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ABSTRACT: The design and use of an inclined-plane trap is described for capturing salmon smolts in medium to large (5–60 $m^3 \cdot sec^{-1}$) rivers of Alaska. The trap was designed to minimize fish scale loss and mortality, be lightweight yet durable, minimize debris loading, be readily moved by 2 people, and be easily transported by a small river boat or helicopter. The tapered design allows traps to be stacked inside one another when being transported. This trap style has been in use since the early 1980s in small clearwater streams and large glacial rivers of southcentral Alaska. Catch efficiencies from mark-and-recapture tests have exceeded 10% for a single trap. The highest daily catch to date for 1 trap occurred in June 1994 when 96,979 sockeye salmon *Oncorhynchus nerka* smolts were caught in the Kasilof River.

INTRODUCTION

Assessment of juvenile salmon survival, size and age, and the success of hatchery fry plants requires a tool that successfully collects migrating smolts. Since 1976 sockeye salmon *Oncorhynchus nerka* fingerlings have been stocked in Tustumena Lake, located on the Kenai Peninsula. Population and hatchery contribution estimates of sockeye salmon smolts emigrating from Tustumena Lake via the Kasilof River have been made since 1980 (Kyle 1992). During the 1980s several different types and sizes of traps were used to capture smolts, including fan traps and inclined-plane traps (Flagg 1983; Flagg et al. 1985). Both types of traps have a large opening at the front that becomes constricted as it leads fish into a live box. The fan trap opening is square at the front and back. The inclined-plane trap has rectangular front and back openings. Both fan traps and inclined-plane traps sit on the river bottom but can be suspended, if necessary, in deep rivers.

The fan traps used in the Kasilof River had unacceptable mortality from smolts becoming impinged on the converging walls of the trap. If the throat became plugged, almost all fish were impinged and killed. Brett (1945) found that young sockeye salmon move as schools and enter a wide, horizontal opening more readily than a similar-sized vertical opening. This behavior favors the inclined-plane trap over the fan trap because the current inclined-plane trap opening at the back is 36 in wide compared to 1 ft wide for fan traps. Furthermore, the largest catches of smolts were from inclined-plane traps, especially those placed in the middle of the river. I have been refining these traps since first designing, constructing, and using them in the Kasilof River in the early 1980s and during their subsequent use in Crescent River, Quartz Creek, and numerous smaller creeks. In this paper I describe the current design and deployment of inclined-plane traps and provide pertinent information on their use to sample sockeye salmon smolts in 3 rivers.

The glacially fed Kasilof River, which drains a watershed of 1,376 km^2, is relatively large and turbid. At the trap location during mid June, the river is 83 m wide and approximately 1 m deep in the middle. All 5 species of Pacific salmon inhabit this river system, but sockeye salmon predominate. Sockeye escapements into the Tustumena Lake/Kasilof River system average about 225,000 (1980–1994). Discharges range from 10 to 62 $m^3 \cdot sec^{-1}$ during May and June when most of the smolts emigrate from the system.

Quartz Creek is also located on the Kenai Peninsula in the Chugach National Forest. This small clearwater tributary of Kenai Lake is subject to rapid flooding during periods of high snowmelt or rain. The creek drains a watershed area of 291 km^2. In addition to sockeye salmon, chinook salmon *O. tshawytscha* and coho salmon *O. kisutch* inhabit Quartz Creek, but sockeye salmon predominate. Sockeye salmon escapements from 1982 to 1984

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averaged 60,000 (Flagg et al. 1986). Normal discharges range from 5 to 18 $m^3 \cdot sec^{-1}$ during May and June, and have reached 29 $m^3 \cdot sec^{-1}$ during periods of flooding.

Crescent River is a small semiglacial river that becomes more turbid in midsummer. The river is about 20 m wide at the trapping location. This lake system is located on the west side of Cook Inlet across from the Kenai Peninsula and drains an area of 300 km^2. All 5 species of Pacific salmon are found in this system, but sockeye salmon predominate. No flow data are available for Crescent River.

