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NOTES

Comparison of Predator Avoidance Capabilities with Corticosteroid Levels Induced by Stress in Juvenile Coho Salmon

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Abstract.—The relationship between predator avoidance deficits induced by a simple handling stress and the level of plasma corticosteroids was determined for juvenile coho salmon *Oncorhynchus kisutch*. Groups of fish were held out of water for 1 min, then allowed to recover from this stress for 1, 90, or 240 min. After each recovery period, some unstressed and stressed fish were sampled for plasma cortisol, and others were subjected to predation by lingcod *Ophiodon elongatus*. Levels of corticosteroids in stressed fish remained high throughout the 240-min period of recovery, but predator avoidance returned to control levels in less than 90 min. Results suggest that juvenile coho salmon quickly recover basic survival skills of predator avoidance after mild stress, even though cortisol levels continue to indicate a stressed condition.

Activities associated with the transportation and release of hatchery-reared salmon may induce sublethal levels of stress that may subsequently affect survival skills and thus survival. Physiological indices of sublethal stress have been well established, and in some cases the relationship between these indices and potential deficits in performance have been examined (for a recent review see Schreck 1990). However, the ecological consequences of performance deficits associated with physiological changes have been mainly neglected. If the ecological consequences of molecular or biochemical changes are not assessed at the organismal level, the utility of applying such measures at the population and ecosystem level may be severely limited (Thomas 1990). Stress-induced alterations in behavior associated with

the acquisition of food affect survival over the long term, but deficits in predator avoidance may be manifested almost immediately when hatchery fish are placed in the natural environment. In an earlier study, smolts of coho salmon *Oncorhynchus kisutch* subjected to handling stress had lowered ability to avoid predation for up to 60 min after stress induction (Olla and Davis 1989). Our aims in the work reported here were to confirm that the handling to which the fish were subjected was indeed stressful, as judged by the presence of a clinical stress response (elevated circulating cortisol concentration) and to evaluate any correlation between clinical stress response and predator avoidance ability.

Methods

The juvenile coho salmon we used were hatchery-reared, age-0 smolts from Oregon Aqua Foods; these fish originated from a mixture of stocks from the Green River, Washington, and the Siletz River, Oregon. Groups of 200–500 fish, ranging in length from 110 to 150 mm, were held in flowing seawater (30–33‰, 10–13°C) in circular tanks (1.9-m diameter, 0.66-m depth, 1.87-m³ volume). Fish were fed moist BioDiet pellets daily for 1–4 months prior to testing. We used lingcod *Ophiodon elongatus* (45–70 cm long) as natural predators of juvenile coho salmon and obtained the lingcod by hook-and-line fishing offshore from Newport, Oregon. We conducted all experiments from June through September in two plastic-lined circular pools (4.54-m diameter, 0.915-m depth, 14.81-m³ volume), each supplied with flowing seawater (40 L/min). We kept one lingcod in each pool continuously for up to 360 d and fed each fish 10–12 live coho salmon weekly during predation trials. We conducted one trial per pool per week, which allowed for recovery of lingcod appetite.

Six days before a trial, we placed 10 coho salmon that were to serve as control, unstressed fish into each of two opaque enclosures (0.60-m diameter, 0.80-m depth, 0.23-m³ volume) within

one of the experimental pools. The opaque enclosures were supplied with seawater recirculated from the experimental pools by air-lift pumps. Twenty coho salmon that were to be stressed were transferred to a separate tank (1.2-m diameter, 0.5-m depth, 0.57-m³ volume). Both groups were fed daily during a 6-d pretrial period. In alternate trials, the control or treatment group of coho salmon was marked for later identification by clipping the adipose fins.

On the day of a trial, we transferred fish to be stressed to a 20-L bucket with a mesh bottom and held them out of water for 1 min as described by Olla and Davis (1989). We then distributed 10 of these fish to each of the two opaque enclosures that held control fish in the predator pool. After a stress-recovery period of 1 min (five trials), 90 min (six trials), or 240 min (six trials), the fish in one opaque enclosure were released into the predator pool and the fish in the other enclosure were carefully netted and killed with buffered tricaine (MS-222) for plasma cortisol analysis. We left the prey fish with the lingcod for 1 h or until half were eaten; then we netted, weighed, and measured the survivors and identified them to group. We sampled blood immediately from fish killed in anesthesia by severing the caudal peduncle and collecting blood into heparinized capillary tubes; the plasma was separated from other constituents by centrifugation and stored at -20°C for later analysis. Cortisol concentrations in the plasma samples were determined with radioimmunoassay techniques as described by Foster and Dunn (1974) and modified by Redding et al. (1984). Values for cortisol concentration obtained from 10 unstressed fish and 10 stressed fish per replicate trial were pooled to give a mean value per treatment per replicate.

Values for cortisol concentration and number of fish eaten did not fit normal distributions, so we used nonparametric statistical tests. To assure that appetite was not a factor in the analysis, the sign test (Conover 1980) was used to test differences in number eaten between unstressed and stressed fish based on results from trial pairs within a recovery time. The Tukey two-sample test (Tukey 1959) was used to test differences in concentration of cortisol between stressed and unstressed fish within a recovery time.

