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ELECTRONIC TAGS

Feasibility of Using Implantable Passive Integrated Transponder (PIT) Tags in Salmonids

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Abstract.—The technical and biological feasibility of using passive integrated transponder (PIT) tags for tagging salmonids has been evaluated by the U.S. National Marine Fisheries Service. Each tag is 12.0 mm long by 2.1 mm in diameter and is coded with one of 34×10^9 codes. When energized at 400 kHz, the tag transmits a return signal at 40 to 50 kHz. The tag can be detected in situ at a distance up to 18 cm, which eliminates the need to anesthetize, handle, or restrain fish during data gathering. The tag's longevity is estimated at 10 or more years. The body cavity of juvenile and adult salmonids was found to be an acceptable site for implantation. The PIT tag did not adversely affect growth or survival in laboratory and field tests. Swim-chamber tests showed no significant effect of the tag on respiratory rate, tail-beat frequency, stamina, or survival of juvenile salmonids. Tag retention within the body cavity was nearly 100% for salmonids ranging in size from 50 to 800 mm, fork length. Previously PIT-tagged salmon that were hand-stripped of sperm and eggs showed high tag retention and no adverse effects of the tag.

The ability to recognize individuals or groups within a population is important in fisheries research, and many types of tags and marks have been developed to aid biologists in such recognition (Rounsefell 1963; Farmer 1981). No single technique has been totally satisfactory from a biological or technical standpoint. In 1983, the National Marine Fisheries Service (NMFS) began a study to evaluate the technical and biological feasibility of implanting passive integrated transponder (PIT) tags in salmonids. This paper describes how the tags operate, and it discusses their biological acceptability in salmonids tested under laboratory and field conditions. Details of the tests can be found in Prentice et al. (1984, 1985, 1986, 1987). We present additional information on PIT tagging and on monitoring systems elsewhere in this volume (Prentice et al. 1990a, 1990b).

PIT Tags in Operation

The PIT tag consists of an antenna coil that has about 1,200 wraps of a specially coated copper wire 0.0254 mm in diameter. The antenna coil is bonded to a pad and an integrated circuit chip. The electronic components of the tag are encapsulated in a glass tube 12.0 mm long by 2.1 mm in diameter (Figure 1).

The passive tag relies on an external source of energy to operate. The excitation energy comes from a tuned loop that is part of the tag interrogation system. The system transmits an alternating current via the loop at 400 kHz to establish a magnetic field. When a tag enters the magnetic field for as little as 25 ms, an induction current is established in the transponder antenna coil. The induced current energizes the transponder's integrated circuit. The circuit divides the fundamental frequency by 8 and 10, which results in a frequency shift between 40 and 50 kH giving mark–space coding. The signal from the tag is received by the loop of the interrogation system and passed through a filter to separate it from the 400-kHz excitation signal. The tag signal is then passed through amplifiers and filters, where it is decoded.

Each tag is programmed at the factory with one of about 34×10^9 unique code combinations. The identification code consists of a preamble and a 40-bit code arranged as five 8-bit bytes, each with a parity bit. One reading error per byte can be detected and self-corrected, but more than one error may result in a bad code identification. For a complete description of coding and decoding, see Housley (1979). The data received by the interrogation system are changed via tag-reader cards to 10 ASCII-encoded hexidecimal charac-

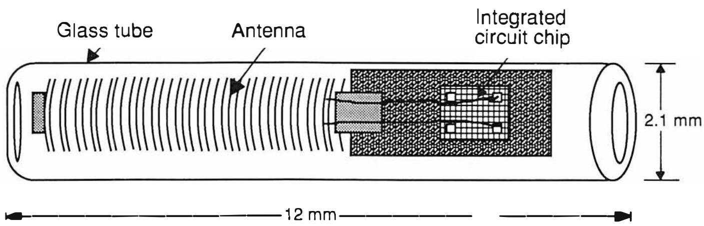

FIGURE 1.—Diagram of a typical PIT tag.

ters for transmission to a computer via an RS232 port, or they are stored within the internal memory of the interrogation system. A portable tag interrogation system (Prentice et al. 1990a) or a fixed tag monitor system (Prentice et al. 1990b) is used to detect and display tag code information. The rate of data transfer is 4,000 bits/s. The range for tag detection varies with the monitoring equipment used—up to 7.6 cm for hand-held tag interrogators, and about 18 cm for fixed full-loop interrogators. The tag can be read easily through soft and hard tissue, seawater, fresh water, glass, and plastic, and with difficulty through metal. Extreme cold or heat (−90 to 60°C) does not appreciably affect detection or reading of the tag. Successful monitoring can take place when the tag is moving at velocities up to 3.6 m/s. Because of the passive nature of the tag, an operational life of 10 years or more is expected.