METHODS

Trap Design History

Inclined-plane traps evolved from fan traps used in the Kasilof River. The first fan trap was constructed of a ¼-in angle iron (2 in x 2 in) frame and had a flat-bottom plate with 1/8-in-diameter holes. It was 12 ft long, had a 6-ft x 6-ft front opening, and required 6 people to move it. The second generation of fan traps was similar to the first, except the frames were made of ¼-in aluminum angle (2 in x 2 in), and the bottom plate had 2 V-shaped ridges. All fan traps had sides of ¼-in-mesh polyethylene netting (Vexar®).

The inclined-plane traps, designed after the fan traps, were constructed of aluminum frames and had a 42-in-high by 48-in-wide front opening. These traps were 96 in long (4 ft x 8 ft model), excluding the live box, and had a current-aligned, corrugated bottom plate and ½-in-mesh Vexar sides. Vexar netting offers many advantages over wire screen — is relatively inexpensive and lightweight yet durable, retains its shape better in fast currents, is less abrasive on fish, and does not readily collect debris (Anderson and McDonald 1978; Noltie 1987).

Several traps were made with ½-in-diameter holes in the bottom plate and with ¾-in-mesh Vexar sides to ease cleaning. Several frame sizes were used, including 3/16-in (2 in x 2 in) angle and 3/16-in (1½ in x 1½ in) angle. A 42-in trap height was chosen because the manufactured width of the Vexar is 48 in, so 1 piece without seams could be used per side, which when properly installed in a tight fashion, made cleaning easy and reduced debris loading. Also, the 42-in-high traps, when anchored on the river bottom, were accessible to personnel wearing chest waders. Meehan (1964) noted that catch efficiencies in the Taku River, a large glacial river in Southeast Alaska, were similar for traps fished at and below a depth of 2 ft, indicating relatively even vertical distribution and that most smolts were not emigrating below the 2-ft level. All metal surfaces on these 4-ft x 8-ft traps were painted a dull, dark gray to decrease trap avoidance.

The 4-ft x 8-ft model inclined-plane traps, which have a 1-piece corrugated plate bottom, led to development of the current 5-ft-wide model. By cutting the 60-in x 104-in perforated bottom plate diagonally and by flipping one-half over and joining the square outside edges in the center, the 5-ft-wide trap opening was made with the same plate. The corrugations are the same for both the 4-ft- and 5-ft-wide traps. The 5-ft-wide trap opening is made with essentially the same amount of material (the frame pieces are wider) for very little added cost, and is the model currently preferred.

Trap Materials and Design

The 5-ft-wide inclined-plane trap consists of 2 major sections: the trap and the live box (Figure 1). The aluminum materials used to construct the trap are standard commercial sizes (Table 1). The trap frame is made of welded, 3/16-in structural aluminum angle (1½ in x 1½ in) with 1/8-in angle (1 in x 1 in) cross-bracing (Figure 1). The trap's front opening is 42 in high by 60 in wide, whereas the back opening is 9 in high by 36 in wide; the overall length of the trap is 96 in. The trap bottom, made of 0.063-in-thick perforated aluminum plate contains 5/16-in-diameter holes on 15/32-in staggered centers, providing a cumulative 40% opening in the bottom. The bottom plate is formed into longitudinal, V-shaped corrugations (8¼ in from corrugated ridge center to center with a 3-in rise per ridge), which increases the filtering area and strength of the plate. Triangles of wood block or aluminum plate are cut to fit underneath the corrugations and are attached to the top, back side of the trap's bottom frame member; these help support the plate and decrease water flow into the live box. The smooth, stamped side of the perforated plate is placed upward because this side is easier to clean and is less abrasive on juvenile fish. To reduce the numbers of fish escaping from the live box, the perforated bottom plate extends 4 in beyond the rear of the trap's frame and into the live box, creating a small, vertical drop of 3–5 in. Vexar netting (½-in mesh) is used on the sides of the trap.

