2.3.

**FISHERIES SOCIETY OF THE BRITISH ISLES
BRIEFING PAPER 2
FISH WELFARE**

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EXECUTIVE SUMMARY

Preamble: Those who work professionally with fishes, whose sports or hobbies involve fish and those concerned with the welfare of animals in general seek answers to a number of questions about the effects of human activities on fish welfare. This Briefing Paper considers how welfare is defined and measured, and examines how various human activities affect fish welfare. No opinion is given about what is acceptable and what is unacceptable, but based on current knowledge harmful effects are identified so that others can make their own informed judgements.

Section 1: "Animal welfare" is a difficult term to define precisely. Different definitions focus on an animal's condition, on its subjective experience of that condition and/or on whether it can lead a natural life. These various definitions are not right or wrong, but simply highlight different aspects of welfare. The contents of this paper reflect all of these facets of welfare in fish.

Section 2: A big unresolved and controversial issue in welfare research is whether non-human animals experience what humans would call suffering when they are exposed to adverse events such as physical injury or confinement. A part of the human brain (the neocortex) generates the subjective experience of suffering. Fish brains lack this structure, so fish clearly cannot suffer in exactly the same way as we do. However, other parts of the fish brain are well developed and are used to produce complex behaviour, so lack of a neocortex does not mean that fish cannot experience some kind of suffering. Recent studies suggest that fish have the capacity to perceive painful stimuli and that these are strongly aversive. Consequently, injury or experience of other harmful conditions is a cause for concern in terms of welfare of individual fish.

Section 3: Some of the human activities that could potentially have negative effects on fish welfare are listed, including anthropogenic changes to the environment, commercial fisheries, recreational angling, aquaculture, keeping ornamental fish and scientific research. If an activity does cause harm to fish welfare, this does not necessarily mean that it should be stopped; the harm represents a cost that should be minimised and weighed against the benefits of the activity concerned.

Section 4: Wild fish experience a variety of adverse conditions, from attack by a predator or another fish of the same species to failure to find food or exposure to poor environmental conditions. This does not make it acceptable for humans to impose the same conditions on fish, but it does suggest that fish will have mechanisms to cope with these environmental challenges.

Section 5: Fish respond to such challenges via a physiological stress response - secretion of the "stress hormones" adrenaline and cortisol into the bloodstream. These induce short term (secondary) metabolic changes that make the fish better able to cope with the challenge. Longer-term (tertiary) effects of chronic stress include suppressed behaviour, immune function, growth and reproduction. Behavioural responses are an important part of the stress response, since they enable animals to avoid or overcome the stressor.

Section 6: There is no simple link between physiological stress responses and welfare. It is perhaps unlikely that short-term adaptive responses to challenge cause suffering, but tertiary responses to prolonged, chronic stress are indicative of poor welfare. A number of indicators (based on physiological stress, general health and behaviour) can be used to assess fish welfare, both in a scientific and in a practical context. None is perfect and the best strategy is to use as many as possible and look for robust effects.

Section 7: An overview of the available information tells us that various human activities can harm fish welfare. It also tells us that such effects depend on the species concerned (for example, farmed Arctic charr do better at high densities but farmed trout do worse) and that they are context-dependent (for example, negative effects of stocking density may disappear if water quality is good).

Section 8: It can be misleading to extrapolate from what we know about the welfare of mammals and birds to fish, because fish are a different in ways that are important when considering their welfare. They do not need to fuel a high body temperature, so effects of food deprivation on welfare are not so marked. For species that live naturally in large shoals, low rather than high densities may be harmful. On the other hand, fish are in intimate contact with their environment through the huge surface area of their gills, so they are particularly vulnerable to poor water quality and pollution. General criteria for welfare of other vertebrate animals need to be modified to accommodate these facts before they can be usefully applied to fish.

Section 9: The scientific study of fish welfare is at an early stage compared to work on other vertebrates and a great deal of what we need to know is yet to be discovered. More information is needed about general issues, such as what it means to say that a fish is suffering, and about specific issues, such as the effects of particular activities in particular species. Some areas where more research is needed are:

- The behavioural responses of fish to harmful stimuli and the neural mechanisms that cause these responses.
- The mental capabilities of fish and how measurable events such as physical damage generate subjective states of well-being or suffering.
- Possible 'behavioural needs' that fish must be able to express.
- Diseases in fish and the relationship between health and welfare.
- The development of low-tech, easily applied indicators of fish welfare.
- The welfare of ornamental fish and those held in display aquaria.
- The effects of human activities on welfare in species other than salmon and trout.
- The exact mechanisms by which the adverse effects of human activity come about.

Conclusions: Fish are sophisticated animals, far removed from unfeeling creatures with a 15 second memory of popular misconception. They are also different from birds and mammals in important ways. A heightened appreciation of both these points in those who exploit fish and in those who seek to protect them would go a long way towards redressing some current shortcomings in fish welfare.

1. INTRODUCTION

Aims and intended audience

The aim of this Briefing Paper (which has been prepared by a team with expertise in veterinary medicine, endocrinology, neurobiology, aquaculture, animal behaviour and fish biology) is to give an account of current understanding on a number of issues relating to fish welfare - what it means, why it matters, what humans do that may compromise it and how, in practical terms, it might be measured. We concentrate on the impact of human activity on welfare at the level of the individual, as opposed to the population, the species or the ecosystem and address the experiences of living animals and not the rights and wrongs of killing animals. Our intention is not to make judgements about what is right and what is wrong; instead it is to provide readers with the information needed to make informed decisions on this point. The document is aimed at a broad, non-specialist audience, including scientists in disciplines where fish welfare is relevant but may not be given appropriate consideration, legislative and regulatory bodies who may be more experienced in the welfare of mammals and birds than fishes, welfare and conservation groups, organisations or industries that use live fishes and members of the general public.

1.2 Why is animal welfare a cause for concern?

Animal welfare is the subject of intense debate and attitudes to it are changing fast. In particular, the welfare of fish is coming increasingly to the forefront of public concern, witnessed by a number of web sites (e.g. www.vetmed.ucdavis.colu/CCAB/fish, www.vet.ed.ac.uk/animalwelfare/Fish/Contents), reports and commentaries on this topic (Kestin 1994 for the RSPCA, Lymbury 2002 for Compassion in World Farming, RSPA Welfare Standards for Farmed Salmon 2002) and by discussions at the European Council (Baeverfjord 1998). Increasing concern for welfare is also reflected in the activities of those using or studying fish. For example, the Angling Governing Bodies Liaison Group and the British Field Sports Council commissioned a review of the scientific literature on fish welfare (Pottinger 1995), the European Aquaculture Society has organised sessions on welfare in aquaculture at several recent conferences (Joyce 1996), a number of industrial aquaculture companies have altered their procedures and facilities to take account of fish welfare (for example by developing more humane methods of slaughter, Robb *et al.* 2000), fish producers associations have developed accreditation schemes that include fish welfare as a criterion (www.britishtrout.co.uk; www.scottishsalmon.co.uk), the ornamental fish industry has instituted a code of conduct that addresses, among other things, the welfare of aquarium fish (Davenport 1993, www.aquariumcouncil.org) and the Fisheries Society of the British Isles requires work published in the *Journal of Fish Biology* to adhere to a set of guidelines for the use of animals in research.

The question of why people should care about the welfare of animals raises complex moral issues that have been discussed from many perspectives (e.g. Rollin, 1993; Sandoe *et al.*1997; Fraser 1999; Heeger & Brom 2001). It is beyond the scope of this Briefing Paper to review all these issues; instead we take a simple working position that animal welfare matters, both for moral and practical reasons. In our view, as agents potentially causing animal suffering, people have both a moral obligation and, in many countries, a legal requirement, to respond to concern on this issue. In practical terms also, it is often in our selfish interest to consider the issue of animal welfare; for example, the welfare of wild fish may be a sensitive index of the quality of important water sources, poor welfare of animals used in scientific research means poor science and poor welfare of farmed fish often equates to poor production.

1.3 What does 'animal welfare' mean?

To discuss animal welfare objectively, we need a definition and this is not easy to produce because the concept is complex and the word is used in different ways (Dawkins 1998, Appleby 1999). Most definitions fall into one of three broad categories (Duncan & Fraser 1997, Fraser *et al.* 1997) and it is important to note that none of these is right or wrong; they simply capture different aspects of what the word means. The examples given in this paper reflect all of these facets of welfare.

Feelings-based definitions are set in terms of subjective mental states. Here, the requirement for good welfare is that the animal should feel well, being free from negative experiences such as pain or fear and having access to positive experiences, such as companionship in the case of social species. This use of the term welfare obviously depends on the animal concerned having subjective experiences and our understanding what these are; this controversial point (Dawkins 1998) is discussed in Section 2.

Function-based definitions centre on an animal's ability to adapt to its present environment. Here good welfare requires that the animal be in good health with its biological systems functioning appropriately. This definition is based on things that are relatively easy to see and measure, but it rests on the assumption that an animal whose body is functioning well is in a good mental state, and the converse. Again, this is a complex issue that is discussed further below (in Section 8).