The operator requires no special permits to use the interrogration system other than what is required by the Federal Communications Commission (FCC) in the USA, or its equivalent elsewhere, to operate low-powered transmitting devices. These permits pertain only to permanent specialized monitoring systems (e.g., at hydroelectric dams), and not to the hand-held interrogation system, which has already been certified by the FCC. No special certification is required to operate tag monitoring equipment.

Biological Suitability

Fish tags should not alter growth, survival, behavior, or reproduction; they should be retained; and they should have a long functional life. Laboratory tests were conducted to examine these factors for PIT tags implanted in salmonids. Juvenile and adult chinook salmon *Oncorhynchus tshawytscha*, sockeye salmon *O. nerka*, steelhead *O. mykiss* (formerly *Salmo gairdneri*) and Atlantic salmon *Salmo salar* were used in the studies. The fish ranged in fork length from about 55 to over 800 mm. Tags were injected into the body cavity with a modified hypodermic syringe and a 12-gauge needle (Prentice et al. 1986, 1987, 1990a).

Tag Retention, Fish Survival, and Fish Growth

Tag retention and operational longevity were investigated during 1986 and 1987. Two groups of 300 juvenile fall chinook salmon were established, one with and the other without PIT tags. The two groups were maintained in fresh water until smolted and then transferred to seawater and held in separate cages. Observations on growth (fork length), survival, and tag retention and operation were made on eight occasions. After 570 d, tag operation was 100% and retention was 98%. Growth of tagged fish was slightly depressed from day 1 to 20, after which it was approximately equal for the control and tagged fish until day 409 (Figure 2). Up to day 409, survival for the control and tagged fish was 89.7% and 86.7%, respectively. Afterward, comparisons of growth and survival were confounded by the appearance in the control group of many precocious males subject to high mortality. At the termination of the study (570 d), survival was 36.4% for control fish and 76.5% for tagged fish.

Also in 1986, we conducted a study to determine the minimum size at which juvenile fall chinook salmon can be successfully PIT-tagged. Approximately 200 fish in each of four size-groups were tagged and held separately (Table 1). Fish ranged in fork length from 56 to 120 mm at the time of tagging. Two water sources—well water and stream water—were used to test the effects of stream water containing fish pathogens on tag wounds and tag retention. Tag retention was excellent for all test groups (99–100%). Healing usually occurred within 14 d, regardless of the water source. Survival of PIT-tagged fish ranged from 97.0 to 100% in the well-water groups and

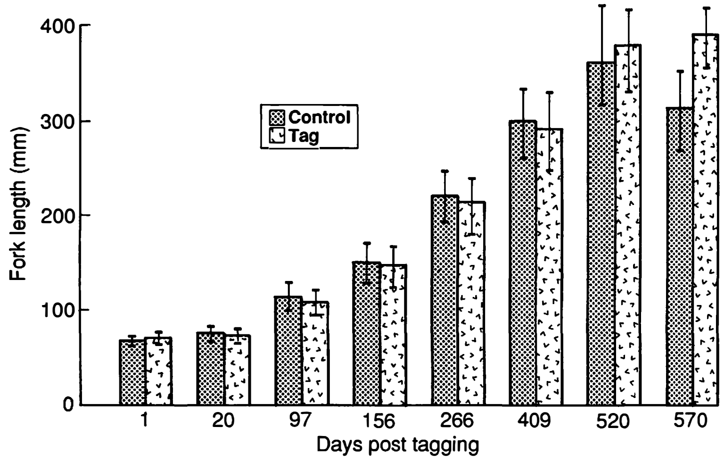

FIGURE 2.—Comparison of growth for 200 PIT-tagged and 200 untagged (control) fall chinook salmon. Columns show means; bars represent standard deviations.

from 95.0 to 98.0% in the stream-water groups. We found no association between survival and fish size, water source, or presence of the tag.

