18·2 g) were turned loose in the lagoon. A total of 40 000 were released, 10% of which were tagged. Dry pelleted feeds were broadcast by hand from a small powered raft, slowly cruising the perimeter. Early spring salinities in the lagoon ranged from 15 to 26 parts per thousand, top to bottom. The rotary screen was damaged in late April, and some fish may have escaped early. Repairs were made, but further damage caused mortality in coho that became trapped in the rotary screen. The screen was removed on 27th May, and all fish were allowed to escape. They averaged 32·4 g and were in excellent condition.

There was no advantage in vaccinating against vibriosis in either group although the pathogenic bacteria are present in Little Clam Bay (Table X). An April transfer to the lagoon was preferred to February. Most important are the high recoveries from these delayed releases and the geographical distributions. These coho salmon evidently spent very little time in Puget Sound as evidenced by the broad range of coastal recoveries, the lack of recoveries in the Puget Sound angler harvest, and, in contrast, large contributions to the Puget Sound net fishery as returning adults. Comparing the sizes of fish between brood years can be misleading, but the overall mean length of the coho from the lagoon on Little Clam Bay was at least 8 cm larger than normal Minter Creek releases (Table XI, 5-8; 5-9), 19 cm larger than the August delayed-release group (No. 5-10), and 4-5 cm longer than a normal Green River release (5-6). Normal Puyallup Hatchery 1972 brood release (6-4) were 4-5 cm shorter, and the 1972 brood Green River delayed releases (6-6) were 16-17 cm shorter than the same group released from the lagoon on Little Clam Bay (Table XI).

Pumped Seawater

Pumped seawater has been used for experimental culture of Pacific salmon in Puget Sound by WDF at Bowman's Bay, NMFS at Manchester, and Lummi Indian projects in Lummi Bay. Pumped seawater has also been used for large experimental research projects by NMFS in Little Port Walter, Alaska (Northwest Fisheries Center *Monthly Report,* Apr. 1977); for production rearing of totally cultured coho salmon in a diked lagoon in Brittany, France (Harache and Novotny, 1976); and for certain types of Atlantic salmon culture in

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Table X. Estimated recoveries and geographical distributions of coded-wire tagged coho salmon released from Little Clam Bay lagoon (central Puget Sound) May 27, 1974.[a]

Date of transfer from Green River Hatchery to Little Clam Bay lagoon	Number tagged at hatchery	Total estimated recovery (%)[b]	Puget Sound sport	Puget Sound net	Washington coastal sport	Washington coastal troll	British Columbia commercial	Oregon coastal	California coastal	Escapement[c]
February 14										
vibrio vaccinated	9 207	7·45	0·6	41·8	8·0	18·1	30·7	0·7	0	0·1
control	9 122	9·41	0·2	54·7	8·2	12·0	24·3	0·7	0	0
April 10										
vibrio vaccinated	9 020	14·75	0·5	38·3	5·9	11·5	33·5	9·1	1·1	0·2
control	9 152	14·55	0·8	41·4	2·8	14·3	32·0	8·5	0	0·2

[a] From Washington State Department of Fisheries data.
[b] Based on the number of fish released into the lagoon.
[c] Adults recovered in the salmon traps in Beaver Creek, Clam Bay.

Table XI. Mean fork lengths (MFL) of 1971 brood normal and delayed release coho salmon from Minter Creek Hatchery and normal Green River Hatchery coho, sampled in the 1974 fisheries, and MFL's of normal 1972 brood Puyallup River Hatchery coho and delayed release coho from Green River Hatchery and Little Clam Bay lagoon, sampled in the 1975 fisheries. Puget Sound sport fishery data are not shown due to insufficient catches of lagoon reared and released fish. (Data from Washington State Department of Fisheries.)

	Mean fork length (cm)			
Year of fishery and test group	Overall (including Puget Sound sport fishery)	Puget Sound net fishery	Washington coast troll fishery	Washington coast sport fishery
1974 FISHERIES (see Table V)				
stock no. 5-6, Green River	63	64	58	59
5-8, Minter Creek	59	62	58	55
5-9, Minter Creek	58	60	57	55
5-10, Minter Creek	48	49	49	—
1975 FISHERIES (see Table X)				
February 14 release group, vaccinated	67	71	64	59
February 14 release group, control	68	71	62	62
April 10 release group, vaccinated	68	63	65	63
April 10 release group, control	67	70	63	61
1975 FISHERIES (see Table VI)				
stock no. 6-4, Puyallup River	63	68	62	60
6-6, Green River	51	58	53	53

release group, vaccinated	67	71	64	59
February 14				
release group, control	68	71	62	62
April 10				
release group, vaccinated	68	63	65	63
April 10				
release group, control	67	70	63	61
1975 FISHERIES (see Table VI)				
stock no. 6-4, Puyallup River	63	68	62	60
6-6, Green River	51	58	53	53

