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Evacuation of Passive Integrated Transponder (PIT) Tags from Northern Pikeminnow Consuming Tagged Juvenile Chinook Salmon

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Abstract.—Prey fish implanted with passive integrated transponder (PIT) tags can be used in predation studies if the timing of tag evacuation from the predators is understood. Laboratory experiments were conducted to determine how PIT tags in juvenile Chinook salmon *Oncorhynchus tshawytscha* that were consumed by northern pikeminnow *Ptychocheilus oregonensis* were evacuated in relation to various parameters. The rate of evacuation was directly related to temperature, while predator size and the number of prey consumed had less effect on the timing of tag evacuation. A power model was fitted to predict the proportion of tags expected to be evacuated at different intervals after ingestion. These results could be used in planning field or laboratory predation experiments with PIT-tagged prey fish.

Passive integrated transponder (PIT) tags consist of an integrated circuit chip, capacitor, and antenna coil encased in glass (Prentice et al. 1990). These tags are implanted into the peritoneal cavity of fish and transmit a unique signal to a reader. The use of PIT tags has become increasingly common during the last decade, and PIT tags are used in studies of fish movement, habitat use, and predation risk (e.g., Utne et al. 1997; MacKenzie and Greenberg 1998; Skalski et al. 1998). Because of their small size (0.07 g; ~12 mm × 2 mm) and internal placement in fish, PIT tags may be especially useful to mark prey in predation experiments because predators are often attracted to an external tag (e.g., Ross and McCormick 1981).

PIT tags have been used to estimate the survival of fish through river reaches, migration rates, adult return patterns, and predation losses in various streams and rivers (e.g., Faengstam et al. 1993; MacKenzie and Greenberg 1998; Zabel et al. 1998). In the Columbia River Basin (USA), PIT tags are used extensively, with over 6.6 million juvenile Pacific salmon *Oncorhynchus* spp. having been tagged and released since 1987 (Pacific States Marine Fisheries Commission 2002). Since 1998, over 1 million juvenile salmonids were tagged yearly in this basin, with a peak of 1.5 million fish tagged in 1999.

Northern pikeminnow *Ptychocheilus oregonensis* prey on juvenile salmonids in western North America, and are a primary source of mortality for downstream migrating salmonids in the Columbia River Basin (Ward et al. 1995). The occurrence of PIT-tagged prey within the gut of northern pikeminnow could be used to identify the species, release location, original size of prey, and the travel history of fish passed through dams that are equipped with PIT tag detectors (Skalski et al. 1998). Since 1990, over 1.1 million northern pikeminnow have been collected in a predator management program (Friesen and Ward 1999), but predators were not checked for the presence of PIT tags.

We conducted a laboratory experiment to determine how PIT tags in juvenile salmonids that are consumed by northern pikeminnow are evacuated in relation to predator size, temperature, and prey size. We compared the evacuation times among test groups and fit an evacuation model that can be used to predict the probability of tags remaining in predator guts over time. Information on the evacuation rates of PIT tags from predators can be used in designing field or laboratory experiments, or in evaluating the presence of PIT tags in captured predators.

Methods

Laboratory experiments.—Northern pikeminnow captured by electrofishing (400-V pulsed DC, 4 amps) below the Bonneville Dam (Columbia River, USA) were placed in 1.5-m circular tanks with a water inflow rate of 7.5 L/min at a temperature of 18°C. Each predator was weighed (g), measured (fork length [FL], mm), and tagged with a uniquely marked dart tag. The predators were also fin-clipped in case of tag loss during handling

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TABLE 1.—Summary results of PIT tag evacuation trials with northern pikeminnow feeding on tagged juvenile Chinook salmon. Experiments were conducted under three treatments: 18°C (one and two prey per predator) and 14°C (one prey per predator). Each treatment was replicated (trials). Numbers in parentheses are SDs. Sample sizes do not match because 3 tags were regurgitated, 13 tags were evacuated prior to our sampling, and 1 tag was retained longer than the observation period (60 h maximum).