Results and Discussion

After a 1-min recovery from handling stress, coho salmon had significantly elevated plasma corticosteroid concentrations ($P = 0.01$); cortisol

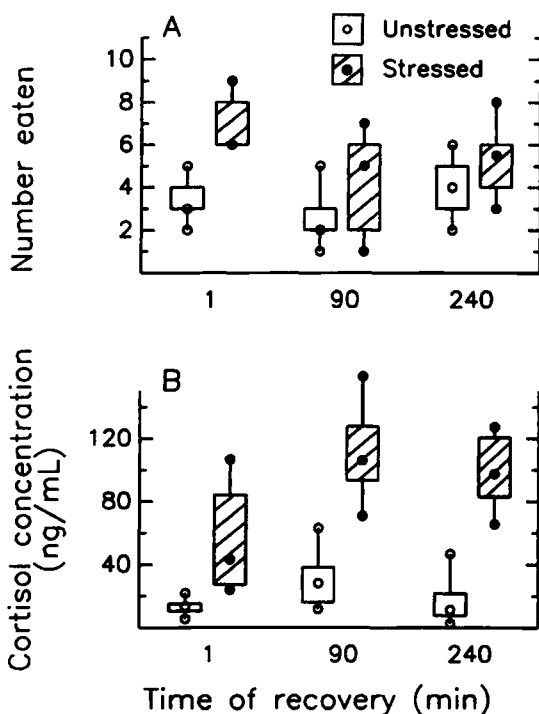


FIGURE 1.—Effect of recovery time after handling stress on (A) predation on juvenile coho salmon (number eaten by lingcod) and (B) cortisol concentration in juveniles. Values are median \pm second and third quartile (middle dot and box) and range (upper and lower dots) for five trials (1-min recovery periods) or six trials (90- and 240-min recovery periods). Median value for the number of stressed coho salmon eaten after the 1-min recovery is the same as the lower range value.

levels were even higher at 90 min ($P = 0.01$), and they remained high at 240 min ($P = 0.01$; Figure 1B). This followed the pattern observed in earlier studies of juvenile coho salmon held in fresh water (Specker and Schreck 1980; Schreck 1981; Schreck et al. 1989)

Although handling stress impaired the ability of coho salmon to avoid predation after a 1-min recovery period ($P = 0.03$), no difference in predation mortality between stressed and unstressed fish was apparent at 90 min ($P = 0.50$) or at 240 min ($P = 0.50$; Figure 1A). A deficit in the ability of stressed juvenile coho salmon to avoid predation followed by recovery of the ability was observed in an earlier study where predation avoidance was impeded at 60 min but recovered by 90 min (Olla and Davis 1989). It appears that handling stress was associated with a short-term predator avoidance deficit that ended sometime between 60 and 90 min after stress. No clear relationship was de-

tected between cortisol concentration and predator avoidance ability. The use of cortisol as a standard bioassay of the potential for survival of smolts clearly needs further evaluation.

It is plausible that the initial pulse of cortisol was instrumental in helping the fish recover from the handling stress. One of the main functions of this steroid in fishes is to mobilize energy, making glucose available for active processes (Leach and Taylor 1980, 1982). This would be beneficial for enhancing both swimming ability and neural and behavioral processes, essential elements to successful predator avoidance. It is also likely that fast-acting psychogenic compounds such as catecholamines are produced during handling. Although these compounds are highly adaptive for sudden flight from danger, they may cause transient deficits or enhancements in more complex behaviors associated with predator recognition and avoidance (Mazeaud et al. 1977). However, identification of linkages between biochemical or physiological processes and complex behavior is still very much in the speculative phase.

Elevations of corticosteroids associated with chronic stress in salmon have been shown to alter functions such as social behavior, ability to learn or remember behaviors, and sensory abilities that mediate behavior for longer periods than observed in the present study. For example, in a dominance hierarchy of coho salmon smolts, subordinate fish had higher concentrations of plasma cortisol than did dominant fish after 14 d (Ejike and Schreck 1980). Paszkowski and Olla (1985) showed that low-ranking subordinate coho salmon smolts held in seawater for 6 weeks or more showed lower levels of agonistic behavior when they were no longer in the presence of dominant fish, indicating that the induced stress from being subordinated for a long time was not readily reversible.

Acute stresses such as handling and transport also have behavioral effects. Unstressed coho salmon juveniles learned to recognize selected odorants in a few days, but they required 5–7 weeks to do so after imposition of transportation stress (Sandoval 1979). Additionally, coho salmon trained to recognize odorants required 2 d of recovery from a short handling stress before regaining their original level of performance. Few if any studies have evaluated ecologically meaningful effects of acute stress on behavior and correlated these effects with biochemical measures.

Although some behaviors can be affected by stress for days or even weeks after a stressful event,

our results indicate that some basic, behaviorally mediated survival skills associated with avoiding predation could recover rapidly (within 90 min). However, the intensity and duration of stress would play a role in the magnitude of behavioral performance deficits because the physiological effects of multiple stresses have been shown to be cumulative (e.g., Barton et al. 1986; Maule et al. 1988; Mesa 1989). We conjecture that recovery of predator-avoidance skills would take longer after exposure to more intense or multiple stressors such as those imposed during transport of smolts from hatcheries for outmigration.

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