Finally, *nature-based definitions* arise from the view that each species of animal has an inherent biological nature that it must express. Here good welfare requires that the animal is able to lead a natural life and express its natural behaviour. This approach is based on something we can potentially measure (what animals do in the wild and in captivity), but it relies on the assumption that animals suffer if they cannot express the full repertoire of behaviour that they show in the wild, which is not necessarily the case. Much behaviour of wild animals is shown in response to adverse conditions (as when fleeing from a predator) and it is hard to argue that welfare is compromised if these responses are not evoked. In other cases, animals may be highly motivated to perform an action independent of its consequences and may suffer if deprived of the opportunity to do so. Chickens are strongly motivated to build nests (as opposed to having access to a completed nest) and will work hard for the opportunity to do so (Hughes *et al.* 1989); arguably then, nest-building reflects a behavioural need that must be met if the hen is not to suffer. To relate this to fishes, wild Atlantic salmon migrate long distances at sea. If this happens because fish leave an area when the local food supply is poor and stop swimming when they find a good place to feed, there is no reason to believe that the welfare of salmon is compromised when they are prevented from migrating, provided they have plenty of food. On the other hand, if they have an instinctive drive to move to new areas regardless of food supply, confinement might well cause suffering, even though fish in cages are able to swim continuously. At present we do not know enough to distinguish between these alternatives.

1.4 Criteria for welfare

Given the difficulty of finding a comprehensive, generally acceptable definition of animal welfare, some authors have concentrated on identifying conditions that must be fulfilled if an animal's welfare is to be considered acceptable. One influential framework (based on the 'five freedoms' defined in the UK Farm Animal Welfare Council) recognises five domains in which welfare may be compromised (Mellor & Stafford 2001). These domains were developed for the commoner farm animals, essentially birds and mammals, but fish were considered later (FAWC 1996). The relevance of these domains to fish welfare is discussed further in Section 8.

Domain 1. Water and food deprivation, malnutrition.

> Animals should have ready access to fresh water and an appropriate diet in sufficient quantities and with a composition that maintains full health and vigour.

Domain 2. Environmental challenge

> Animals should have a suitable environment, including shelter and a comfortable resting area, whether outdoors or indoors.

Domain 3. Disease, injury and functional impairment

> Disease should be prevented or rapidly diagnosed and treated.

Domain 4. Behavioural/interactive restriction.

> Animals should have sufficient space, proper facilities and where appropriate, the company of the animal's own kind.

Domain 5. Mental and physical suffering

> Conditions that produce unacceptable levels of anxiety, fear, distress, boredom, sickness, pain, thirst, hunger and so on should be minimised.

2. WELFARE, SUFFERING AND THE PERCEPTION OF PAIN IN FISH

Evaluation of the fifth domain for welfare is difficult, because it assumes that an animal's condition with respect to domains 1-4 is translated into subjective mental states that humans would describe as well-being or suffering. This raises a big unresolved issue in welfare research - whether in non-human animals events that compromise welfare as defined in domains 1-4 (such as severe food deprivation, confinement and physical injury) generate the mental state of suffering (conscious experience of something as very unpleasant, Dawkins 1998). If not, then arguably it does not matter that animals are exposed to such events (Bermond 1997). A plant may be dying, but as it has no nervous system to generate mental experiences, the possibility that it might be suffering does not arise. In the present context, we need to establish a view on whether fish are capable of suffering and we approach this by considering the controversial issue of whether they experience physical damage as pain (Rose 2002). To anticipate, our view is that, while fish do not have the neural machinery consciously to suffer pain in exactly the same way that humans do, nor do they have the self awareness or emotionality that some would argue are prerequisites for human suffering, they may well experience some of the adverse states that we associate with pain and emotional distress, thereby compromising their well-being. Our working position in this paper is therefore that if fish are injured or exposed to other harmful conditions, this is a cause for serious concern, not just in terms of responsible stewardship of fish populations (Rose 2002), but also in terms of the welfare of individuals.

People arguing on either side of this debate have used a number of kinds of evidence, none of them entirely satisfactory. For example, one might assume that the longer the life span of a given species of animal and the more sophisticated its general behaviour, the greater its need for complex mental processes such as those that generate the conscious experience of pain. In this context, therefore, it is relevant that the longest-living vertebrates are found among the fishes and that fish behaviour is rich and complicated. For example, we know that some species form mental representations of their environment and use these for quite complex feats of navigation (Reese 1989; Rodriguez *et al.* 1994). Also, many fish live in social groups and some can recognise individual companions (e.g. Swaney *et al.* 2001). Fish can remember negative experiences. For example, paradise fish avoid places where they have experienced a single attack by a predator and continue to do so for many months (Czanyi & Doka 1993) and carp learn to avoid bait for up to three years after they have been hooked just once (Beukema 1970). While animals could show this kind of associative learning without necessarily having conscious awareness (Rose 2002), clearly experiences such as exposure to a predator or tissue damage can be strongly aversive for a fish.

On the specific point of whether fish experience physical injury as pain, it is helpful to consider current knowledge of pain perception pathways in mammals (Figure 1). In this context, the sensory structures that detect harmful (or noxious) stimuli are called *nociceptors* rather than pain receptors, to stress the fact that detecting and responding to noxious stimuli is not necessarily the same as feeling pain (Broom 1998). What do we know of these systems in fishes? As far as the possession of receptors that detect harmful stimuli is concerned, lampreys (very primitive fish) have nerves in the skin that respond physiologically to mechanical pressure, but there is no evidence that these fish show anatomical or behavioural reactions that would accompany nociception (Matthews & Wickelgren, 1978). However, in at least one teleost fish (the rainbow trout), anatomical and electrophysiological examination of the trigeminal nerve (which is known to convey pain information from the head and mouth in higher vertebrates) has identified two types of nociceptor, A-delta and C fibres (Sneddon 2002; Sneddon, Braithwaite & Gentle submitted).

In terms of the machinery that generates the conscious experience of pain in humans, the brain of a fish is clearly far smaller relative to body size (some 300 times smaller by volume) and simpler in structure than that of a human (Kotrschal *et al.*1998). In particular, fish do not have a neocortex, the part of the brain responsible for the subjective experience of pain in humans (shaded pale grey in Figure 2. Rose 2002). However, we know that the same job can be done by different parts of the brain in different kinds of animals. For example, visual stimuli are processed by part of the cerebral cortex in mammals but by the midbrain optic tectum in birds. It is not impossible that parts of the brain other than the cerebral cortex have evolved the capacity for generating negative emotional states/suffering in non-mammalian vertebrates, including fish.

Behavioural experiments are now required to determine whether the nociceptors associated with the trigeminal nerve in fish produce pain-like responses when stimulated with a noxious substance. Such responses would seem likely, given that jawed fish are known to produce some of the natural opiates that are involved in nociception in mammals (Substance P, enkephalins and B-endorphins, Rodriguezmoldez *et al.* 1993, Zaccone *et al.* 1994, Veccini *et al.* 1992, Balm & Pottinger 1995) and that the behavioural

response of goldfish to analgesics is similar to that of a rat (Ehrinsing *et al.* 1982). In mammals opiates act at neural levels below the neocortex (Rose 2002), but this does not preclude their having a pain-suppressing effect and one has to ask why they are needed in fish if these animals do not experience pain.

Taken together, these findings suggest that fish have the sense organs and the sensory processing systems required to perceive harmful stimuli and, probably, the central nervous systems necessary to experience at least some of the adverse states that we associate with pain in mammals. Hence our working position that fish have the capacity to perceive painful stimuli and that these are, at least, strongly aversive.

Figure 1. The main components of the pain perception mechanisms in mammals.

> Harmful (noxious) stimuli such as chemicals, heat, pressure etc impinge on the animal.

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> Sensory neurons for the detection of harmful stimuli (nociceptors) react to specific stimuli. There are two common types of nociceptor: myelinated, small, slow-conducting A-delta fibres and smaller, slower conducting C fibres. These are activated by specific nociceptive stimuli.

⇩

> Activity passes through small nerve fibres in the spinal cord to the thalamus (part of the diencephalon, see Figure 2) and then to the cerebral cortex. There are two partially separate systems, one responsible for the sensory discrimination of harmful stimuli and the other responsible for the conscious, emotional response to such stimuli.