	Treatment		Prey size			Predator size		PIT tag evacuation times			
Trial	Temperature (°C)	Number of prey per predator	Mass (g)	Fork length (mm)	*N*	Mass (g)	*N*	Average time (h)	Minimum (h)	Maximum (h)	*N*
1	18	1	15.6 (2.0)	115 (4)	17	779 (294)	16	20.9	15	32	16
2	18	1	16.4 (1.4)	117 (3)	17	788 (301)	15	23.7	14	35	15
1	18	2	5.8 (1.7)	81 (9)	34	766 (286)	15	23.8	13	54	30
2	18	2	5.1 (1.3)	78 (14)	34	645 (226)	14	20.0	10	35	28
1	14	1	12.9 (2.9)	113 (7)	17	671 (232)	17	32.5	24	45	17
2	14	1	12.8 (2.7)	113 (6)	17	688 (248)	14	32.8	23	60	14
3	14	1	13.6 (2.8)	115 (7)	17	670 (239)	16	30.3	18	60	16

and feeding. Northern pikeminnow were acclimated to laboratory conditions for a minimum of 2 weeks and were fed a maintenance diet of juvenile Chinook salmon *O. tshawytscha*. The juvenile Chinook salmon used as prey were measured (FL, mm) and weighed (0.1 g). All prey were individually marked by injecting PIT tags into their body cavity.

We conducted three treatments, varying the water temperature (14°C and 18°C) and the number of prey fed to predators (one or two prey; Table 1). The design was unbalanced, lacking trials of two prey per predator at 14°C. Each experimental treatment was replicated in separate tanks (Table 1). The average daily water temperatures in the Columbia River during July (a period of high predation) ranged from about 13–21°C during 1938–1996 (Petersen and Kitchell 2001). We conducted trials at 14°C and 18°C, which bounds the river conditions during most summers. Water temperatures varied slightly over a diel period in the experiments, but were always within ±0.5°C and usually within ±0.2°C of the target temperature. For the 18°C trials, we also varied the number of prey from one to two fish (Table 1).

To begin a trial, we starved predators for 72 h (Beyer et al. 1988), then force-fed eight or nine predators a meal consisting of one or two PIT-tagged juvenile salmonids. The predators were netted and held in a padded surgical cradle using foam moistened with artificial fish slime (Stress Coat) to reduce injury to the fish. The prey were killed by physical injury to avoid any possible effects of chemicals on northern pikeminnow digestion rates. The salmonid meal was force fed to predators with a 30- or 60-cc syringe, depending on the fish size (Vondracek 1987). The predators were usually out of the water less than 2 minutes for feeding. The time of feeding was recorded and the predators were placed back into the tank.

We estimated the approximate time when PIT tags might be expected to occur in the tank using a prey evacuation model developed by Beyer et al. (1988), and started hourly sweeps of the tank at that time. The sweeps were conducted with a magnet moved slowly around the floor of the tank to minimize fish disturbance. PIT tag recovery time was the midpoint of the interval during which an individual PIT tag was recovered.

Experiments were conducted between 2 August 2000 and 11 October 2000. Predators were replaced in one tank on 23 August due to a fungal infection. The time between trials was about 7 d. For trials at the second temperature (14°C), we acclimated predators at a rate of 1°C/d down to the desired temperature.

Data analyses.—To see if the results from the tanks could be pooled in a treatment, we tested for differences among tanks in prey size, predator size, or evacuation times using an analysis of variance (ANOVA). For each variable, ANOVA was conducted on treatment and tank nested within treatment; an insignificant effect ($P > 0.05$) at the tank level would allow pooling.

The effects of predator size and prey size on the evacuation time were examined by correlation (Pearson's correlation r) because these were not primary treatment variables. Using $\log_e$ transformed times and t-tests, the average times for the evacuation of PIT tags were compared between 14°C and 18°C with one prey, and between one and two prey meals at 18°C.

We used a power function (Elashoff et al. 1982; dos Santos and Jobling 1992) to model the probability of tag evacuation at a given time after ingestion. dos Santos and Jobling (1991) modeled the weight W_t of prey in Atlantic cod *Gadus morhua* evacuated at time t (h) using a power exponential function:

$$W_t = W_0 \times 2^{-(t/H)^S}$$

where W_0 is the initial prey weight, S is a parameter that controls the shape of the function, and H is a measure of the half-life (h) of a meal. This is a very flexible form and can be used to describe a variety of types of evacuation depending upon the value of S.

The probability Ptag_t that a PIT tag would remain in a predator gut at time t was assumed to be analogous to W_t/W_0 in the dos Santos and Jobling formulation:

$$\text{Ptag}_t \cong W_t/W_0 = 2^{-(t/H)^S} \quad (2)$$

We used this model form because it has been shown to describe gastric evacuation processes in a variety of cases (Elashoff et al. 1982; dos Santos and Jobling 1992). We fit equation (2) separately to the three treatments (14°C with one prey per predator, 18°C with one prey per predator, and 18°C with two prey per predator; Table 1). Ptag_t was the proportion of all PIT tags in a treatment that remained in predator guts at 4-h intervals. Model parameters were fit with a nonlinear, least-squares program.