In 1987, using two sizes of fingerlings and one size of smolts, we studied the effect of fish size on tag retention, growth, and survival for sockeye salmon (Table 2). The minimum and maximum fork length at the time the test groups were established ranged from 55 to 107 mm. Each size-group was divided into a control (fish handled but not tagged) and a tagged group. Survival, never below 96.5%, was uniformly high for all test and control groups, and did not differ between them. Fingerlings as well as smolts exhibited high tag retention. The results of this and the previous experiment with fall chinook salmon are in general agreement. Both experiments indicate that the PIT tag can be injected into juvenile salmonids without jeopardizing growth or survival.

To further determine if the PIT tag compromised juvenile salmonids, we conducted a series of field tests on outmigrating yearling chinook salmon, underyearling chinook salmon, and steelhead collected at hydroelectric dams. We compared the survival of PIT-tagged fish with that of control fish (handled but not tagged), coded-wire-tagged fish (CWT), CWT plus freeze-branded fish, and freeze-branded fish. The tests were conducted at Lower Granite Dam on the Snake River and McNary Dam on the Columbia River. Fish from all five treatments were combined in a common holding cage, where they received a continuous supply of untreated river water and examined daily for mortalities. No measurable differ-

TABLE 1.—Growth, survival, and PIT-tag retention for juvenile fall chinook salmon in well and stream water.

Treatment[a] and test group (G)	Number of fish	Test period (days)	Mean (SD) fork length, mm		Survival (%)	PIT-tag retention (%)
			Starting	Ending		
Control–well	202	135	77 (5)	125 (8)	100.0	
Control–stream	200	135	77 (5)	126 (8)	99.0	
PIT-tagged						
Well–G1	201	139	66 (3)	121 (6)	99.5	100.0
Well–G2	200	135	78 (5)	131 (8)	100.0	100.0
Well–G3	201	134	84 (5)	129 (8)	100.0	100.0
Well–G4	200	137	99 (6)	138 (9)	97.0	100.0
Stream–1	200	139	66 (3)	122 (7)	95.0	99.0
Stream–2	200	135	77 (5)	127 (7)	98.0	100.0
Stream–3	203	134	85 (5)	130 (8)	95.0	100.0
Stream–4	202	137	100 (6)	135 (9)	98.0	100.0

[a]The artesian well water had a constant temperature of 10°C and was pathogen-free; the stream water came from Big Beef Creek, had an ambient temperature of 9.3°–14.4°C, and contained pathogens.

TABLE 2.—Growth, survival, and PIT-tag retention for juvenile sockeye salmon.

Fish group and treatment	Number of fish per group	Mean (SD) fork length, mm		Survival (%)	PIT-tag retention (%)
		Starting	Ending		
Small presmolts					
Control	200	67 (4.8)	135 (9.6)	99.5	
Tagged	200	68 (4.1)	137 (10.7)	99.5	100
Large presmolts					
Control	200	82 (6.8)	134 (10.1)	98.5	
Tagged	200	83 (6.5)	130 (10.2)	99.0	98.5
Smolts					
Control	200	96 (4.0)	143 (9.3)	97.0	
Tagged	200	99 (3.8)	144 (9.2)	96.5	100

ence in survival was noted among the groups at the end of 14 d (Table 3).

Wound Healing and Tissue Response to the Tag

The insertion of a PIT tag or other foreign body into a fish is a trauma that may provoke such host reactions as inflammation, melanomacrophage aggregation, encapsulation, and rejection. In 1986, we examined the responses of fall chinook salmon (3.7 g, average weight) to PIT tags. The fish were held in tanks 1.2 m in diameter and supplied with constant 10°C well water. Wound healing was documented visually and histologically. PIT-tagging procedures followed the methods described by Prentice et al. (1990a), and all tags were placed in the body cavity.