The live box is also constructed of structural aluminum and measures 48 in long, 36 in wide, and 24 in deep. Its frame is made of 1/8-in welded aluminum angle; the top and front sections are made of 1½-in x 1½-in angle, and the remainder is 1-in x 1-in angle. The sides of the live box are made of

Table 1. List of materials used for construction of the inclined-plane trap and live box.

Trap frame[a]	1 1/2" x 1 1/2" x 3/16" Angle	Trap bottom
Top stringer	2 @ 93 3/4"	Aluminum perforated plate
Bottom stringer	2 @ 99 3/8"	.063" thickness, 5052 grade
Front spreader	2 @ 60"	5/16"-dia. holes on 15/32" staggered centers
Front riser	2 @ 42"	1 @ 5' x 10'
Back spreader	2 @ 36"	
Back riser	2 @ 9 1/2"	Trap sides
	Total feet 62	Vexar polyethylene netting
		No. PN4, 1/2" grid
Trap bracing	1" x 1" x 1/8" Angle	1 @ 4' x 12'
Front spreader	2 @ 53 3/4"	
Front riser	2 @ 33 3/4"	Miscellaneous hardware
Back spreader	2 @ 44 5/8"	bolts, eye-bolts, nuts, washers,
Back riser	2 @ 21 3/8"	pop rivets, back-up plates
Plate joint	1 @ 104"	Wood lath - 1" x 2", 5 @ 8'
	Total feet 38	
		Live box sides
Live box frame	1 1/2" x 1 1/2" x 1/8" Angle	Aluminum perforated plate
Top stringer	2 @ 48"	.050" thickness, 5052 grade
Top spreader	2 @ 36"	1/8"-dia. holes on 3/16" staggered centers
Front spreader	1 @ 35 1/2"	2 @ 2' x 4'
Front riser	2 @ 9"	
	Total feet 24	Live box bottom & back
		Aluminum plate
	1" x 1" x 1/8" Angle	.063" thickness, 5052 grade
Front riser (diag.)	2 @ 15 3/4"	bottom/front - 1 @ 35 1/2" x 57"
Back riser	2 @ 22 1/2"	back top - 1 @ 35 1/2" x 13"
Bottom spreader	1 @ 36"	back bottom and door - 3 @ 13" x 13"
Bottom stringer	2 @ 39"	
	Total feet 17	Divider
		plywood 1/2"
	1" x 1" x 1/8" Channel	1 @ 24" x 35"
Divider riser	2 @ 23 5/8"	
Divider spreader	1 @ 34 3/4"	Live-box cover
	Total feet 11	Vexar netting (PN4)
		1 @ 4' x 5'
	1" x 1/8" Flat bar	
Vexar strap	1 @ 32 1/2"	

[a] Trap and live box frames made of 6061-grade structural aluminum.

0.050-in-thick perforated aluminum plate (23½ in x 47½ in) containing 1/8-in-diameter holes on 3/16-in staggered centers. These holes provide a 42% cumulative opening. A single aluminum plate (0.063 in thick) measuring 35½ in x 57 in forms the bottom and front, and 39½ in from the back it is bent up at 60º to form the front side of the live box. The back of the live box is also 0.063-in plate and contains a sliding door to quickly release captured fish if overcrowding occurs and to facilitate cleaning.

The live box is hinged or bolted to the back of the trap, and a Vexar strap on the front of the live box extends underneath the V-shaped corrugations of the trap bottom; this keeps captured fish from escaping through the trough gaps. A ½-in piece of plywood is slid vertically into channel slots to divide the live box into 2 compartments. A gap of approximately 0.5–1 in between the bottom plate and the plywood allows smolts to swim under the divider board. Most of the water flow entering the live box exits through the perforated-plate sides in front of the divider board. Thus, in the back compartment of the live box, the water is calm, providing juvenile fish with a less turbulent holding area that effectively reduces mortality.