Results

The predators (Table 1) used in the experiments ranged in weight from 246 to 1,260 g (mean ± SD = 737 ±283 g; N = 25), and were from 288 to 485 mm FL (mean ± SD = 399 ± 53 mm; N = 25). Juvenile salmonids (Table 1) used as prey ranged in size from 2.9 to 19.4 g (mean ± SD = 10.4 ± 5.0 g; N = 153) and were from 67 to 130 mm FL (mean ± SD = 99 ±18 mm; N = 153). Of 153 prey fish tagged and fed to predators, three were regurgitated, 13 tags were evacuated prior to our sampling, and one tag was retained past our sampling interval (60 h). We observed no significant difference between replicate tanks for prey weight (F = 1.11; df = 4, 146; P = 0.352), predator weight (F = 0.56; df = 4, 146; P = 0.690), or evacuation time (F = 1.19; df = 4, 129; P = 0.319), so replicate trials were pooled for analyses below.

The median evacuation times were 40 h for fish with one prey fish at 14°C, 22 h for fish with one prey at 18°C, and 19 h for fish with two prey at 18°C. Comparing the one-prey treatments only, the average time for PIT tag evacuation was slower at 14°C (31.9 h; N = 47) versus 18°C (22.2 h; N = 31; t = 5.48; df = 76; $P < 0.001$). Comparing the treatments at 18°C, average evacuation times were not significantly different between the one-prey (22.2 h; N = 31) and the two-prey treatments (21.9 h; N = 58; t = 0.16; df = 87; P = 0.87). The results of this second test are confounded somewhat by a difference in the total meal size between the one- and two-prey meal sizes. We attempted to hold meal size constant for the one- versus two-prey comparison by using smaller prey; however, the total meal weight was significantly less in the two-prey treatment (11.3 g; SD = 2.9; N = 58) than in the one-prey treatment (16.1 g; SD = 1.7; N = 31; t = 8.51; df = 87; $P < 0.001$).

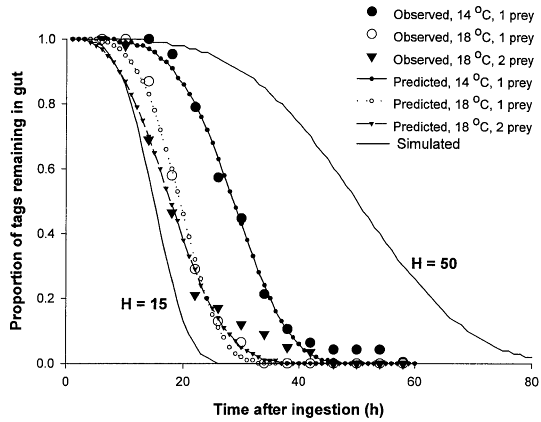

FIGURE 1.—Observed and predicted proportions of PIT tags remaining in a northern pikeminnow gut for experiments at 14°C (one prey per predator) and 18°C (one or two prey per predator). Model predictions are based on equation (2) in the text. The solid lines without symbols were simulated with parameter H set to 15 and 50 and parameter S to 3.7; these simulations correspond to temperatures of roughly 10°C (H = 50) and 20°C (H = 15).

The evacuation time was not significantly correlated ($P > 0.05$) with prey mass or fork length for any of the three treatments. While evacuation time was negatively correlated with predator size ($r = -0.33$; N = 47; P = 0.025) for the 14°C one-prey treatment, the correlations between predator mass and evacuation time were insignificant for the treatments at 18°C, either with one prey ($r = -0.21$; N = 31; P = 0.246) or with two prey ($r = -0.044$; N = 58; P = 0.746).

The power function provided a highly significant fit to the data for each of the three treatments (Figure 1; Table 2). The models tended to underpredict slightly the cases where tags were retained for long times (e.g., >40 h at 14°C; Figure 1). The

TABLE 2.—Parameter estimates (95% confidence intervals in parentheses) used to predict the proportion of PIT tags remaining in northern pikeminnow guts at different times following ingestion. A power function (equation 2 in the text) was used to fit parameters to laboratory experiments conducted at 14°C (one prey per predator) and 18°C (one or two prey per predators).

	Parameters		Fit statistics		
Treatment	*S*	*H*	*F*	df	*P*
14°C, one prey	4.23 (3.48, 4.99)	28.55 (27.62, 29.48)	808.6	2,7	<0.001
18°C, one prey	3.98 (2.95, 5.01)	19.39 (18.44, 20.34)	436.3	2,4	<0.001
18°C, two prey	2.79 (1.89, 3.69)	17.80 (16.21, 19.39)	205.6	2,8	<0.001

shape parameter S was much greater than 1.0 for all treatments, but the 95% confidence intervals for S overlapped among the three treatments (Table 2). The half-life of tag evacuation H was different among treatments (Table 2).