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> Physiological responses to harmful stimuli include protective vegetative responses (inflammation and cardiovascular changes) and reflex avoidance responses. More complex, higher order responses include changes in physiology (eg secretion of natural opiates) and behaviour (eg avoidance of locations where harmful stimuli have been experienced).
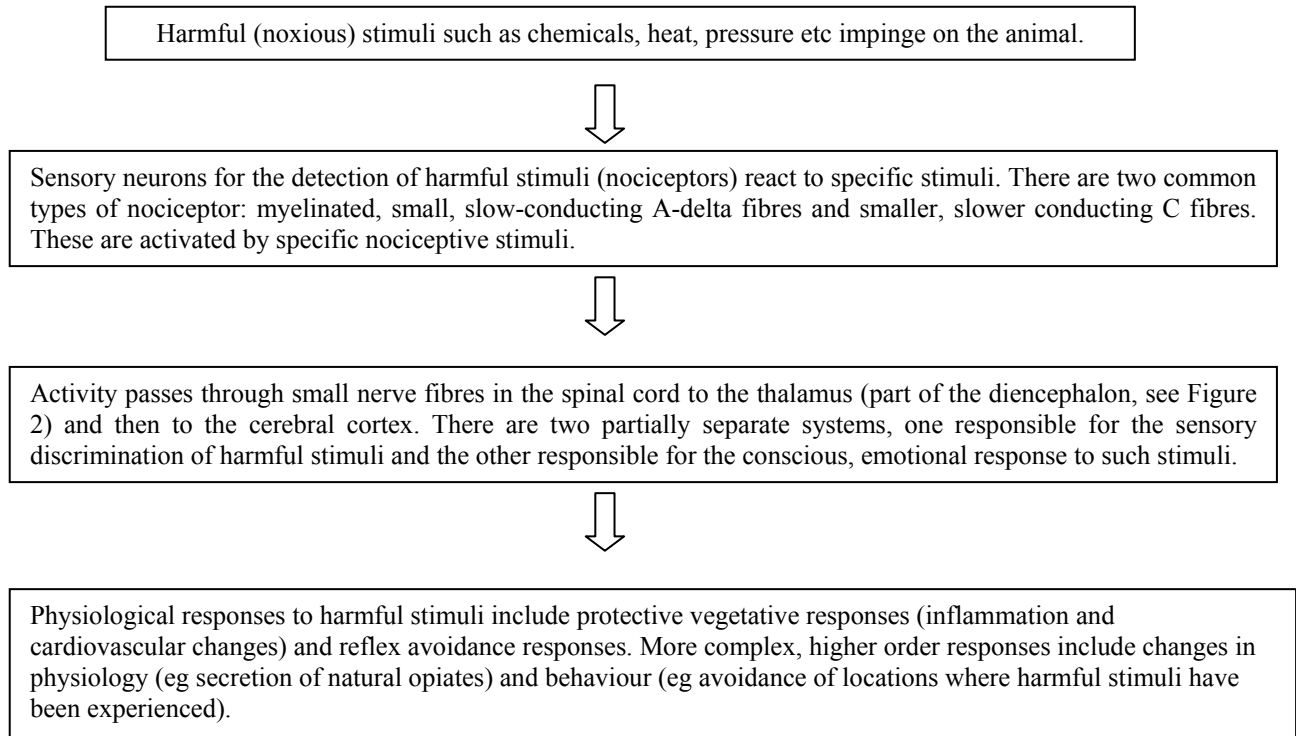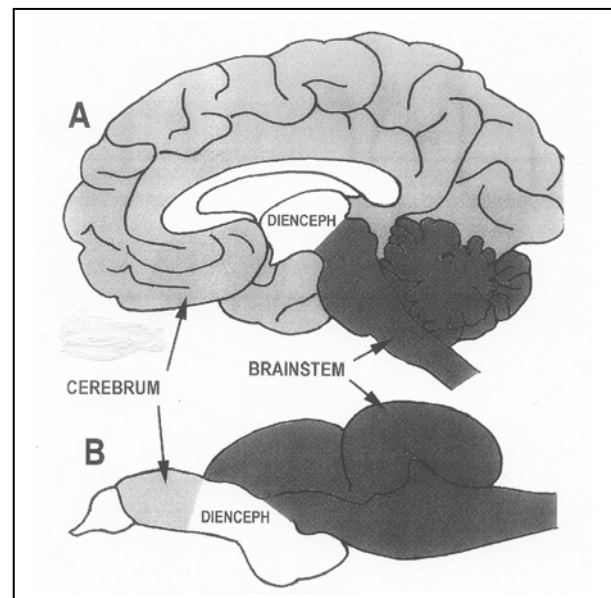

Figure 2. Comparison of the structure of the mammalian (human) brain (A) and the trout brain (B), in midline view (after Rose 2002). The cerebral cortex is shown in light grey, the brain stem in dark grey.

3. COSTS AND BENEFITS OF HUMAN INTERACTIONS WITH FISHES

Accepting that the welfare of individual fish matters, some would argue that any activity that harms fish should be discontinued. An alternative, utilitarian, view is that an activity is not necessarily wrong because it impairs fish welfare; judgments should be made on both the amount of harm caused to fish and the benefits derived as a result. The Farm Animal Welfare Council 1965) concluded that such a utilitarian approach is appropriate (though only up to a point). With this in mind, Table 1 outlines a number of human activities that may *potentially* compromise the welfare of individual fish and so cause the harm against which any benefits must be weighed. The word "potentially" is stressed because at this point we simply identify areas of possible concern; whether or not any of these activities does harm fish is considered later, in Section 7. Harmful effects on welfare can be indirect, as when we inadvertently alter natural habitats or expose fish to poisonous chemicals, or direct, for example through commercial fisheries, through sports fisheries, through intensive production, through keeping fish as pets or in public aquaria or through scientific research. This briefing paper does not aim to make judgments about what is acceptable and what is unacceptable, but to identify harmful effects of human activities on fish welfare as far as possible, on the basis of current knowledge.

4. NATURAL THREATS TO THE WELFARE OF WILD FISH

Although what is natural is not necessarily good and although there is a clear moral difference between suffering due to natural events and suffering caused by human activity (especially when fish have no choice of environment), an understanding of the threats encountered by wild fish and how frequently these occur (Table 2) can clarify our thoughts on fish welfare. Clearly, wild fish experience injury, poor environmental conditions and stressful events due to encounters with potential predators and with other fish of the same species, to restricted food supplies, to parasitic infection and disease and to natural environmental change. One implication is that fish are likely to have mechanisms for dealing with the adverse conditions that they encounter naturally and that these will come into play during their interactions with humans. These natural responses might provide a means of assessing fish welfare.

5. HOW FISH RESPOND TO NATURAL THREATS TO THEIR WELFARE

5.1 The stress response in fish

Much, though not all, of our understanding of how fish respond to the kinds of natural adverse conditions outlined above comes from the extensive literature on the biology of stress. All animals need a stable internal environment in order to grow, survive and reproduce; the maintenance of this stable environment is termed homeostasis. In response to a destabilizing stimulus (or stressor) the animal seeks to maintain homeostasis through altered behaviour and physiology (the stress responses). The stress response can therefore be considered to be part of an adaptive strategy to cope with a perceived threat to homeostasis (e.g. Sutanto & de Kloet 1994; Tsigos & Chrousos 1994). The stress physiology of fish is directly comparable to that of higher vertebrates (see reviews by Colombo *et al.* 1990; Wedemeyer *et al.* 1990; Barton & Iwama 1991; Wendelaar Bonga 1997), but we know much less about the emotional content of stressors in fish, which are critically important when making the link between physiological stress and suffering (see Section 6).

5.2 Primary stress responses

The immediate neuroendocrine changes that occur when fish are subjected to a stressor (Figure 3) are termed *primary* stress responses, during which perception of the stressor by the fish initiates a rapid, neurally-stimulated release of adrenaline and noradrenaline from the chromaffin tissue, the equivalent of the mammalian adrenal medulla (Gingerich & Drottar 1989). At the same time the hypothalamic-pituitary-interrenal axis is activated (Sumpter 1997) by the release of corticotropin-releasing hormone (CRH) from the hypothalamus and subsequent release of cortisol from the interrenal tissue, the equivalent of the mammalian adrenal cortex (Okawara *et al.* 1992; Weld *et al.* 1987).

Table 1. Some human activities that may *potentially* compromise fish welfare, and a reminder of the benefits these can confer. Evidence on whether such activities actually do or do not compromise welfare is given in Section 8.

ACTIVITY	EXAMPLES OF *POTENTIAL* EFFECTS ON WELFARE	EXAMPLES OF POSSIBLE BENEFITS
Environmental degradation	• Reduced availability of natural food • Introduction of exotic species into existing fish communities • Habitat modification, creating (e.g.) sub-optimal temperatures or flow regimes • Loss of or displacement from natural habitats • Reduced population densities (or crowding) and abnormal social experiences • Disturbance through tourism • Acute and chronic exposure to pollutants and litter	There are numerous examples of cases where humans have benefited from activities that alter the natural habitat of wild fish. e.g. Dams provide humans with power, irrigation, flood control and recreation, but result in loss of habitat (including spawning habitat) for fish and barriers to migration (International Commission on Large Dams http://genepi.louis-jean.com/cigb/BandC.pdf)
Commercial and sports fisheries	• In both, tissue damage, physical exhaustion and severe oxygen deficit during capture • In both, pain and stress during slaughter • In angling, pain and stress in tethered fish when live bait is used • In angling, release of reared fish inappropriately equipped for survival in the wild • In angling, stocked fish introduced to lakes may be denied the opportunity to migrate	In 1995 there were 20 million anglers in the USA, creating 1.3 million jobs and with an estimated value of 70 billion US dollars. (USA Fish and Wildlife Service Survey)
Intensive production	• High densities in simple and constraining conditions, both in normal rearing conditions and for husbandry • Poor water quality • Aggressive interactions, which can cause damage and constrain access to food • Food deprivation (e.g. during disease treatment and before harvest) • Handling and removal from water during routine husbandry procedures • Unnatural light-dark regimes, to suppress breeding • Handling, constraint and, sometimes, low oxygen levels during transportation • Permanent adverse physical states and possibly increased levels of aggressiveness due to selection for fast growth • Increased exposure to predators, attracted to fish farms or used to grade out smaller fish (in Tilapia aquaculture) • Transmission of disease to wild stocks • Crowding, handling, removal from water and pain during slaughter	Between 1987 and 1997 world production of farmed fish increased from 10.6 to 28.3 million tonnes (FAO, 1998). 75% of the rural population in some areas of Vietnam is engaged in aquaculture. Even in 1985, the European aquaculture employed 150,000 people (Ackefors 1989)
Keeping ornamental fish and display fish in public aquaria	• For ornamental fish, capture by sub-lethal poisoning • For ornamental fish, permanent adverse physical states due to selective breeding • For ornamental fish, release or escape of exotic species • Inappropriate temperatures, poor water quality and physical constraint during transport • Confined space and poor water quality once housed. • Inappropriate physical conditions • Inappropriate social conditions, with shoaling fish at low densities and predators with prey • Inappropriate diets	Ornamental fish are the third most popular pet after dogs and cats, up to 40 million entering the USA and up to 1 million entering the UK per annum. The retail value of the fish and accessories ranged between 189 and 305 million US$ (Andrews 1990, Mintel 1991). Sustainable keeping of endangered species has conservation value
Scientific research	• Fish used in the laboratory for experimental purposes are often confined and may be exposed to a range of deliberately-imposed adverse physical, physiological and behavioural states • Fisheries research often involves electrofishing, tagging, fin clipping or otherwise marking fish, which potentially cause pain and injury. • In both laboratory and field, handling during research procedures may cause injury	In addition to underpinning effective aquaculture and aquarism, scientific research on fish can have benefits for human health. e.g. Toxicology testing (Purchase 1999) and biomedical research using the pufferfish model genome (Hedges & Ku,ar 2002). Where research leads to (e.g.) better husbandry procedures, fish themselves benefit