The Kasilof River trap has 2 live boxes bolted in tandem to facilitate large catches during the peak of the emigration (Figure 2). The sliding-door opening

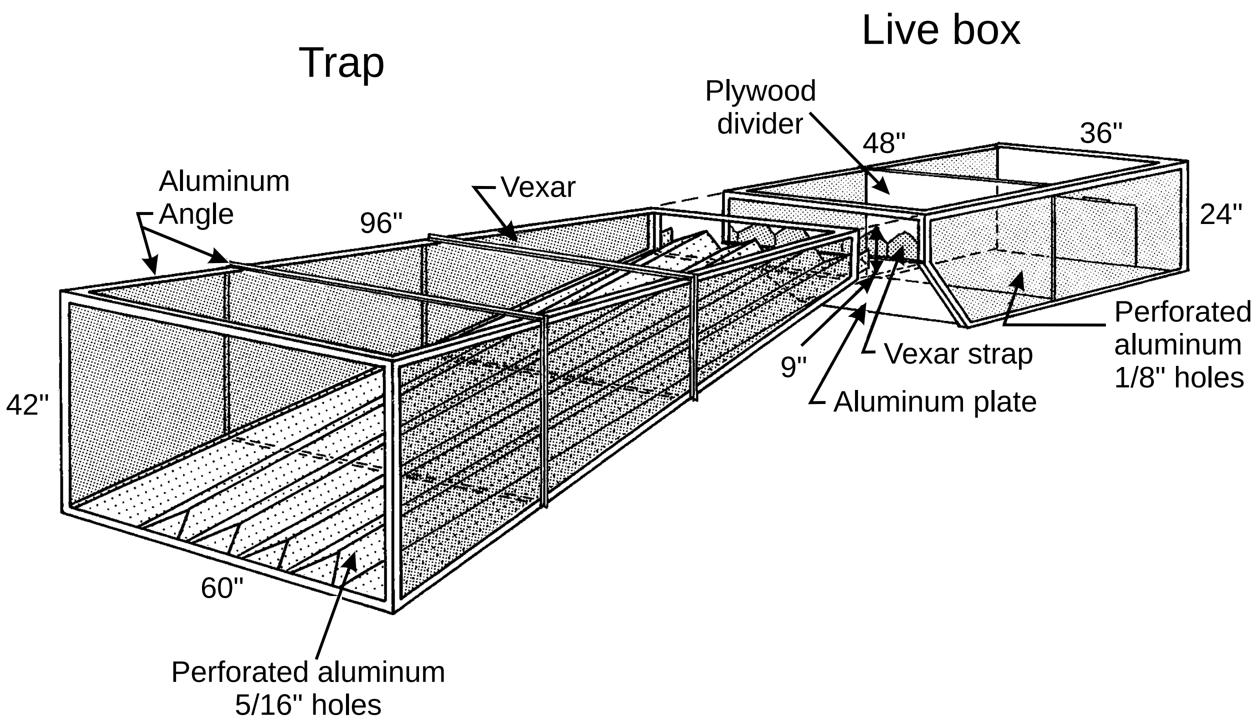

Figure 1. Schematic diagram of the inclined-plane trap, including trap and live box.