Discussion

PIT tags in juvenile salmonids ingested by northern pikeminnow were retained for less than 60 h in all but one instance, and the process for tag evacuation could be largely predicted by temperature alone. The exponential power function that we used for modeling the probability of tag retention worked reasonably well, although the model did not fit those few tags that were retained for a long period in the predator gut (Figure 1). The model tended to underestimate the proportion of tags remaining in a predator compared with the observations at both 14°C and 18°C. However, the underestimation was not great; for example, the 18°C two-prey model predicted no tags would be retained at 36 h, while the experimental data suggested that about 5% of tags would be retained at this time.

Dos Santos and Jobling (1991) studied the rates of evacuation of small pieces of wire, plastic, or glass from cod, and observed patterns similar to ours. For cod fed a single meal, large plastic beads (5 mm) showed a relatively slow rate of evacuation compared with the evacuation of the Atlantic herring *Clupea harengus* meal. Dos Santos and Jobling (1991) also fit a power function to their data. The half-life (H) of plastic beads was greater than 300 h and the shape parameter (S) was greater than 1 (1.2), suggesting a delay period. Two-mm beads passed through the gut more rapidly than the large beads, but still slower than digested herring. The cod experiments were conducted at 5.0–7.2°C, compared with 14–18°C for our experiments with northern pikeminnow; this would partially explain the longer retention times for the particles in the cod compared with the PIT tags in the northern pikeminnow. Also, northern pikeminnow lack a true stomach, while cod have a typical stomach and intestine.

Our results may have been influenced by the force-feeding of prey, although it is unclear whether PIT tags would have been retained for longer or shorter times if the prey had been voluntarily consumed. For studies conducted with northern pikeminnow and Sacramento pikeminnow *P. grandis*, digestion times at 10°C for similar meals and predator sizes were 29 h (Falter 1969; Beyer et al. 1988), 38 h (Sacramento pikeminnow; Vondracek 1987), and 51–141 h (Steigenberger and Larkin 1974). Vondracek (1987) force-fed Sacramento pikeminnow in his experiments, which may have caused longer digestion times than those observed by Beyer et al. (1988) or Falter (1969). Swenson and Smith (1973) concluded that the digestion rate of walleye *Sander vitreus* (formerly *Stizostedion vitreum*) was decreased by the force-feeding of prey, although they looked at only the first 8 h after feeding. In our experiments, the handling stress caused by force-feeding may have caused some change in the digestion rate, but our times for the evacuation of tags are fairly similar to the total digestion times from other *Ptychocheilus* studies. Thus, volitional feeding by predators likely would not have produced different results in our study. We did not conduct volitional feeding experiments because northern pikeminnow do not feed well when alone in a tank (personal observations), and volitional feeding with several predators per tank would have made it difficult to collect data on the time of the ingestion of prey, predator size, and prey size.

About 8% of the tags in our experiments were evacuated prior to the start of our sampling effort (~6 h after feeding), and we therefore could not use these untimed tag evacuations in our analyses. Thus, the reported evacuation times and model parameter estimates are slightly biased. For example, the mean tag retention time for the 18°C experiments was 22.0 h (N = 89), and this mean would have been 20.7 h (N = 98) if we included the untimed tag observation and assigned them random evacuation times between 1 and 6 h. The inclusion of the untimed observations in the probability model, and assuming random time distributions for the untimed observations, caused parameter estimates to vary less than 15% (results not presented). The tags evacuated early came from somewhat smaller prey than for the data used to fit the models (8.3 g versus 10.6 g, respectively), but this difference in average size was not significant ($t = 1.59$; df = 146; $P = 0.114$).

The model for evacuation probabilities could be used to approximate the times that PIT tags might be expected to be in predators in a specific area, which could guide the sampling efforts for predators. For example, with a predator population that would be sampled at 18°C, the half-life of PIT tags in predator guts would be 18 h, and 90% of the tags would be evacuated within 27 h. At 14°C, 90% of the tags in an experiment would be expected to be evacuated in less than 50 h. In field experiments near hydroelectric dams, large numbers of PIT-tagged juvenile salmonids are often released to estimate route-specific survival (Skalski et al. 1998). If significant numbers of these tagged fish were consumed by downstream predators, and predators were recaptured, it would be possible to estimate the total number of prey consumed and the relative mortality by route of passage. Knowledge of the timing of evacuation is necessary in this type of experiment to plan the period for predator sampling. These results could also be useful in laboratory experiments with PIT-tagged prey, providing guidance on the period of time an experiment might be run to assure that any tagged prey fish had been evacuated from a predator.

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