Table 2. Natural threats to the welfare of wild fish

STRESSOR	COMMENT AND EXAMPLES
Predators	• Predation rates can be very high. e.g. Excluding predators reduces mortality by 36% in wrasse (Shima 2002) • Unsuccessful predatory attacks may cause wounding and an increased risk of disease. e.g. 30% of wild sticklebacks bear injuries due to failed predatory attacks (Reimchen 1994) • The threat of predation may suppress feeding and may cause fish to forage sub-optimally (Hart 1997)
Conspecifics	• Many species live naturally in groups of the same species, which provide protection against predators. Obligate shoaling fish separated from companions will strive to join a shoal (Pitcher and Parrish 1993). • In many other species (or in shoaling species under particular circumstances) conspecifics fight over resources and this can cause physical damage and depletion of energy reserves (Neat *et al.*1998). Many wild Atlantic salmon that mature as juveniles have wounds from attacks by larger males (Garcia de Leaniz 1990). Losers may be deprived of resources and/or exposed to chronic social stress (Abbott and Dill 1989, Alanara 1997)
Food availability and body condition	• Wild fish often experience periods of when food is in short supply (Dutil and Lambert 2000), though many species have flexible metabolic systems to cope with periods of prolonged food deprivation (O'Connor *et al.*2000a) • Growth rates in fish held captive with excess food consistently and markedly exceed those achieved by fish in the wild (e.g. in *Cynolebias viarius* – Errea & Danulat 2001) • Lipid deposition rates and mineral content of body tissues may also differ between wild and captive reared fish (e.g. Orban *et al.*2002 for sea bass) • Many larvae (at least 50% in the common Japanese goby *Rhinogobius brunneus*) die through starvation prior to obtaining their first food (Iguchi & Mizuno 1999)
Extensive migration	• Daily vertical migration by pelagic fishes results in slower growth (Lima 1998) • Energy reserves in spawning salmon are reduced by more than 90% following upriver migration (e.g. Johnson *et al.* 1991)
Parasites and disease	• In the wild most fish carry a parasite burden that impairs their health • High gill parasite loads in fish from the Slaton Sea, California, cause damage to gills, poor respiration and osmoregulation and juvenile mortality in several species (Kuperman *et al.*2001) • In Orange roughy *Hopostethus atlanticus* from New Zealand, parasite loading is negatively correlated with growth (Gauldie & Jones 2000).
Suboptimal environmental conditions	• Most environmental variables fluctuate naturally, so wild fish will experience conditions that deviate from optimal for the species concerned. • Fish can avoid or adapt to sub-optimal environmental conditions (at an energetic cost), but exposure to conditions beyond their limit of tolerance is, by definition, lethal

Figure 3. The main hormonal components of the stress response in fishes.
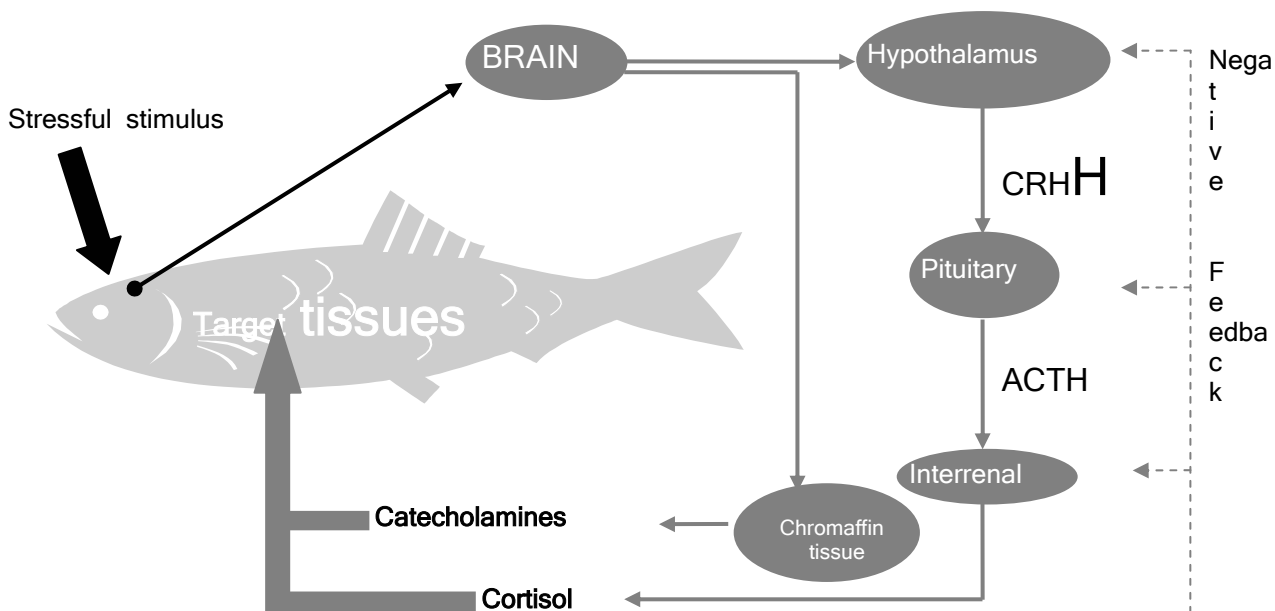
Because of the rapidity of the catecholamine response following disturbance and consequent difficulties in accurately measuring blood levels in free-swimming fish, we know little about the dynamics of the catecholamine response to stressors in fish, other than that it is extremely rapid. As far as cortisol is concerned, the size and duration of stress-induced elevation in plasma levels are usually proportional to the severity and duration of the stressor. Recovery from short-term, acute stress takes a matter of hours (Pickering & Pottinger 1989, Waring *et al.* 1992), but elevated cortisol levels generally persist during continuous, chronic stress (Pottinger & Moran 1993, Pottinger *et al.*1994a). Under some circumstances, fish will acclimate to a repeated stressor and cease to show a stress response, despite initially responding with elevated cortisol levels (Pickering & Pottinger 1985).

5.3 Secondary stress responses

As a direct consequence of elevated circulating levels of catecholamines and cortisol, a wide range of *secondary* changes are evoked. These include:

- Altered rates of secretion of other pituitary hormones and of thyroid hormones.
- Changes in rates of turnover of brain neurotransmitters such as dopamine and serotonin.
- Improved respiratory capacity via increased heart rate and stroke volume and increased blood flow to the gills (at the expense of disrupted salt and water balance).
- Mobilization of energy by breakdown of carbohydrate and lipid reserves and by oxidation of muscle protein.

5.4 Behavioural responses to stress

In some respects, behavioural responses are an animal's first line of defence against adverse environmental change, often being triggered by the same stimuli that initiate the primary stress response. The exact behavioural response depends on the stressor concerned. For example, after an attack by another fish of the same species, fish may flee and hide or take up a submissive posture, often with altered body colour (e.g. O'Connor *et al.* 2000). When attacked by a predator, fish may respond by shoaling (Pitcher & Parrish 1993), "freezing" (e.g. Goodey & Liley 1985) or taking shelter (e.g. Brown & Warburton 1999) and may change colour in this context as well (Endler 1986). Feeding may be suppressed following an encounter with a predator, or inefficient feeding strategies may be adopted (Hart 1997) and fish may avoid areas in which they have been attacked (Lima 1998). Specific adaptive behaviour patterns are observed in response to tissue damage (for example, fish that are hooked in the mouth show rapid darting, spitting and shaking of the head, Verheijen & Buwalda 1988) or to parasitic disease (Furevik *et al.*1993).

5.5 Tertiary stress responses

The primary and secondary stress responses are short-term effects of acute, short-lived challenges. Where a stress response is prolonged or repeated (Schreck 2000) and the fish has no way of avoiding or escaping the challenge, a series of *tertiary* effects become apparent, including changes in immune function and disease resistance, in growth and in reproductive status.