Norway. Pumped seawater is the basis of the largest private salmon sea-ranching operations on the coast of Oregon and California (Fig. 9). A total of over 50 million chum, coho, and chinook salmon were cultured for delayed release and imprinting in 1976-78 in pumped seawater raceways; these same firms are licensed to culture 100 million. In Oregon and California, delayed releases from these facilities are so recent that recovery data are still being processed, but data are available from a Lummi Indian Tribal Enterprises (LITE) experiment in 1976 (Table XII).

Four groups of yearling coho salmon were released: two directly from the Skookum Creek hatchery and two after 14 days rearing in concrete circular ponds in seawater pumped from Lummi Bay (Fig. 2). The geographical distribution of the recoveries varied little and unlike the results from other tagging experiments with Puget Sound fish, the

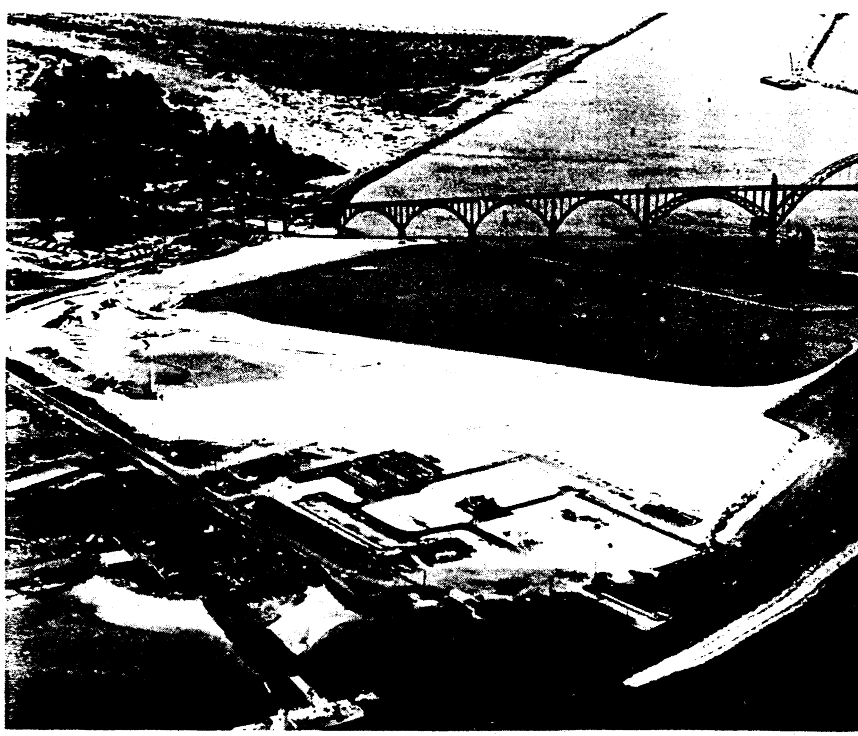

Fig. 9. The pumped seawater release and recovery sites of Oregon Aquafoods Inc. at Newport, Oregon.

Table XII. A comparison of estimated recoveries of coded-wire tagged coho salmon released from a river site and a delayed release from a pumped seawater pond in Lummi Bay. All fish were from the 1974 brood Cascade-Sandy River (Oregon) stock, and all were reared at the Lummi Indian Skookum Creek Hatchery.[a]

Treatment[b]	Number of fish tagged	Average weight (g)	Days reared in seawater	Release date	Total estimated recoveries (%)	Distribution of estimated recoveries (%)				
						Washington (all fisheries)	British Columbia	Oregon	California	Escapement (trap)
I	14 243	33·6	0	7/5/76	2·9	55·0	23·2	11·6	0	10·1
II	10 486	33·6	0	7/5/76	4·7	53·5	20·2	18·7	0	7·5
III	12 677	33·6	14	26/5/76	9·0	59·3	23·0	11·5	0	6·1
IV	14 440	37·2	14	26/5/76	7·5	55·5	25·2	12·1	1·5	5·7

[a]Summarised from data provided by Steve Seymour, Manager, Fish Culture Program, Lummi Indian Tribal Enterprises, Marietta, Washington.
[b]I. Orally vaccinated against vibriosis; released S. fork, Nooksack River.
II. Control for oral vaccine test.
III. Released into Lummi Bay from concrete pumped seawater ponds.
IV. Also released into Lummi Bay from pumped seawater ponds.