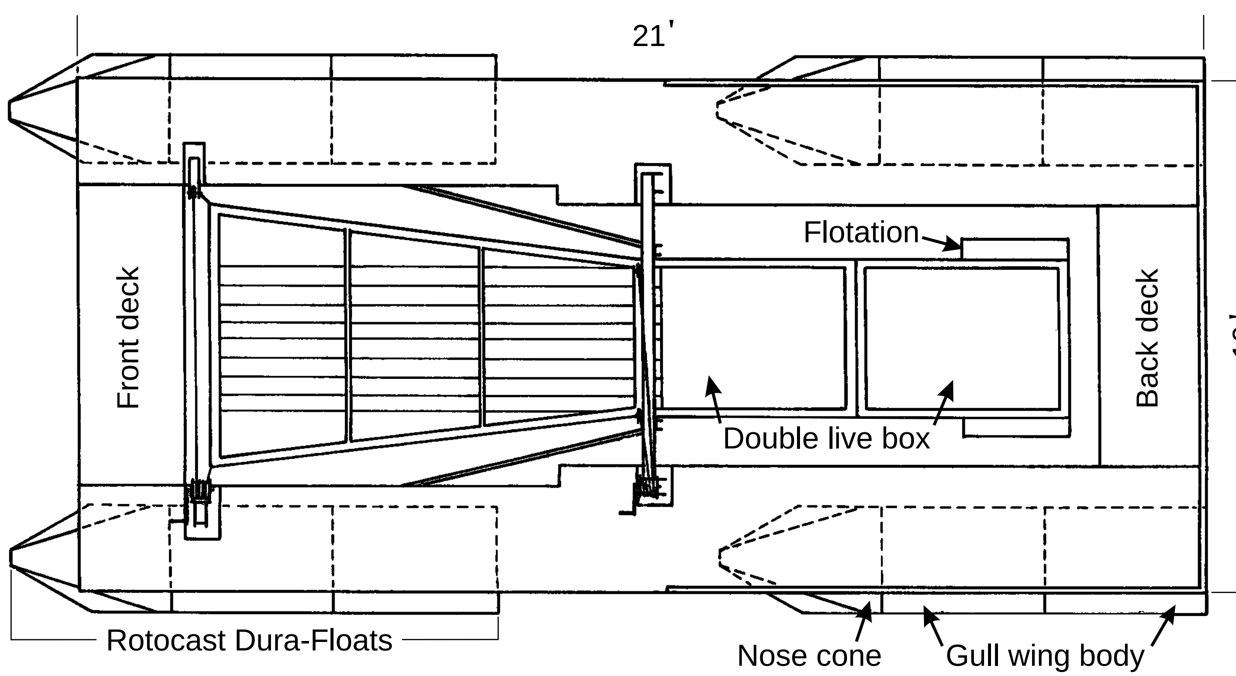

Figure 2. Top view of the Kasilof River inclined-plane trap showing the double live boxes and floating platform.