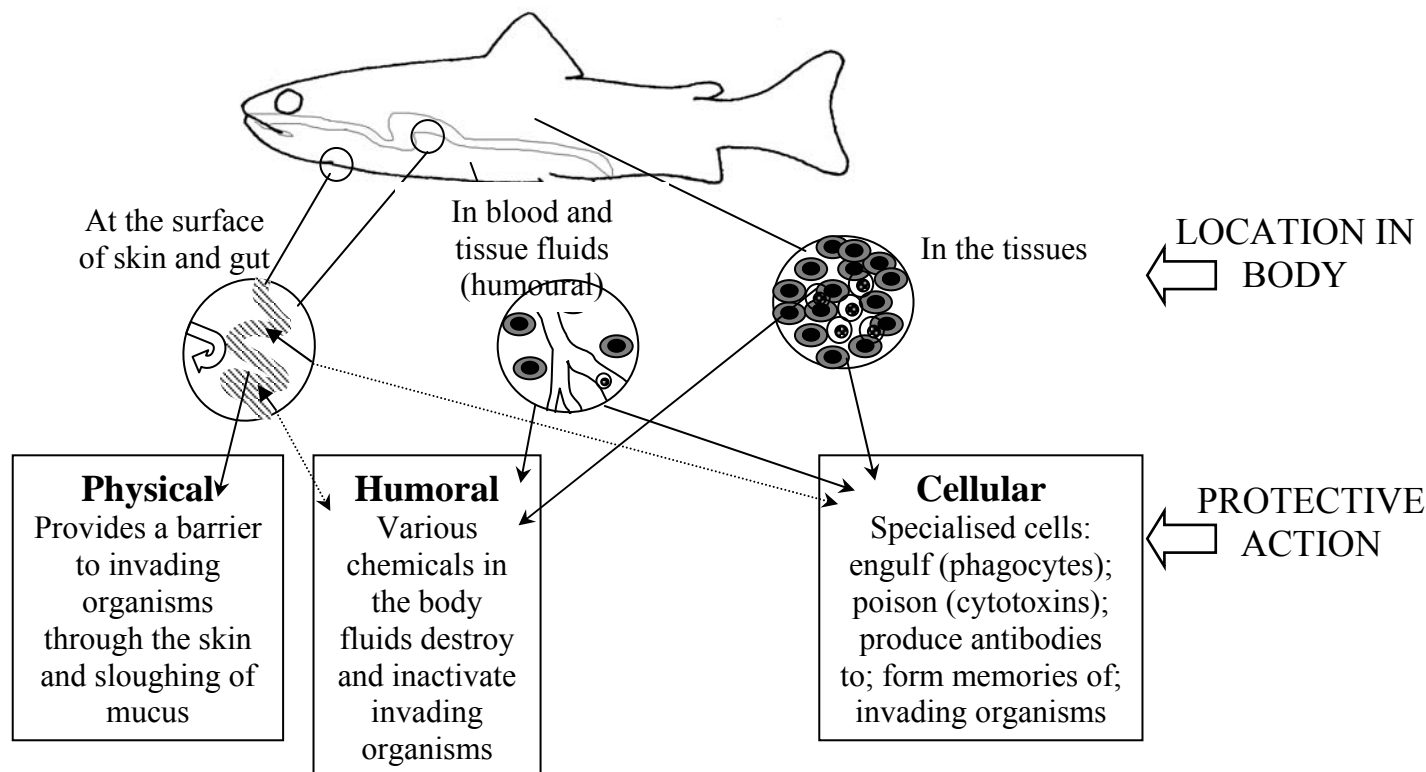### *5.5.1 Changes in immune function and disease resistance*

Animals are defended against invasion by disease-causing organisms by their anatomy, physiology and normal microflora (Bøgwald *et al.* 1994, Ringø & Gatesoupe 1998). Jawed fish all have a non-specific immune system that does not depend on prior disease challenge and also a specific immune system with a memory component that can adapt to different invading organisms (Flajnik 1996, Klein 1997, Warr 1997; Press 1998). Compared with higher vertebrates fish are more reliant on the non-specific immune system and the specific system is less well developed. The main components of these systems (summarized in Figure 4) are:

- Chemicals in the body fluids that are able to destroy or inactivate invading organisms.
- Circulating and tissue-dwelling cells that engulf or destroy invading organisms (phagocytes).
- In the specific system, circulating cells responsible for antibody production (lymphocytes) and phagocytic cells, which have an additional role in presenting antigens to the specific immune system.

As in mammals, the best known link between stress and immune status in fish arises through effects of cortisol (Wendelaar Bonga 1997). Cells involved in the immune response contain receptors for cortisol (Maule & Shreck

1990) and raised cortisol concentrations suppress many aspects of immune function. However, the relationship between stress and the immune system goes in two directions, since components of the immune system can influence stress responses (Ottaviani & Franceschi 1996, Balm 1997). For example, cytokines (chemicals that are secreted by blood cells - leukocytes including macrophages - in response to a microbial challenge) can cross the blood-brain barrier and affect secretion of stress mediators and stress hormones. Additionally, some cells of the immune system (macrophages) are known to produce stress mediators such as ACTH (Brown 1994).

Figure 4. The components of the immune response in fishes. The different elements interact and communicate to protect fish from invasion.

One consequence of such stress-induced changes in immune function is that chronic exposure to adverse conditions makes fish more vulnerable to disease. Following administration of cortisol to salmonid fish, mortality due to fungal and bacterial pathogens increases (Pickering & Pottinger 1989) and there are numerous reports of stress-mediated bacterial diseases, typical examples include furunculosis and vibriosis (Plumb 1994).

5.5.2 Changes in growth and reproduction

Growth in most fish is indeterminate and flexible and varies over short time scales as rates of energy intake and utilization change. Many of the effects of stress described above cause reduced energy intake and increased energy utilization, so stress is likely to reduce rates of growth indirectly through a negative effect on energy balance. In addition, growth hormone secretion is reduced in fish during periods of stress (Pickering *et al.* 1991, Farbridge & Leatherland 1992), so there are also direct effects on the mechanisms that control growth. A number of studies have demonstrated reduced growth in response to administration of cortisol (Barton *et al.* 1987) and to prolonged activation or frequent intermittent activation of the stress response in the laboratory (e.g. Pickering 1993). Poor growth has been reported in wild fish populations as a result of environmental stressors such as altered pH (e.g. Puste & Das 2001), reduced dissolved oxygen levels (Kramer 1987) and altered salinity (Brett 1979).

Growth and reproduction are complementary processes that depend upon availability of energy and nutrients obtained through foraging. Life history strategies have evolved to produce patterns of growth that maximize lifetime reproductive capacity, in a condition-dependent manner that takes nutritional status into account (Thorpe *et al.* 1998). Since growth and reproduction are adaptively linked, stress-induced impairment of growth may indirectly interfere with maturation. Additionally, reproductive activity can be suppressed directly during periods

of stress, via an effect on reproductive hormones (Pickering *et al.* 1987, Donaldson 1990, Carragher & Pankhurst 1991, Campbell *et al.* 1992, Pankhurst & Dedual 1994, Pankhurst & Van der Kraak 1997).

5.6 Functional considerations

Most natural stressors are probably short lived, since fish will either avoid/overcome the challenge or succumb. The beneficial nature of the secondary stress responses to such short-term stressors is evident - all are associated with maintaining cardio-respiratory performance and mobilising energy under challenging conditions (Randall & Perry, 1992). Some tertiary responses also may be adaptations to adverse conditions; for example, stress-induced suppression of immune function may prevent auto-immune lesions and suppression of reproductive activity may be an adaptive "switching-off" of an energy demanding process in poor environmental conditions. Other tertiary responses (e.g. diseases arising from weakened defences) are wholly adverse in nature.

6. ASSESSING FISH WELFARE

6.1 Ways of measuring fish welfare.

This knowledge of the natural responses of fish to adverse conditions suggests ways of probing the physical, physiological or psychological state of individual fish to determine whether their welfare is compromised. The aspects of an animal's condition that are often used in this context are its health status, its physiology and its behaviour. Relating each of these to welfare is not simple, and ideally all three should be taken into account when assessing welfare in any given case.

6.1.1. Stress physiology and fish welfare

Stress responses represent an animal's natural reaction to challenging conditions and are often used as indicators of impaired welfare, so studies of physiological stress feature prominently in welfare research. However, it is important to recognise that physiological stress is not synonymous with suffering (Dawkins 1998). Low cortisol levels might mean that a fish is not stressed, but it might mean that the capacity of its interrenal tissue to produce cortisol is exhausted. There is no particular reason to suggest that the temporary physiological activation that prepares fish for activity is detrimental to welfare and in some contexts short term stress responses (for example, in anticipation of feeding) may well be beneficial (Moberg 1999). Tertiary stress effects such as suppressed reproduction may well be adaptive responses to poor condition in the wild, but even so it seems reasonable to assume that in captive fish they indicate exposure to chronic, unavoidable stress, which may compromise welfare. Thus although the concept of stress does not fully capture the complexities of animal welfare, monitoring stress responses may give us part of the picture. In particular, where several components of the stress response are all influenced in a similar way by the same condition, this suggests that there is cause for concern about the welfare of the fish involved.