Canadian proportion of the catch was low (Table XII). More importantly, the total recovery could be increased by as much as 3:1 with a simple 14-day seawater conditioning. Thus, this technique also appears to be a promising method of enhancing local fisheries.

Extended rearing programmes generally require an increase in available rearing capacity, and in freshwater hatcheries this may be limited (mainly because of water supplies). Therefore, the most likely areas for continued expansion of extended rearing are in salt water, where more areas for diked lagoons, pumped water, and floating pens are available.

IMPRINTING SALMON IN SEAWATER AND ITS IMPLICATIONS

This limited analysis of delayed releases of salmon is focused on changes in survival and geographical distributions of freshwater hatchery releases. Survival includes escapement of the adults to the hatcheries as well as recoveries in the various fisheries. But, when salmon are released into seawater, do they return to their natal stream or imprint to the sea release site? The first substantial salmon returns to a seawater release site (no available freshwater imprinting) were probably at Kennedy's Lagoon in 1962. This lagoon contained 4·5 ha of pure seawater. Biologists of WDF captured 1700 coho and 300 to 400 chum salmon at the tidal dike discharge (WDF Annual Report, 1962).

Scientists at the NMFS Manchester facility on Clam Bay culture some salmon in fresh well-water and water from a small, adjacent stream (Beaver Creek) that terminates at the head of the bay (Fig. 10). Any fish cultured in this hatchery system and released in the bay are expected to return there, eventually entering the small fish ladder at the mouth of Beaver Creek. However, most releases of large numbers of fish in Clam Bay or in other Puget Sound areas such as off Fox and Squaxin Islands (Fig. 5), are trucked from hatcheries that are far from the release site.

The first reported returns from net-pen released salmon were from recoveries in Clam Bay in 1972 from the 1969 brood of Minter Creek coho salmon that were released in 1971 (see p. 341). The fish entered

[a]Summarised from data provided by Steve Seymour, Manager, Fish Culture Program, Lummi Indian Tribal Enterprises, Marietta, Washington.
[b]I. Orally vaccinated against vibriosis; released S. fork, Nooksack River.
II. Control for oral vaccine test.
III. Released into Lummi Bay from concrete pumped seawater ponds.
IV. Also released into Lummi Bay from pumped seawater ponds.