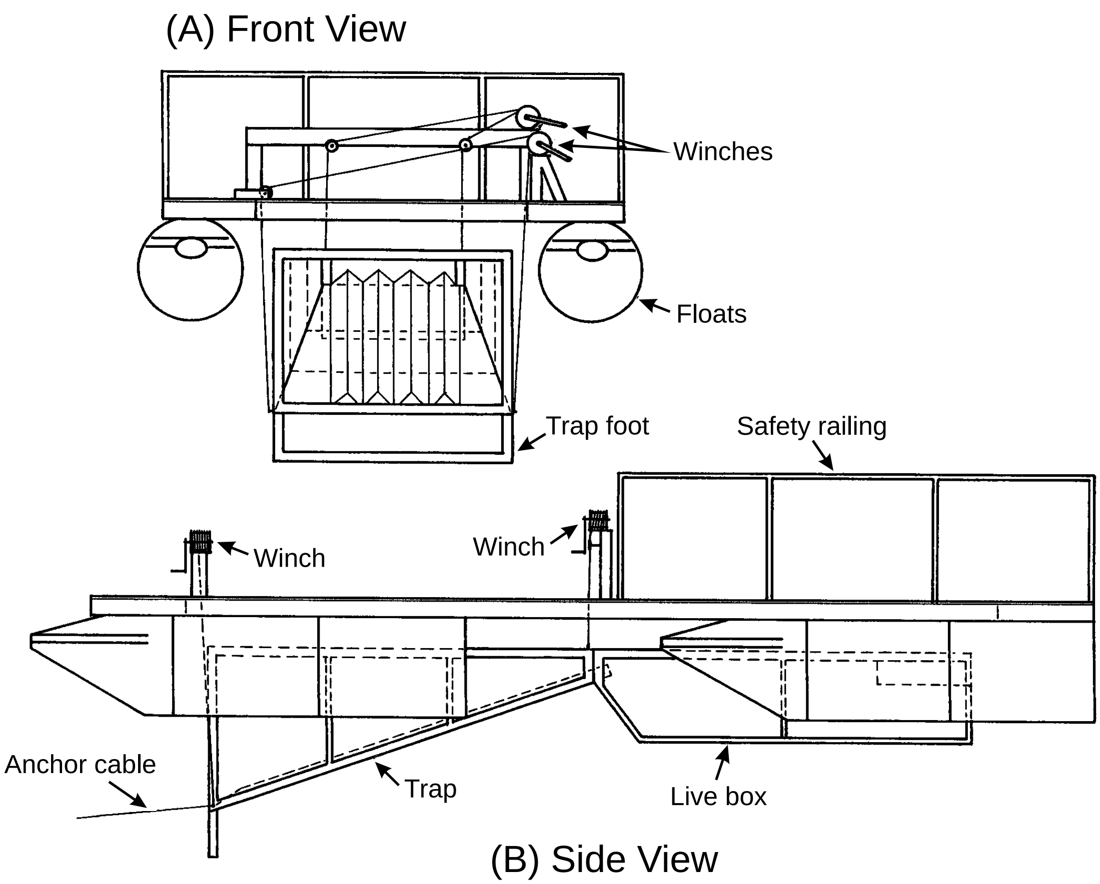

Figure 3. Front (A) and side (B) views of the Kasilof River inclined-plane trap and floating platform, including the front and rear winches used to remove and adjust the trap.

between the live boxes acts as a divider and no plywood divider boards are used. For additional flotation a polystyrene log (4 in x 6 in x 24 in) wrapped with Vexar is wired at the water line to each side near the back of the second live box. Live boxes and the rear 3 ft of the trap have Vexar covers to keep birds from preying upon the fish.

Trap Deployment

Several different winch mechanisms were used to adjust trap height (fishing depth) for both stationary and floating traps. Originally, lumber and later aluminum A-frames were stationed over the back of the trap onto which a pipe-winch system was attached. This consisted of 2 cables that attached to the back corners of the trap and at the other end to a T-handle pipe, which raised or lowered the trap. In some locations hand winches replaced the pipe-and-cable system.

The inclined-plane trap (5 ft x 8 ft model) used in the Kasilof River is suspended from a floating platform that is 21 ft long by 10 ft wide (Figure 2). The platform is constructed of welded, 1/8-in aluminum rectangular tubing (4 in x 1½ in) stringers and 3/16-in angle (2 in x 2 in) frame cross-members. The ½-in plywood decking is coated with a skid-resistant paint. Rotocast Flotation Dura-Float® modular pontoons provide flotation for the trap and platform. Under each side of the platform, two 26-in-diameter Dura-Float nose cones and four 26-in-diameter by 36-in-long Gull Wing body sections are used for flotation (Figure 2). The pontoons have tabs that are bolted to the aluminum rectangular tubing. The front and back decks of the platform disassemble to allow the float sides to be transported separately.

To reduce debris loading, the bottom of the trap is suspended 1 ft off the river bottom by a foot framework attached to the bottom front of the trap. The trap can be removed from the water (for cleaning or

Table 2. Sockeye salmon smolt catches, catch efficiency, and emigration estimates in 3 southcentral Alaska rivers.

River	Year	Number of traps	Peak	Catch season date	Catch total	Estimated efficiency[a]	Emigration
Kasilof River	1991	2[b]	55,149	6-Jun	599,790	12.5	4,735,439
	1992	2[b]	38,928	8-Jun	514,220	11.9	4,118,676
	1993	1[c]	44,779	29-May	569,200	7.2	9,022,270
	1994	1[c]	96,979	1-Jun	680,840	7.9	9,139,022
Quartz Creek	1982	3[d]	703	6-Jun	11,570	7.7	171,847
	1983	3[d]	396	22-May	5,609	7.2	100,783
	1984	3[d]	338	6-Jun	5,351	6.5	128,461
Crescent River	1982	5[e]			41,988	7.6	471,768

[a] Based on a dye mark and recapture method (Flagg 1983; Rawson 1984).
[b] 5 ft x 5 ft x 12 ft floating traps
[c] 5 ft x 8 ft floating trap
[d] 4 ft x 8 ft stationary traps
[e] 4 ft x 8 ft floating traps

maintenance), or the incline can be adjusted by the front and back winches (Figure 3). With double cables and pulleys on each winch, one person can easily raise or lower the trap and adjust fishing depth while the trap remains oriented horizontally.