6.1.2 Health, disease and welfare

The link between health and welfare is complex. If an individual fish shows signs of disease, it seems reasonable to infer that it is in a poor state of welfare, for that very reason. The converse is not necessarily true, because the welfare of a healthy fish may be compromised in other ways, for example if a schooling fish is held in isolation. In addition to welfare problems raised directly by the signs of disease themselves, because stress can suppress immune function, a high incidence of disease (and mortality) is often taken as a warning sign for other welfare problems. The causes of disease in fish are invariably complex and the risk of disease does indeed increase as the conditions under which the fish are living deteriorate, in the wild or in captivity. Therefore the occurrence of disease in fish will usually be associated with a poor state of welfare and may be an indication that there is an underlying problem with the environment or conditions to which the fish are subjected. However, it is overly simplistic to assume that disease is invariably the result of poor living conditions; even fish experiencing optimal conditions may suffer from disease and will, eventually die. Nor does the occurrence of disease inevitably imply that the problem is due to human mismanagement and that it is possible to rectify the situation. Infectious diseases occur and cause significant losses in populations of wild fish and there are well-documented examples of serious epidemics in wild populations (e.g. Epizootic Ulcerative Syndrome, Lillie *et al.* 1996). Under some circumstances disease may be preventable in captive populations, for example where some form of therapy or vaccine exists, and this may promote fish welfare.

6.1.3 Behaviour and welfare

The idea that animals suffer if they cannot perform their full behavioural repertoire has been used to identify conditions that detract from welfare (Section 1.3), so behavioural studies have an important role in welfare research (Mench & Mason 1997). In addition, because altered behaviour is an early and easily observed response to adverse conditions, specific responses to natural stressors (such as 'freezing' in the presence of a predator or chafing/flashing to remove ectoparasites) can be used as an indicator of impaired welfare. Finally, and importantly since so many controversial issues in discussions of welfare stem from the impossibility of getting inside the minds of animals, choice tests that allow animals to express their natural preferences can help to identify things that may promote/detract from their welfare. This approach has proved useful in welfare research on birds and mammals, even though the underlying assumption that animals choose what is good for them is not always valid (Dawkins 1998).

There are many examples of the use of choice tests in fish (for example, choice between different temperatures or between schools of different sizes). The results have not usually been directly related to fish welfare, but can be interpreted in this context. For example, fish of various species avoid potentially lethal concentrations of some harmful pollutants such as copper, suggesting that these impair welfare; however, they ignore other equally harmful substances such as selenium (Giattina & Garton 1983), which either means that these do not impair welfare or that fish are unable to detect them and so cannot choose what is good for them. Similarly, territorial damselfish will learn to swim through a simple maze if rewarded by the opportunity to display aggressively to a neighbouring damselfish (e.g. Rasa 1971). This suggests that being involved in an exchange of aggressive displays (as opposed to losing or being injured) is not necessarily aversive and so may not impair welfare, at least when the fish concerned can chose whether to interact with its neighbour.

6.2 Sensitive and easily applied welfare indicators for fish

Collecting data on fish physiology, biochemistry and behaviour is time consuming and technically complex. It also involves handling and anaesthetizing or killing fish in order to collect blood or other tissue. There are non-invasive methods such as measuring cortisol levels in the water in which fish have lived (Oliviera 2001, Scott *et al.*2001), but some of these lack the precision of measurements made on individual fish. Such intensive work is necessary in scientific research, but is impractical for everyday use, in pet shops or on working fish farms for example. What is needed here is a set of simple, non-intrusive signs or danger signals that can be used easily without needing access to laboratory apparatus. A number of possible hands-off welfare indicators can and have been used to assess the welfare of individual fish and these are listed below. All are well known to people with a practical interest in fish welfare, such as good fish farm managers and careful owners of ornamental fish.

Changes in colour: Stress-induced changes in skin or eye colour (with a complex hormonal background) have been reported in a number of fish species, including ornamental species (Etscheidt 1992), and so could be a sign of exposure to adverse events. Eye colour as an index of social stress/subordinate status in salmonids provides an example.

Changes in ventilation rate: A high oxygen demand is reflected by rapid irrigation of the gills. The rate of opercular beats is therefore increased by stress and can be counted, automatically or by eye. This, together with a visual assessment of gill status, is used as a sign of incipient problems in ornamental fish (Etscheidt 1992) and to monitor exposure to pollutants in salmonid fish.

Changes in swimming and other behaviour patterns: Fish may respond to unfavourable conditions by adopting different speeds of swimming and by using of different regions of a tank or cage (Morton 1990, Etscheidt 1992, Juell 1995). Abnormal swimming has been used as a sign of poor welfare in farmed fish (Holm *et al.* 1998). Known behavioural responses to adverse events and conditions are potential signs of both general and specific trouble (Morton 1990). These include excessive activity or immobility (Etscheidt 1992), body positions that protect injured fins, escape attempts in confined conditions and chafing movements to dislodge ectoparasites (Furevik *et al.*1993).

Reduced food intake: Notwithstanding that there are many reasons why a fish might not eat, the fact that feeding is suppressed by acute and chronic stress means that loss of appetite is potentially a sign of impaired welfare.

Slow growth: Notwithstanding that growth rates in fish are flexible and naturally variable, sustained reductions in growth may be indicative of chronic stress. Thus where fish are regularly weighed or where size can be assessed by eye (or by underwater camera) slow growth can be used as a possible sign of trouble.

Loss of condition: Fish change shape and/or lose weight for many reasons, but because reduced feeding and mobilisation of reserves are secondary stress responses, where fish are regularly weighed and measured, or where body shape can be assessed by eye (for example by the visibility of the vertebrae, Escheidt 1992) loss of condition can be used as a possible sign of trouble.

Morphological abnormalities: Because adverse conditions can interfere with normal development, the occurrence of morphological abnormalities can be used as an indicator of poor larval rearing conditions (Boglione *et al.* 2001).

Injury: Injury may be a direct consequence of an adverse event, in which case, the presence of such injuries is a sign of poor welfare. For example, dorsal fin injury in salmonids is often caused by attacks from conspecifics (Turnbull *et al.* 1998) and scales that are dislodged rather than lying flat are a sign of poor welfare in ornamental fish (Etscheidt 1992). In addition, because immune responses can be suppressed by cortisol, slow recovery from injury (or a high incidence of injury) may be a sign of generally poor conditions. However, fin erosion has multiple causes and these are not fully understood

Disease states: Since the causes of most aquatic diseases are complex and dependent on environmental conditions, a diseased state can indicate an underlying problem with the environment or management. Increased incidence of disease in any population of fish should be treated as a warning that there may be other underlying problems. However, interpreting the welfare implications of an observed disease requires a detailed understanding of the natural history of the disease and in some cases diseases are not sufficiently well understood to interpret their implications for welfare.

Reduced reproductive performance: For many farmed species, reproduction is prevented or avoided in growing stock. Where this is not the case, for example, in brood stock or where ornamental fish are concerned, because chronic stress impairs reproductive function, failure of adult fish to breed or to display normal patterns of reproductive

How well these signs work in any given case will depend on the species concerned (eye colour may be a good indicator of social stress in salmon, but not in sticklebacks), on circumstances (depleted energy reserves might be cause for concern in an immature salmon, but not in one that has just bred) and also on individual status (failure to feed may be a sign of poor welfare in a juvenile salmon in the summer, but not necessarily in the winter when they may show adaptive natural anorexia). In addition, the potential for using this full list will vary with the context in which fish welfare is to be assessed; fish farmers may have to rely on a few signs, collected on a small proportion of their stock, but people keeping ornamental fish are well placed to use many of them.

7. HOW DO HUMAN ACTIVITIES AFFECT FISH WELFARE?

The scientific study of fish welfare lags behind that of the welfare of other vertebrates (reflecting the pressure of public concern), but there is still an extensive literature on the subject, using the welfare indicators outlined above. A survey of this literature shows that different studies do not always come up with the same results. This is not necessarily because any of them are wrong. Rather it reflects the complex nature of fish welfare and the fact that the various factors that impact on it may interact. For example, a given stocking density may generate signs of poor welfare at one temperature or level of disturbance, but not at another and conditions appropriate for one species may be entirely inappropriate for another. We are not yet in a position to make definitive statements about how a given activity impacts on fish welfare and more research is needed.

However, people reading this Briefing Paper will wish to know how particular human activities affect fish welfare, so this section gives a brief synopsis of current understanding on the subject (Table 3), using just a few examples. We concentrate on three activities, chosen because they are of known current public concern and because people can have an impact on these activities through their own personal choices. These are: the keeping of ornamental fish (one can choose not to keep ornamental fish or buy only from suppliers who take welfare seriously), angling (one can choose not to go fishing or to use practices that minimise suffering) and aquaculture (one can choose not to eat farmed fish or to buy only from sources that guarantee a high standard of welfare). On this last point, it should be noted that the welfare of fish caught by commercial fisheries (still the largest area of human-fish interactions) is also a cause for serious concern. Fish are harmed by capture (e.g. cortisol levels increase in sea bream captured by trammel net and many fish are mortally injured, Chopin & Arimoto 1995) and slaughter methods (especially asphyxia) are highly stressful (Poli *et al.* 2002). In addition, non-target species captured as by-catch are often injured or killed (Pronovi *et al.* 2001). Scientific research on fish raises serious ethical concerns, but is already strongly regulated in many countries to ensure that harm in terms of compromised welfare is outweighed by benefits in terms of enhanced knowledge on important issues (e.g., the UK Animals (Scientific Procedures) Act, 1986). As far as environmental degradation is concerned, while this is clearly a cause of poor welfare in very large numbers of fish (Montgomery & Needleman 1997), we have many more pressing motives for minimising human impact on the environment than concern for fish welfare.

