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THE STRESS RESPONSE AND ITS CONSEQUENCES IN CULTURED FISH

JOHN P. SUMPTER

Department of Biology and Biochemistry, Brunel University, Uxbridge, Middlesex UB8 3PH, U.K.

J. P. Sumpter (1991) The stress response and its consequences in cultured fish. *Bull. Inst. Zool., Academia Sinica, Monograph* **16**: 229-236. The consequences of stress on the performance of cultured fish are discussed. It is shown that stress leads to wide-ranging physiological changes. These changes include reduced reproductive performance, manifest as a reduction in the quality and quantity of gametes, a reduced growth rate and an increased susceptibility to disease, leading to an increased rate of mortality of stressed fish. Thus, for optimum performance of cultured fish, stress should be minimized as much as possible.

Key words: Stress, Reproduction, Growth, Disease.

Many different factors, which here I will call stressors, cause stress to fish. These stresses can be of many different types; for example, they can be chemical, such as pollutants in the water, or physical such as disturbance or an elevated water temperature. Many practices in aquaculture, some necessary but others not, lead to disturbance or overcrowding of fish, which will be stressful to them. There is probably almost an infinite list of the various ways and means of stressing fish in culture. As far as we can tell presently, any stressor causes a common series of well-defined physiological changes (these are described below). However, of greatest interest to people trying to make a living culturing fish is not so much the details of these physiological changes, but rather the consequences of them, and hence it is on these ultimate effects of stress that this brief review will concentrate.

THE PHYSIOLOGY OF A STRESS-RESPONSE

It is generally considered that two main components make up the response of a fish to stress. These are both neuroendocrine: one is the

sympatheticochromaffin system and the other is the hypothalamic-pituitary-interrenal (HPI) axis.

The former consists of sympathetic nervous stimulation of the chromaffin tissue of the interrenal gland, leading to the very rapid release (within seconds) of catecholamines, principally adrenaline and noradrenaline. The main sites of action of these catecholamines are the respiratory and cardiovascular systems; thus both the respiration rate and the heart rate (and blood pressure) increase. The objective of these rapid changes is increased uptake and utilization of oxygen, to provide the energy necessary for the fish to escape the stressor (if that is possible). The catecholamines also act directly on the liver to stimulate glycogenolysis (the hydrolysis of stored glycogen to glucose-1-phosphate, which may then be converted to free glucose), hence providing a ready supply of glucose for muscular activity (such as may be necessary to flee the stressor).

Stimulation of the HPI axis leads to a sequence of endocrine events. The first of these is the release of corticotrophin-releasing factor (CRF) from the hypothalamus, which is conveyed to the anterior pituitary gland where it stimulates the release of adrenocorticotropin (ACTH) from the corticotrophs. Circulating ACTH in turn stimulates the interrenal gland to synthesize and secrete cortisol, the major corticosteroid in fish (Sumpter *et al.*, 1986). Neither CRF nor ACTH are thought to play any role in the stress-response other than as intermediaries in the release of cortisol; it is considered that all the effects that follow from activation of the HPI axis are caused by the elevated cortisol concentrations. Whereas the release of catecholamines is extremely rapid, and their effects also rapid, this is not the case with the HPI axis. The actual release of cortisol from the interrenal gland occurs within a few minutes of the stressor being perceived, but the effects of an elevated cortisol concentration (which can last for weeks, if not months, if the stressor persists), may not manifest themselves for some considerable time.

Although almost all attention to date has centred on the effects of activation of these two major components of the stress response, it appears increasingly likely that many other regulatory systems are affected. For example, evidence is steadily accumulating that the secretion of other pituitary hormones (besides ACTH) is altered when a fish is

stressed (Sumpter *et al.*, 1985; Pottinger *et al.*, 1991b) and therefore the effects of these hormones will in turn also be altered. It may well be that all of the endocrine system is affected by stress.

THE CONSEQUENCES OF A STRESS RESPONSE

I have already mentioned the major consequences of elevated catecholamine concentrations; the remainder of this review will deal with the effects of activation of the HPI axis. There are probably a large number of distinct consequences of an elevated cortisol concentration; presently we know of a few only, and even these have only come to light through research conducted in the last few years. The following text focuses on three areas where stress has strongly deleterious effects on aspects of great importance to aquaculture.

Impaired reproduction

Reproduction is controlled by hormones, and hence to assess whether stress affected reproduction we chose initially to monitor the concentrations of the "reproductive hormones". We showed that stress affected the endocrine control processes at various levels; for example, fish subjected to stress had lowered circulating concentrations of sex steroids and vitellogenin (Pickering *et al.*, 1987; Pottinger *et al.*, 1991c). Subsequent research demonstrated that the implantation of cortisol-releasing pellets into fish could reproduce these effects; that is, it appeared that cortisol was the agent responsible for the effects we observed on the reproductive system (Carragher *et al.*, 1989). This hypothesis was confirmed when we showed, using *in vitro* techniques, that cortisol could suppress gonadotrophin secretion from pituitary glands (Carragher and Sumpter, 1990a) and sex steroid secretion from ovarian follicles (Carragher and Sumpter, 1990b).

It is all very well to demonstrate such effects, but what is really of importance is whether such effects on the endocrine system lead to a reduction in the quantity and/or quality of the gametes produced. We have begun recently to examine this issue, and we have found that stress does indeed affect the gametes; in females ovulation was delayed and egg size was reduced, and in males sperm volume and number were reduced (Campbell *et al.*, 1991). Further and perhaps of greatest

importance, when sperm from males that had been stressed was used to fertilize eggs from females that had also been stressed, there was a marked reduction in the survival rate compared to the offspring from control fish (Campbell *et al.*, 1991). Our next step will be to try and determine exactly how stress led to the eggs and/or sperm being of poor quality.