The trap is held in place in the middle of the river by two ¼-in cables that attach to the bottom front corners of the trap. These cables are attached to 2 Duckbill® model 88-DB1 earth anchors. The anchors and cables were pounded into the riverbed in the early spring during low water. The platform is also attached on both sides to a single shackle that attaches to a 5/8-in safety cable in case an anchor cable breaks or an anchor pulls free. The safety cable is anchored on each side to large boulders that were previously drilled and fitted with eye bolts.

Trap Efficiency

Dye marking and recapture of smolts were conducted to determine trap efficiency and to estimate the number of emigrants; the methods used in this study are described in detail by Flagg (1983) and Rawson (1984). At the Kasilof River site, sockeye salmon smolts were dyed weekly by first placing a known number of smolts into an aerated transport container containing the dye solution (6 g of Bismarck Brown Y dye in 180 L water). The smolts remained in the dye for 30 min while being transported to the release location, which was approximately 2 km upstream from the trap site. At the release site, the dyed smolts were then placed in a stationary live box in the river to assess handling mortality prior to release

Table 3. Sockeye salmon smolt mark and recapture test results in 3 southcentral Alaska rivers.

			Marked smolts released		Marked smolts recaptured			
River	Year	Number of tests	Total release	Average release	Total recapture	Average recapture	Average rate %	Highest rate %
Kasilof River	1991	7	4,895	699	612	87	12.5	15.2
	1992	7	4,933	705	588	84	11.9	16.8
	1993	8	6,459	807	465	58	7.2	10.7
	1994	7	6,315	902	501	72	7.9	10.9
Quartz Creek	1982	6	1,810	302	139	23	7.7	11.8
	1983	5	1,837	367	133	27	7.2	11.2
	1984	5	2,371	474	155	31	6.5	9.3
Crescent River	1982	5	1,838	368	140	28	7.6	11.0

approximately 3–5 h later. Dyed smolts were recaptured in the trap, enumerated, and released. Trap catch efficiency (number of marked recoveries divided by number of marked releases) was used to estimate the weekly migrations by expanding weekly catches by the catch efficiency. Weekly estimates were then summed to estimate the total outmigration (Rawson 1984).

RESULTS AND DISCUSSION

In the Kasilof River, fan traps and inclined-plane traps have been used successfully to sample and estimate the population of sockeye salmon smolts since 1980 (Kyle 1992). In 1993 and 1994 a single, 5-ft x 8-ft floating inclined-plane trap was used. In 1994 the trap captured an estimated 681,000 sockeye salmon smolts from 10 May through 25 June. A record daily catch of 96,979 (Table 2) smolts were caught in the trap, which based on the catch efficiency (7.5%), represented a daily migration of 1.3 million smolts. Seven dye-marking tests were conducted in 1994, and approximately 900 smolts were marked and released per weekly test. Of a total release of 6,315 marked smolts, 501 marked smolts were recovered (Table 3).

In 1993 the Kasilof River trap was fished from 10 May to 30 June; peak catch occurred on 29 May when 44,800 sockeye smolts were caught. The total catch was 569,000 (Todd and Kyle 1994). Eight dye-marking tests were conducted in 1993: 700 smolts were marked and released each week for the first 4 tests and 900 smolts were released each week for the last 4 tests. The total release was 6,459 marked smolts; 465 of the marked smolts were recovered. Catch efficiencies in 1994 varied from 6.3% to 10.9% and averaged 7.9%. Efficiencies were similar in 1993, ranging from 4.2% to 10.7% with an average of 7.2% (Table 3).

In 1991 and 1992, 2 floating inclined-plane traps, which were actually modified fan traps, were used for sampling in the Kasilof River. They were relatively large: 12 ft long with a 5-ft x 5-ft front opening. The 1991 peak catch of 55,000 sockeye salmon smolts occurred on 6 June. Catch efficiency in 1991 ranged from 8.6% to 15.2% and averaged 12.5% (Todd and Kyle 1991). The 1992 peak catch of 39,000 smolts occurred on 8 June (Todd and Kyle 1992). Catch efficiency ranged from 16.8% during the early-season, low-water period to 6.2% during the late-season, high-water period and averaged 11.9%. Thus, catch efficiencies varied within and between years because of different flows and trap placements. Interestingly, often when the catch went down in one trap, the catch went up in the other trap.