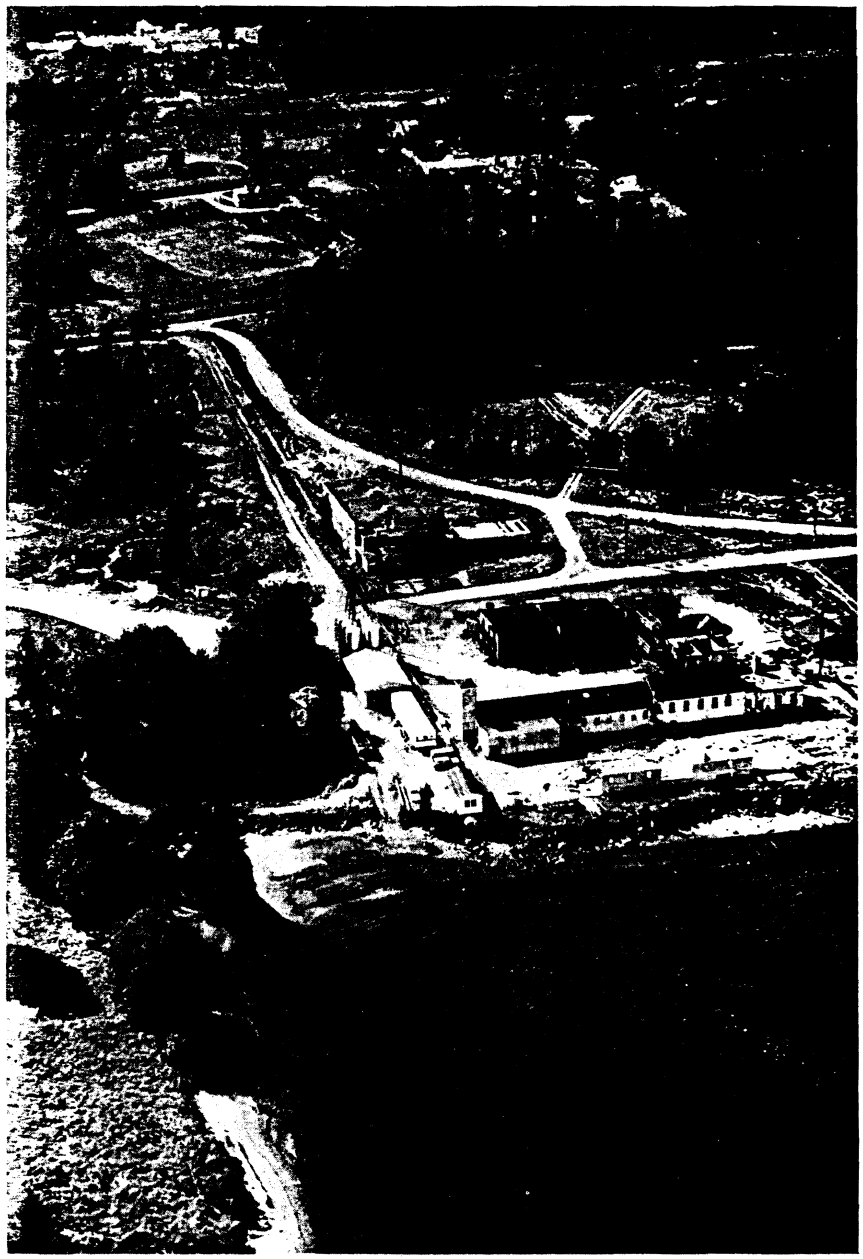

Fig. 10. An aerial view of the head of Clam Bay near Manchester, Washington. Beaver Creek discharges into the head of the bay (lower left corner).

lam Bay near Manchester, e head of the bay (lower left

the bay in September, milled in the net-pen area, and attracted many sports anglers. In early November, approximately 400 mature coho entered the trap in Beaver Creek (Northwest Fisheries *Monthly Report,* Nov. 1972). None of the tagged fish returned to Minter Creek, although it is possible that straying to other streams may have occurred.

In 1971 and 1972, biologists of NMFS found that imprinting Issaquah Hatchery coho salmon for four hours to water from an NMFS hatchery in Seattle was just as effective in establishing a "homing" station as imprinting for 168 hours. All adults returned to the Seattle Hatchery, and none to the Issaquah Hatchery (Fig. 2) (Northwest Fisheries Center *Monthly Report,* Jan. 1974). However, it was not known whether short-term imprinting in seawater would be similarly successful, and a series of experiments were designed to test this. In 1973, four lots of 5000 yearling Issaquah coho were "cold-branded" and treated as follows: (1) trucked from Issaquah Hatchery to Beaver Creek and released in the lowest pond at tide water; (2) reared in net-pens in Clam Bay for 3 weeks and released in the lower Beaver Creek pond; (3) reared in net-pens in Clam Bay for 3 weeks and released; and (4) released directly from the transport truck into seawater in Clam Bay. No marked adults from this group returned to Issaquah Creek in 1974, when recoveries of marked coho (with identifiable brands) in the Beaver Creek trap were as follows: Group one, 2·2%; two, 1·6%; three, 1·4%; four, 0·2% (Northwest Fisheries Center *Monthly Report,* Jan. 1975). This indicated that short-term retention in net-pens before release had good potential for imprinting salmon to sea-release sites.

In 1973, WDF and NMFS released over 600 000 coho in Clam Bay from extended rearing schedules that ranged from 3 weeks to several months. In 1974, returning adults from this release jammed the small fish ladder in the lower Beaver Creek pond after the first November freshet. Moreover, there was also a large return of jack coho (2-year old males) to Little Clam Bay from delayed release there in spring 1974 (Table X). Despite a concentrated and successful sport fishery in Clam Bay from September to mid-November 1974, 8827 salmon entered the Beaver Creek trap (Northwest Fisheries Center *Monthly Report,* Jan. 1974) including 21 large chinook (Fig. 11) from other experimental releases and 2 adult pink salmon from an NMFS experiment with delayed release from a net-pen that was an attempt to develop a run of even-year pink salmon from Alaskan eggs (Northwest Fisheries Center *Monthly Report,* Sept. 1974). A second generation from that pair of

Fig. 11. Adult male chinook salmon that returned to the sea-release site in Clam Bay.

pink salmon returned to Clam Bay in 1976 from delayed releases from net-pens in 1975 (Northwest Fisheries Center *Monthly Report,* Sept. 1976).

The extensive numbers of coho salmon returning to Clam Bay in 1974 created a serious handling problem for our small (NMFS) staff and WDF (Fig. 12). Since a large return of adult fish from this release was expected in 1975, the problem was resolved by establishing a commercial fishing area in the bay for local Indians. Most of the fishing was done by 8 to 10 gill-netters (Fig. 13), using small, outboard powered skiffs (Fig. 14). The fishermen harvested over 6000 coho, catching approximately 20 to 150 fish per boat per night (Fig. 15). Gross revenues were $60 000-70 000, and the coho averaged about 4·8 kg. In spite of this intense fishing effort, many coho attempted to enter the seawater discharge pipe from Little Clam Bay during low tides. Over 400 were diverted into the Beaver Creek trap during the November freshets (Northwest Fisheries Center *Monthly Report,* No. 1975). None of the marked fish returned to the Green River Hatchery.