A number of general points emerge from this synopsis:

1. *What we do to fish does indeed compromise their welfare:* If one accepts chronically elevated cortisol levels, impaired disease resistance and poor growth (for example) as indicators of welfare in fish, then Table 3 gives many examples of harmful effects of human activities on fish welfare.

2. *Fish are different from other vertebrates in ways that have important implications for welfare:* The effects of human activity on fish welfare are not always what one would predict by extrapolating from birds and mammals. For example, fish allow their body temperature to fluctuate with that of the environment (i.e. they are ectothermic animals) and also show striking natural variation in appetite and the evidence suggests that food deprivation is not such a critical aspect of their welfare; this is not to say that it is acceptable to starve fish for long periods but that under appropriate circumstances periods of food deprivation may not cause welfare problems. Similarly, for species of fish that naturally spend their lives in dense shoals with many companions, being held at too low rather than too high a density may cause welfare problems. On the other hand, fish are in intimate contact with their environment through the huge surface of their gills and current evidence shows that many aspects of water quality are critical for their health and welfare.

3. *It is not possible to specify conditions that guarantee fish welfare:* The effects of varying one factor (such as density) frequently depends on the status of other factors (such as disturbance and water quality), which highlights the fact that, even for a particular species, gender and age of fish we cannot guarantee the welfare by defining a simple set of husbandry conditions. This in turn emphasises the need for sensitive on-the-spot indicators of welfare.

8. ANOTHER LOOK AT CRITERIA FOR FISH WELFARE

Knowing how fish respond to adverse conditions, we can revisit the question of what constitutes fish welfare, reworking the five welfare domains specified by Mellor & Stafford (2001) (and used in the RSPCA's report on standards for farmed Atlantic salmon, 2002) into a form that is more appropriate for fish. The details under each domain will depend on the species concerned, and also on age, gender and reproductive condition.

Domain 1. Water and food deprivation, malnutrition

> Fish should:
> - Have access to an adequate, nutritionally complete diet, taking into account the fact that fish vary greatly in their natural diet, that they do not need to maintain a constant body temperature and that in many cases they show marked differences in requirements with season and life history stage.
> - Be presented with food in a manner that is appropriate to the natural feeding behaviour of the species concerned (e.g. pellets of the correct shape to elicit feeding) and that avoids undue competition.

The natural diet of wild fish varies markedly between species and as with other vertebrate groups, it is important to ensure that captive fish are given a nutritionally appropriate diet, although in many cases we do not know exactly what this should be. For example, diets lacking in critical micronutrients impair welfare in many species, according to a range of indicators, such as high mortality, morphological abnormalities, poor immune function, abnormal behaviour, poor feeding, impaired sensory function and slow growth (De Silva & Anderson 1995).

The fact that fish are ectotherms is critical to how they are affected by periods of food deprivation. They do not need to maintain a fixed body temperature, so periods without food are less detrimental than for endothermic animals (that must do so). This is not to say that it is a matter of indifference if fish are starved; they certainly have mechanisms that motivate them to feed when their stomachs are empty and their nutritional reserves are low and restricted food may have other effects such as increasing levels of aggression. However, it does mean we cannot extrapolate from what we know about the effects of food deprivation in birds and mammals when considering appropriate conditions for fish. Expressing periods of deprivation in "degree days" takes this complexity into account. Secondly, wild fish show marked changes in appetite (some temperature-based and

other depending on life history events) that determine the effect of food deprivation on welfare. In the winter juvenile salmon may become naturally anorexic, eating little for weeks (Metcalfe *et al.*1988). These fish will feed when their energy reserves fall to a critical level, but up to this point, low rations would not compromise welfare. On the other hand, maturing salmon show a spontaneous peak in appetite in spring, when nutrient reserves for migration and spawning are accumulated, and food deprivation at this point may well compromise welfare (Kadri *et al.*1993).

Domain 2. Environmental challenge

> Critical for fish welfare are:
> - Water quality, flow rates and temperature appropriate for the species concerned
> - Appropriate seasonal and daily patterns of light intensity
> - Provision of cover and shelter

Fish are in intimate contact with their environment through the huge surface of their gills and of necessity they defecate into the medium in which they live, so water quality (in terms of dissolved oxygen, ammonia and pH) and the presence of contaminants (organic and inorganic pollutants) are probably the most critical aspects of the environment for fish welfare and also the best defined. Optimal conditions vary markedly between species; for example, catfish do poorly in clear water, whereas salmon do poorly in cloudy water and cyprinid fish are very tolerant of low dissolved oxygen levels whereas salmonid fish are not. The flow characteristics of the fish's natural habitat are also of importance, some species preferring static water, others tolerating or preferring relatively high flow rates. The nature of the substratum is also important for welfare, particularly in bottom-dwelling species; skin diseases are less common in flat fish housed in tanks with rough rather than smooth bases.

Domain 3. Disease, injury and functional impairment

> Disease should be prevented or rapidly diagnosed and treated where possible.

Diseases frequently indicate an underlying environmental problem, so diagnosing and controlling a disease must always take account of the whole system and not consider the fish alone. Diseases of fish are mostly species and system specific and many are poorly understood.

Domain 4. Behavioural/interactive restriction

> - Fish should have sufficient space to allow a degree of freedom of movement, but the definition of 'sufficient' will be species-specific.
> - For shoaling species, the company of their own kind is important for welfare, but for territorial species, this may not be the case.
> - A degree of environmental complexity may be important, depending on the species concerned

Many species form dense schools in the wild (Figure 5) and this is important when assessing the welfare if such species are held at high density, so here too it can be misleading to extrapolate from birds and mammals to fish. As discussed in Section 1.3, we do not know whether fish such as salmon are motivated to migrate by a particular route (as opposed to swimming long distances, which they can do in farm cages for example); if this were the case, their behavioural needs could not be met in a sea cage. The concept of "facilities" (Mellor & Stafford 2001, see section 1.4) may be inappropriate for fish, though some species need shelter or cover, some may require nesting material when
breeding, some need tough structures on which to chew (Etscheidt 1995).

Figure 5. Schematic representation of a natural shoal of herring, based on echosounding (Mackinson 1999)
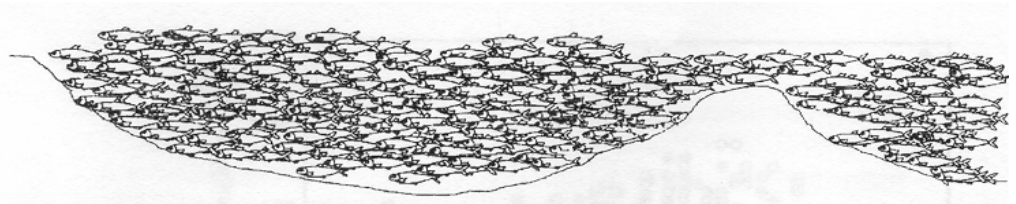
Domain 5. Mental and physical suffering

Conditions that produce unacceptable levels of anxiety, fear, distress, boredom, sickness, pain, thirst, hunger and so on should be minimised in fish as in other vertebrates, but we know little about such states in fish, or how to recognise them.

Domain 5 is critical since it relates adverse experience to emotional response. The subjective experience of fish are very hard to understand, so it is not easy to identify "conditions that produce unacceptable levels of anxiety… and so on." Most of the cues that are employed to identify fear and distress in other vertebrates are simply not accessible for fish - for example, there are no direct parallels for facial or vocal signalling. Greater understanding of cognitive processes in fish is needed before we can make the link between welfare and suffering in this group.

9. AREAS OF IGNORANCE

Clearly, a fair amount of information is available about fish welfare and about how common human practices impinge on it, but equally clearly there are big gaps in our knowledge. Some of these areas of ignorance concern issues that are fundamental to the whole concept of fish welfare, what it means and how it might be measured. These are critical areas where better general understanding is needed if we are effectively to promote fish welfare, though providing this better understanding will certainly be challenging.

- The single most important area of ignorance is a lack of understanding of the mental capabilities of fish and whether and how measurable things (such as physical damage and the physiological and behavioural responses to challenge) generate subjective states of well-being or suffering.
- On a related point, there is an equally pressing need for better understanding of the behavioural responses of fish to noxious stimuli and the neural mechanisms (from sense organs to higher brain function) that produce these responses.
- Also on a specific point, for each exploited species, it is important to discover whether there are actions that the fish are highly motivated to perform and that, like nest building in domestic hens, may be described as 'behavioural needs'.
- More knowledge is required about diseases in fish, about the links between stress, immune function and disease states and therefore about the relationship between health and welfare.
- In practical terms, a better array of welfare indicators (for example, easily observed morphological and behavioural cues) is requires for everyday use in circumstances where time consuming scrutiny of fish is impossible. In this context, more information is needed on the causes of fin erosion.

Other gaps in existing knowledge are also important, but will be somewhat easier to fill because they involve expanding the information already available for some species and in some contexts.

- A certain amount is known about the effect of angling and aquaculture practices on fish welfare, but there is very little information on the welfare of ornamental fish, particularly from capture to point of sale. Questions also remain about conditions within aquaria and ornamental ponds - what are the effects of being confined in a small, exposed space, of social isolation or of frequent interactions with a

predator?