Random samples of 10 fish were taken from the population (N = 161) on days 22, 30, and 45 post-tagging and examined histologically. Tissues were embedded in paraffin, sectioned at 6-μm thicknesses, and stained with hematoxylin and eosin. By day 22, the injection wound consisted of granulation tissue that had replaced the dermis and underlying muscle damaged during injection of the tag, and the peritoneum and epidermis had regenerated. By days 30 and 45, the injection site was difficult to locate histologically and complete healing of the wound had occurred.

No host reaction to the tag was observed in any fish. Neither melanomacrophage accumulations nor tissue adhesions were noted, which indicates that the fish did not recognize the tag as a foreign body. The glass-encapsulated tag appears to be biologically inert.

Tagging wounds on the remaining fish were visually evaluated between days 14 and 45. The tag wound had closed on all fish by day 14, when a scar was noticeable on most of them. By day 30, the epidermal pigmentation appeared normal. These observations support the histological evidence and indicate that complete healing occurs within 2 weeks.

Tag retention was 100% during this study. We found most of the tags near the abdominal musculature posterior to the pyloric caeca close to the spleen, but some were between the midgut and the pyloric caeca (Table 4). No tissues adhered to the tags. We have preliminary evidence, however, that some tags may become encapsulated with tissue

TABLE 3.—Percent survival at day 14 post-tagging of fish tagged or marked with PIT tags and other devices at Columbia River dams.

Dam (year)	Species	Control	Tag or mark			
			PIT tag	Freeze brand	Coded wire tag (CWT)	CWT plus freeze brand
Lower Granite (1986)	Yearling chinook salmon	95	98	96	97	99
	Steelhead	100	99	100	99	97
McNary (1985)	Age-0 chinook salmon	96	87	94	92	93
	Yearling chinook salmon	86	83	86	80	89
McNary (1986)	Steelhead	89	87	93	91	94
	Age-0 chinook salmon	64	65	59	68	66

TABLE 4.—PIT-tag locations within the body cavities of juvenile fall chinook salmon over time. Data are percentages of fish examined.

	Days after tagging						
Tag location	14	15	16	23	28	36	39
Near abdominal musculature[a]	91.7	100	100	100	92.8	100	100
Elsewhere[b]	8.3	0	0	0	7.2	0	0

[a]Often embedded posteriorly among the pyloric caeca near the spleen or in the adjacent adipose tissue.

[b]Generally between the midgut and air bladder or between the liver and pyloric caeca. Tags were never found between the pyloric caeca and midgut. All fish retained their tags and none of the tags protruded through the abdominal wall.

after a year or so in the host. The uniform locations noted during this study confirm that a reliable implantation technique has been developed.

Effects of PIT Tagging on Swimming Performance

We evaluated the effects of the PIT tag on swimming performance in 726 juvenile chinook salmon and steelhead (Prentice et al. 1986, 1987). The fish were tested in a modified Blaska respirometer-stamina chamber described by Smith and Newcomb (1970). Experimental fish of several sizes were obtained from a hatchery or collected as in-river migrants (Table 5). We recorded all tests on videotape, which we examined at slow speed to determine swimming stamina, stride efficiency (tail beats per minute), and respiratory rate. Fish were held up to 14 d following the test and monitored for survival.

Neither the act of tagging nor the presence of the PIT tag compromised swimming stamina, stride efficiency, or respiratory rate of juvenile salmonids. Moreover, post-test survival was not affected by the PIT tag, and tag retention was 100% (Table 5). After 14 d, all tagged fish were killed and examined for signs of tissue reaction to the tags. No adverse tissue reactions or tag migrations within the peritoneal cavity were noted. On the basis of these tests, we conclude that the PIT tag

TABLE 5.—Swimming performance, post-test survival, and tag retention of PIT-tagged and control juvenile salmonids.