Similarly, the Squaxin Indians were able to establish a new fishery around their Squaxin Island sea-pens, and many coho returning to the WDF Fox Island net-pen release site entered run-off culverts along the near beaches during heavy rains. Salmon released from pumped seawater ponds and pen enclosures in the Lummi diked tidal pond returned to the seawater trap there. The annual production of 2 million coho smolts from the Lummi Indian's Skookum Creek Hatchery could be acclimatised and imprinted (in 7-day intervals) in the pumped seawater ponds over a 6-week period (personal communication, Steve Seymour, Manager, Fish Culture Program, Lummi Indian Tribal Enterprise, Marietta, Washington).

These tests suggest that imprinting salmon to marine release sites could be an effective management tool. None of the fish released from marine sites returned to the freshwater hatcheries, unless they were close to the delayed sea-release site, such as at NMFS's Little Port Walter facility in Alaska, where 8% of the 1974 delayed release coho smolts returned, first to the net-pen site in the bay and then to the stream used for early rearing. Normally 150-300 wild adult coho returned each year from wild smolt production; in 1975, there were 13 800 adults—survivors of cultured, delayed, sea-release smolts (Northwest Fisheries Center *Monthly Report,* Oct. 1975).

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Fig. 12. About 9000 adult coho salmon that had been released as juveniles from floating net-pens in Clam Bay entered the small fish ladder in Beaver Creek.

Fig. 13. A new commercial fishing area was established in Clam Bay as a result of delayed sea releases of juvenile coho salmon from a diked, tidal lagoon. Set gill-nets proved to be the most efficient method of harvesting the adult salmon that returned to the lagoon.

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Fig. 14. Fishermen from the Suquamish Indian tribe were able to harvest the adult coho salmon returning to the sheltered waters of Clam Bay with a modest investment in gear.

Fig. 15. National Marine Fisheries Service, NOAA, biologist examining the coho salmon harvested in the terminal fishery in Clam Bay to look for marked ("branded" and fin-clipped) fish.

DISCUSSION

The potential benefits of delaying the releases of salmon have not been limited to the coastal region of the northeastern Pacific Ocean. Sutterlin and Merrill (1978) discussed releases of Atlantic salmon smolts in the early 1960s in Norway after 6-12 months of seawater rearing. The adult returns range from 10-14%; they were probably the stimulus for studies now being conducted in Norway on using early saltwater rearing and delayed releasing to increase oceanic survival and influence migration patterns.

Management research on Pacific salmon and collection of economic data on the production of normal releases of salmon from freshwater hatcheries are extensive. For example, the cost of producing a kilogram of fish for release at any size can be computed; furthermore, data are available for juvenile production strategies for coho salmon that will reveal the weight of fish harvested per weight of fish and time released (Bilton, Chapter 16, pp. 303-322). Firm economic data of this type are not yet available for delayed sea releases, and there are still many variables that must be examined that influence the survival and growth of these salmon and relate to economics. It does seem reasonable to assume, however, that both recreational and commercial fishermen, and even the consumer, will reap an economic benefit from increased survival of fish and establishment of new fishing areas at marine release sites as results of delayed sea releases.

The implications of the additional tools (and problems) given to fisheries management by altering salmon migrations are still being studied. The creation of fishing areas in the sea that salmon return to as adults may only be limited by oceanic capacity to absorb the potential output of cultured fish. In theory, some freshwater hatchery releases could be restricted to provide just enough returning adults for egg production. The remaining hatchery production of smolts could be transported for seawater acclimatisation, imprinting, and delayed release. This theoretical concept of a marine "terminus" for cultured salmon may eventually help management by concentrating some harvest activity there. Great care would be needed in planning releases to avoid conflicts with historical allocations of fishing areas, user groups, and most of all, vulnerable wild stocks.

The last and perhaps most important result of delayed-release studies has been the concurrent and fortuitous discovery of imprinting

to a sea-release site, without the benefit of a source of "cuing" freshwater. Not only can the coho salmon imprint to a sea-release station and return to it as adults, but they can do this after being transported over land for great distances before being unceremoniously transferred to a marine extended rearing station. How accurately coho salmon (and, presumably other species of salmon) perform this remarkable feat of navigation will probably be the subject of study for some time to come.

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