Interestingly, Munkittrick and colleagues have reported similar effects during their studies on *wild* populations of white sucker (*Catostromus commersoni*) which live in water contaminated with the effluent from pulp mills (McMaster *et al.*, 1991; Munkittrick *et al.*, 1991). Thus, it may be that both physical (our studies) and chemical (Munkittrick and colleagues' studies) stressors can reduce the reproductive performance of fish. This may be of particular importance in culture situations where the water is susceptible to contamination.

Reduced growth rate

The growth rate of fish under culture is obviously an extremely important factor in determining the overall economic viability of aquaculture, and hence knowledge of the factors that control the growth rate is vital. Many factors affect the rate of growth: these can be somewhat arbitrarily separated into environmental, nutritional, genetic and physiological factors (Sumpter, 1991). In practice, however, many factors operate simultaneously to determine the rate of growth. Although we know a reasonable amount about some of these factors, such as the nutritional requirements for optimal growth, we know relatively little about others, such as the physiological factors controlling growth.

At the centre of the physiological control of growth is growth hormone. This hormone, of pituitary gland origin, acts *via* insulin-like growth factors (especially IGF-I, which is synthesized primarily in the liver) to regulate growth. Unfortunately our knowledge of the factors influencing circulating growth hormone (and presumably IGF-I) concentrations is poor presently (see Sumpter, 1991, for a review of what is known). Obviously some factors will lead to an increase in circulating growth hormone concentrations, and hence probably to an increased growth rate (if other factors, such as food intake, are appropriate), whereas others will lower circulating growth hormone concentrations, and hence retard (or even stop) growth.

One factor which definitely suppresses growth is stress (see review by Pickering, 1991). Environmental factors which, if outside the desired range, have a major influence on growth rate include water temperature, ambient photoperiod, and food supply. These may not, however, necessarily, trigger a stress response (that is, they may not cause the endocrine changes described earlier), even though growth rate is affected. Other environmental stressors, however, can and do cause a physiological stress response while concomitantly depressing the rate of growth; any physical disturbance of the fish, poor water quality, or social domination by other fish are good examples. The physiological mechanisms underlying the reduced growth rate of fish exposed to unfavourable environmental conditions are poorly understood presently (partly because the techniques for quantifying circulating growth hormone and IGF concentrations have only recently been established, require improvement, and are not widely available). Some environmental stressors, such as disturbance followed by confinement (crowding) can cause lowering of circulating growth hormone concentrations (Pickering *et al.*, 1991), which may well be responsible for the reduced growth rate such conditions cause. However, other stressors, such as chronic poor water quality (associated with a low oxygen content), can cause an elevation in circulating growth hormone concentration (Pickering *et al.*, 1991), which may well be responsible for the reduced growth rate such conditions cause. However, other stressors, such as chronic poor water quality (associated with a low oxygen content), can cause an elevation in circulating growth hormone concentration, even though growth would be slow under such conditions. Another stressor that is obviously going to influence the growth rate, namely starvation, also causes an increase in circulating growth hormone concentrations (Sumpter *et al.*, 1991). These examples demonstrate the complex links between stress and growth, and how little we understand them presently.

Increased susceptibility to disease

Fish, like all vertebrates (and probably invertebrates) possess a wide variety of defence systems to protect themselves against an equally wide array of organisms that cause disease. Usually fish remain healthy because these defence mechanisms are able to control the pathogens

(fungi, bacteria and viruses, for example) which, if they infect the fish in sufficient numbers, would lead to an outbreak of disease. However, these defence mechanisms may not be able to cope if the fish are subjected to stressors; there is now a lot of evidence demonstrating that various stressors (pollution, poor water quality, etc) increase the susceptibility of fish to common pathogenic organisms, and hence ultimately increase the mortality rate (Pickering, 1989). Although in all probability various physiological processes account for this increased susceptibility to disease, elevated circulating concentrations of cortisol appear to play a central role. Certainly the administration of cortisol to fish increases the incidence of disease and hence reduces the probability of survival. Further, elegant analysis by Pickering and Pottinger (1989) has shown that there is a clear, positive correlation between the circulating cortisol concentration and the mortality rate; in fact some species of fish (brown trout, for example) are extremely sensitive to cortisol, and an apparently minor elevation in the circulating cortisol concentration leads to increase susceptibility to disease (Pickering *et al.*, 1989).

The exact mechanism whereby cortisol reduces a fish's ability to combat infectious organisms is unclear, although it is very likely that the effect is mediated *via* the immune system. The part played by the various components of the immune system in stress-induced suppression of resistance to disease is an area of very active research presently.

CONCLUSION

The stress response is a mechanism that has evolved to protect fish against stressful situations. However, the stressor may be of such magnitude or duration to lead to harmful and deleterious effects. In this review I have discussed briefly those such effects—negative effects on reproductive performance, reduced growth rate and increased susceptibility to disease that are of prime importance to the success of aquaculture. The message is a very clear one: minimise stress to maximise the efficiency of fish farming. In a recent review, Pickering (1991) has discussed at length many practical ways to minimise stress.

Finally, it should be stated that it is likely that different species have different sensitivities to stress; some

may be exquisitely sensitive, especially wild fish brought into captivity to initiate an aquaculture programme on that particular species, whereas other species may be more resilient; these may be the more "domesticated" species, such as the rainbow trout. Selective breeding from more hardy individuals, to produce a strain less susceptible to stress, may be possible, now that it is established that the magnitude of a stress-response in fish is at least partially genetically determined (Pottinger *et al.*, 1991a). It is also likely that different stages of the life cycle have different sensitivities to stress and/or are sensitive to different types of stressor to different degrees.

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