Species (mean length) and test group[a]	Stride efficiency: mean (SD) tail beats/min[b]	Respiratory rate: mean (SD) opercular beats/min[c]	Swimming stamina: mean (SD) body lengths/s[d]	Post-test[e] Survival (%)	Post-test[e] Tag retention (%)
		Laboratory tests			
Steelhead (83 mm)					
Control	94.3 (22.4)	143.1 (21.2)	5.2 (0.7)	100	100
PIT-tagged	95.8 (22.7)	143.7 (20.8)	5.0 (0.7)	100	100
Steelhead (112 mm)					
Control	95.5 (16.6)	148.8 (16.8)	4.7 (0.6)	100	100
PIT-tagged	99.8 (17.1)	147.7 (15.4)	4.6 (0.5)	100	100
Steelhead (171 mm)					
Control	122.5 (18.4)	135.5 (21.3)	3.1 (0.3)	100	100
PIT-tagged	125.6 (18.4)	135.6 (17.3)	3.1 (0.3)	100	100
Fall chinook salmon (67 mm)					
Control	122.9 (37.9)	137.2 (27.5)	5.5 (0.4)	100	100
PIT-tagged	125.1 (37.3)	136.8 (22.6)	5.4 (0.4)	100	100
Fall chinook salmon (89 mm)					
Control	124.4 (29.7)	130.8 (15.3)	4.7 (0.6)	100	100
PIT-tagged	124.4 (28.9)	130.7 (17.2)	4.6 (0.6)	100	100
		Field tests			
Steelhead (201 mm)					
Control	129.1 (20.9)	145.7 (19.3)	2.9 (0.5)	70.0	100
PIT-tagged	125.8 (17.8)	145.7 (16.3)	2.8 (0.8)	70.0	100
Yearling chinook salmon (137 mm)					
Control	131.8 (23.8)	125.0 (7.5)	3.2 (0.7)	63.6	100
PIT-tagged	124.8 (25.1)	114.3 (16.1)	3.4 (0.8)	56.7	100
Age-0 chinook salmon (111 mm)					
Control	129.6 (35.6)		5.2 (1.2)	26.7	100
PIT-tagged	125.3 (33.0)		5.2 (1.4)	30.0	100

[a]Laboratory fish were reared and tested at the Big Beef Creek facility near Seabeck, Washington: 96–144 PIT-tagged and 32–48 control fish were tested for each group. Migrant fish were collected and tested at the McNary Dam juvenile fish collection facility near Umatilla, Oregon; 30 PIT-tagged and control fish were tested for each group.

[b]Tail-beat rate required to maintain a swimming speed of 1 body length/s.

[c]Respiratory rate is number of opercular beats per minute until impingement on a screen barrier.

[d]Swimming stamina is fatigue level (time to impingement) in body lengths per second.

[e]Post-test holding period was 14 d for laboratory tests and 5 d for field tests.

should not compromise swimming performance of juvenile salmonids during downstream migration.

Effects on Maturing Fish

We investigated whether morphological and physiological changes during maturation altered the response of salmonids to PIT tags. We used 21 male and 60 female maturing Atlantic salmon *Salmo salar* ranging in weight from 2,500 to 10,000 g and in length from 61 to 80 cm. We PIT-tagged the fish according to the method of Prentice et al. (1990a), and examined them several times prior to spawning to determine wound condition, tag retention, readiness to spawn, and general condition. Eggs were collected by hand stripping.

No adverse tissue reaction was noted. All tag wounds were closed and healing by the third day following tagging. No infection or discoloration appeared in the area of the tag. All 21 males matured, and milt was collected from each fish. Tag retention was 100% for the males. Forty-eight females were spawned. Tag retention was 83% for the spawned females and 100% for the nonspawners. Four tags were passed during the first egg stripping and four more during the second through fourth strippings. When a tag was passed, it was easily seen among the eggs. The presence of tags did not appear to adversely affect egg quality or survival.

Future Applications

The PIT tag is the first generation of sophisticated identification systems to take advantage of the computer age. Its use is not limited to salmon—prawns and crabs also have been tagged, and the tag is applicable to any animal that can accept and retain it. Advantages and applications of the PIT tag include individual identification of brood stock, serial measurements (e.g., growth) of individuals, reduction in number of replicates, and combination of treatments. It can also be used in behavioral studies to monitor animal movements automatically or through capture–recapture methods. Pelagic animals might be monitored by means of trawl nets equipped with PIT-tag detectors mounted in an open cod-end or a specially constructed purse seine, whereas movement of benthic animals might be monitored with a grid system or underwater sled. Innovation is the key to future use of the PIT tag.

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