In Quartz Creek, 3 inclined-plane (4 ft x 8 ft) traps in stationary placement (anchored on the stream bottom) were fished during 1982–1984 (Flagg et al. 1986). In 1983 a fourth trap was used intermittently. The seasonal catches of sockeye salmon smolts were 11,570 in 1982, 5,609 in 1983, and 5,351 in 1984 (Table 2); the smolt population estimates were 171,800 in 1982, 100,800 in 1983, and 128,500 in 1984. Catch efficiency ranged from 2.1% to 11.8% and averaged 7.1% during those years.

The 5 traps fished in Crescent River during 1982 (Kyle 1983) had the same dimensions as the traps used in Quartz Creek. These traps were placed in a staggered configuration and were suspended from floats that were attached to a cable stretched across the river. The weekly peak catch was 17,200 smolts, the total seasonal catch was 41,988 smolts, and the estimated emigration was 471,768 smolts (Table 2). The catch efficiency for the season was 7.6%.

The inclined-plane traps worked well in medium to large rivers with flows ranging from 5–60 $m^3 \cdot sec^{-1}$. Velocity readings recorded in the mid 1980s at the trap openings in both Quartz Creek and the Kasilof River were approximately 1 $m \cdot sec^{-1}$ for midriver traps and 0.5 to 0.7 $m \cdot sec^{-1}$ in the side-river traps. These traps have been used over a broad discharge range and have caught sockeye smolts over a broad size range (60–85 mm); however, further assessment is required to determine the best-suited flow range and the degree of trap avoidance by larger-sized smolts. To prevent overcrowding in the live box and minimize mortalities, catches were processed at different schedules depending on migration intensity. Traps captured both chinook and coho smolts; however, both species were observed swimming out of the trap. Fishing traps at higher velocities would reduce escapement. Alternatively, leads could be used that extend upstream of the trap front. Leads would increase the trap length and reduce smolt escapement. A piece of Vexar hanging right behind the trap Vs should keep almost all smolts, even the larger ones, from escaping out of the live box.

The inclined-plane traps proved more effective than the fan traps for several reasons. The inclined-plane trap was able to fish in higher velocities and was not as susceptible to plugging from debris. Smolt mortalities were normally 15% to 20% for fan traps and higher if the throat was partially plugged with debris or if it was fished in velocities >0.7 $m \cdot sec^{-1}$. Mortality in the inclined-plane trap averaged <5%; based on personal observations, scale loss is much less, possibly because the trap is not as constricted at the back. However, the larger-diameter holes (½ in) in the bottom plate in some inclined-plane traps caused more scale loss and torn fins than the 5/16-in-diameter holes. At slower velocities (0.5 m·sec^{-1} or less), the fan trap generally works well; conversely, the inclined-plane trap needs at least 0.7 m·sec^{-1} to prevent smolts from backing out of the trap and to develop a small waterfall into the live box, which also prevents captured smolts from escaping.

Inclined-plane traps are also easy to maintain and repair and have low debris loading. The Kasilof River trap was cleaned once a day, taking approximately 10–15 min. The Quartz Creek traps were cleaned every 6 h during the early season and every 3 h from 1800 to 0300 h during the mid to late season; cleaning took 15 to 20 min per trap. I found that the ¾-in-mesh Vexar sides installed on some of the traps took longer and were harder to clean than the ½-in-mesh Vexar. When floods occurred at Quartz Creek the live boxes were disconnected from the traps and the back of the trap was lowered to the streambed to decrease scouring around and underneath the traps.

Finally, the cost of materials per trap, not including the platform and floats, was approximately $900.00, and it took 2 people about 30 h for fabrication. The lightweight but durable design of this inclined-plane trap has facilitated easy transportation and effective use, even in extreme flow conditions.

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