- Where angling and aquaculture are concerned, much is known about effects on welfare of salmonids, but little information is available about other kinds of fish that are reared commercially or caught by anglers. For example, information is needed on the effects of food deprivation and of different methods of slaughter in more kinds of fish.
- Even for the well studied species and well documented effects, the exact mechanism by which the adverse effects come about are unknown. For example, there is plenty of evidence of poor welfare in salmon and trout held at very high densities, but it is not clear whether this is the result of poor water quality, high levels of aggression, simple physical damage or some other process (Ellis *et al.* 2002). The effects of density must be separated from those of other factors before appropriate remedial measures can be developed.

10. CONCLUSIONS

By spelling out current understanding on the welfare of fish, this Briefing Paper will hopefully contribute to debate on the subject. This is a difficult area to review, because many academic disciplines have an interest in it, because complex concepts are involved that are hard to define and because there are large areas of ignorance and, consequently, of disagreement. In this document a pragmatic working position has been taken on a number of important questions (Do fish suffer? Does this matter?), recognising that this position may have to be changed in the light of facts that emerge in the future. In spite of these difficulties, a great deal of painstaking research has shown how fish respond to the adverse events that they experience in nature and how these could be used to probe their welfare. A picture is beginning to emerge (partial and blurred at present) of how various human activities impinge on the welfare of fish and therefore of what might be done to improve matters. This review of the literature on fish welfare highlights the need for better knowledge and a fuller understanding of fish welfare, which will allow the development of better ways of promoting it. In the shorter term, the broader aim of improving the welfare of fish might best be achieved by education - by demonstrating that fish are very sophisticated animals in all respects and are far removed from unfeeling creatures with a 15 second memory of popular misconception. A heightened appreciation of fish by those who work with or exploit them might go a long way towards redressing some current shortcomings in fish welfare.
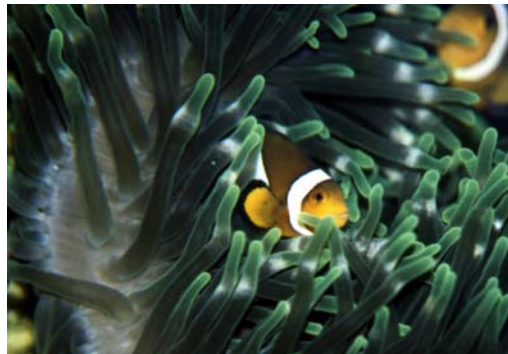
Table 3. Overview of current scientific understanding of the impact of common practice in, aquaculture, angling and the keeping of ornamental fish, with a few representative examples.

AQUACULTURE	SOME DEMONSTRATED EFFECTS ON WELFARE
Transportation	Certain kinds of transportation induce physiological stress responses and a prolonged recovery period may be necessary (Bandeen & Leatherland 1997, Barton 2000, Rouger *et al.* 1998, Iversen *et al.* 1998, Sandodden *et al.* 2001).
Handling/netting	Physical disturbance evokes physiological stress responses in many species of farmed fish (reviewed by Pickering 1998) and reduces disease resistance (Stangeland *et al.* 1996).
Confinement and short-term crowding	Physical confinement in otherwise favourable conditions increases cortisol and glucose levels and alters macrophage activity in various species (Garci-Garbi *et al.* 1998). Carp show a mild, physiological stress response to crowding that declined as the fish adapted, but crowded fish are more sensitive to an additional acute stressor (confinement in a net; Ruane *et al.* 2002). Crowding during grading increases cortisol levels for up to 48h (Barnett & Pankhurst 1998).
Inappropriate densities	High densities impair welfare in some species (trout, salmon: Ewing & Ewing 1995, bass: Vazzana 2002, red porgy: Rotllani & Tori 1997), but enhance it in others (catfish and Arctic charr, Jorgensen *et al.* 1993). Halibut suffer less injury at high densities (Greaves 2002) but show more abnormal swimming (Kristiansen & Juell 2002). The relationship between welfare and density may be non-linear; low densities may harm rainbow trout, in salmon negative effects start to appear at a critical density and density interacts with other factors such as disturbance or water quality (Ewing & Ewing 1995, Bell 2002, Scott *et al.* 2001).
Enforced social contact	Aggression can cause injury in farmed fish, especially when competition for food is strong (Greaves & Tuene 2001). Subordinate fish can be prevented from feeding (Cubitt 2002), may grow poorly and are more vulnerable to disease (reviewed by Wedermeyer 1996).
Water quality deterioration	Many adverse effects of poor water quality have been described, with different variables interacting. e.g. undisturbed salmonids use c 300 mg of oxygen per kg of fish per hour and this can double if the fish are disturbed. For such species, access to aerated water is essential for health (Wedermeyer 1996). Immunoglobulin levels fall in sea bass held at low oxygen levels (Scapigliati *et al.*1999). Heavy metals cause extensive gill damage in acidic water but are non-toxic in hard, alkaline water. (see Wedermeyer 1996)
Altered light regimes	Atlantic salmon avoid bright surface lights, except when feeding (Fernoe *et al.*1995). Continuous light increases growth in several species (e.g. cod: Puvanendran & Brown 2002).
Food deprivation	Dorsal fin erosion increases during fasting in steelhead trout (Winfree *et al.*1998). Plasma glucose increase in Atlantic salmon after 7 days without food, but other welfare indices are unaffected (Bell 2002). Atlantic salmon deprived of food for longer periods (up to 86 days) lose weight and condition, stabilising after 30 days (Einen *et al.* 1998). Farmed Atlantic salmon swim slower and fight less during feeding bouts when fed on demand (Andrews *et al.* 2002).
Disease treatment	Therapeutic treatments themselves may be stressful to fish (e.g. Griffin *et al.* 1999, 2002, Thorburn *et al.* 2001, Yildiz & Pulatsu, 1999)
Unavoidable contact with predators	Brief exposure to a predator causes increased cortisol levels and respiration rate and suppressed feeding (e.g. Metcalfe *et al.* 1987). Mortality and injury due to attacks by birds and seals can be high among farmed fish (e.g. Carss 1993).
Slaughter	All slaughter methods are stressful, but some are lees so than others (Robb *et al.*2000). Small, warm water fish such as sea bass killed by chilling in ice water had lower plasma glucose and lactate levels and showed less marked behavioural responses than those killed by other methods, in particular asphyxia (Poli *et al.* 2002, Skjervold *et al.* 2001). Electostunning may be less harmful for larger fish such as trout.

TABLE 3 continued

ANGLING	SOME DEMONSTRATED EFFECTS ON WELFARE
Capture – hooking	Injury and mortality following hooking is common, primarily in deep-hooked fish (Dubois *et al.* 1994; Hulbert & Engstrom-Heg 1980, Muonehke & Childress 1994).
Capture – playing / landing	Capture of fish by rod and line elicits a stress response of short duration (Gustaveson *et al.* 1991, Pankhurst & Dedual 1994, Pottinger 1998). Estradiol levels are suppressed in rainbow trout within 24h of capture by rod and line (Pankhurst & Dedual 1994).
Capture – handling	Exposure of exercised fish to air can have severe metabolic effects (lactate increase and altered acid-base balance), especially in larger fish (Ferguson *et al.* 1993). Capture and handling suppress reproductive function in brown trout (Melotti *et al.* 1992).
Retention / constraint / release	Retention of fish post-capture in either keepnets or stringers induces physiological stress responses, but recovery following release can be rapid (Pottinger 1998, Sobchuk & Dawson 1988). Hooking and handling for release can increase scale damage by 16% (Broadhurst & Barker 2000), possibly making released fish liable to infection. Abnormal behaviour can occur following release after a stressful event (Mesa & Schreck 1989, Olla & Davis 1989).

KEEPING ORNAMENTAL FISH	SOME DEMONSTRATED EFFECTS ON WELFARE
Capture. Exposure to Poisons	Marine tropical fish captured by sodium cyanide suffer very high mortality for several weeks after capture (Hignette 1984). Clove oil is a better alternative (Erdmann 2002).
Transportation	Estimates for mortality during capture of ornamental fish from South America range from 5 to 10% but may be as high as 30%. A further 5 to 10% mortality is estimated to occur during transportation and at the holding facilities (Ferraz de Olivera 1995). During the acclimation period following importation mortalities can be up to 30% (FitzGibbon 1993). However, in all these aspects of the ornamental fish trade there is a great deal of variability. The Ornamental Fish Trade Association has regulations to improve all aspects of capture and transport of fish (www.aquariumcouncil.org).
After purchase, constraint in a confined space	See above, under aquaculture.
Handling	See above, under aquaculture.
Inappropriate densities/species combinations	Lack of appropriate social environment (wrong species or inappropriate numbers) is an important cause of poor health in ornamental fish (Etscheidt 1995).
Poor water quality	81% of ornamental fish are held outside the optimal pH range, 36% at inappropriate temperatures (Etscheidt & Manz 1992). Poor water quality is the commonest cause of mortality in ornamental fish (Schunck 1980).
Deprivation of social contact	Angelfish transferred singly to a new tank take longer to resume feeding than those transferred in groups of 3 or 5 (Gomez-Laplaza & Morgan 1993).
Inappropriate feeding regimes	Inappropriate range and types of food can cause poor health in ornamental fish (Etscheidt 1995). Inappropriate feeding is not usually a direct cause of mortality in ornamental fish, but can be a contributory factor (Schunck 1980).
Unavoidable contact with a predator	In 19% ornamental tanks prey were housed in small tanks in direct contact with predators (Escheidt & Manz 1992, Foggitt 1997). See above under aquaculture.

| Disease treatment | See above under aquaculture. |

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