Erik Höglund - DTU Orbit (10/02/2018)

Erik Höglund

Organisations

Visiting Researcher, National Institute of Aquatic Resources
15/03/2007 → 03/11/2015 Former
erh@aqua.dtu.dk
VIP

Section for Aquaculture
25/02/2012 → 03/11/2015 Former
VIP

Publications:

Bigger is not better: cortisol-induced cardiac growth and dysfunction in salmonids
Stress and elevated cortisol levels are associated with pathological heart growth and cardiovascular disease in humans and other mammals. We recently established a link between heritable variation in post-stress cortisol production and cardiac growth in salmonid fish too. A conserved stimulatory effect of the otherwise catabolic steroid hormone cortisol is probably implied, but has to date not been established experimentally. Furthermore, whereas cardiac growth is associated with failure of the mammalian heart, pathological cardiac hypertrophy has not previously been described in fish. Here, we show that rainbow trout (Oncorhynchus mykiss) treated with cortisol in the diet for 45 days have enlarged hearts with lower maximum stroke volume and cardiac output. In accordance with impaired cardiac performance, overall circulatory oxygen-transporting capacity was diminished as indicated by reduced aerobic swimming performance. In contrast to the well-known adaptive/physiological heart growth observed in fish, cortisol-induced growth is maladaptive. Furthermore, the observed heart growth was associated with up-regulated signature genes of mammalian cardiac pathology, suggesting that signalling pathways mediating cortisol-induced cardiac remodelling in fish are conserved from fish to mammals. Altogether, we show that excessive cortisol can induce pathological cardiac remodelling. This is the first study to report and integrate the etiology, physiology and molecular biology of cortisol-induced pathological remodelling in fish.

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Individual differences in physiological and behavioural responses to stressors are increasingly recognised as adaptive variation and thus raw material for evolution and fish farming improvements including selective breeding. Such individual variation has been evolutionarily conserved and is present in all vertebrate taxa including fish. In farmed animals, the interest in consistent trait associations, that is coping styles, has increased dramatically over the last years because many studies have demonstrated links to performance traits, health and disease susceptibility and welfare. This study will review (i) the main behavioural, neuroendocrine, cognitive and emotional differences between reactive and proactive coping styles in farmed fish; (ii) the methodological approaches used to identify coping styles in farmed fish, including individual (group) mass-screening tests; and (iii) how knowledge on coping styles may contribute to improved sustainability of the aquaculture industry, including welfare and performance of farmed fish. Moreover, we will suggest areas for future...
How do individuals cope with stress? Behavioural, physiological and neuronal differences between proactive and reactive coping styles in fish

Despite the use of fish models to study human mental disorders and dysfunctions, knowledge of regional telencephalic responses in non-mammalian vertebrates expressing alternate stress coping styles is poor. Since perception of salient stimuli associated with stress coping in mammals is mainly under forebrain limbic control, we tested region-specific forebrain neural (i.e. mRNA abundance and monoamine neurochemistry) and endocrine responses at basal and acute stress conditions for previously characterised proactive and reactive Atlantic salmon. Reactive fish show a higher degree of the neurogenesis marker proliferating cell nuclear antigen (pcna) and dopamine activity under basal conditions in DI (proposed hippocampus homologue) and higher post-stress plasma cortisol levels. Proactive fish displayed post-stress higher serotonergic signalling (i.e. higher serotonergic activity and expression of the 5-HT1A receptor abundance) in the proposed amygdala homologue (Dm), increased expression of the neuroplasticity marker brain derived neurotropic factor (bdnf) in both DI and Vv (lateral septum homologue), as well as increased expression of the corticotropin releasing factor 1 (crf1) receptor in the DI, in line with active coping neuro-profiles reported in the mammalian literature. We present novel evidence of proposed functional equivalences in the fish forebrain with mammalian limbic structures.
Uncontrollable chronic stress reduces growth disparities in farmed Atlantic salmon

Individual variation in behavior and physiological traits in a wide variety of animals has been the focus of numerous studies in recent years. In this context, early life experiences shape responses that individuals have to subsequent environments, i.e., developmental plasticity. In this experiment, we subjected 10-month old fish to an unpredictable chronic stress (UCS) regime or no stress (control) for 3 weeks. These individuals then underwent the parr-smolt transformation, when salmonids become adapted for the seawater environment, and were subsequently transferred into seawater before the final sampling. Biometric data was collected at the end of each period. Sampling on the final day was conducted in order to analyze basal monoaminergic activity in the brain stem and hypothalamus, as well as gene expression of target genes in the telencephalon. We found that post-hoc sorting of individuals by their serotonergic activity (high and low) resulted in the elucidation of growth and gene expression differences. UCS groups were found to have less growth disparities throughout the experiment, compared to control fish. Furthermore, we found brain serotonergic signaling and corticotropic releasing factor binding protein expression were positively associated with brain stem serotonergic activity, which is consistent with fish showing a stress reactivity neurophysiological profile. In conclusion, we here submit evidence that sorting individuals by their basal serotonergic activity levels may be a useful tool in the study of developmental plasticity. These results may thus apply directly to improving husbandry practices in aquaculture and elucidating neural mechanisms for coping behavior.

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Authors: Vindas, M. A. (Ekstern), Madaro, A. (Ekstern), Fraser, T. W. (Ekstern), Höglund, E. (Intern), Olsen, R. E. (Ekstern), Kristiansen, T. S. (Ekstern), Øverli, Ø. (Ekstern)
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A novel role for pigment genes in the stress response in rainbow trout (Oncorhynchus mykiss)

In many vertebrate species visible melanin-based pigmentation patterns correlate with high stress- and disease-resistance, but proximate mechanisms for this trait association remain enigmatic. Here we show that a missense mutation in a classical pigmentation gene, melanocyte stimulating hormone receptor (MC1R), is strongly associated with distinct differences in steroidogenic melanocortin 2 receptor (MC2R) mRNA expression between high- (HR) and low-responsive (LR) rainbow trout (Oncorhynchus mykiss). We also show experimentally that cortisol implants increase the expression of agouti signaling protein (ASIP) mRNA in skin, likely explaining the association between HR-traits and reduced skin melanin patterning. Molecular dynamics simulations predict that melanocortin 2 receptor accessory protein (MRAP), needed for MC2R function, binds differently to the two MC1R variants. Considering that mRNA for MC2R and the MC1R variants are present in head kidney cells, we hypothesized that MC2R activity is modulated in part by different binding affinities of the MC1R variants for MRAP. Experiments in mammalian cells confirmed that trout MRAP interacts with the two trout MC1R variants and MC2R, but failed to detect regulation of MC2R signaling, possibly due to high constitutive MC1R activity.

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Organisations: National Institute of Aquatic Resources, Section for Aquaculture, University of Rochester Medical Center, King Abdullah University of Science and Technology, University of Oslo, Norwegian School of Veterinary Medicine, Norwegian Institute for Water Research, Norwegian University of Life Sciences
Authors: Khan, U. W. (Ekstern), Øverli, Ø. (Ekstern), Hinkle, P. M. (Ekstern), Pasha, F. A. (Ekstern), Johansen, I. B. (Ekstern), Berget, I. (Ekstern), Silva, P. I. M. (Ekstern), Kittilsen, S. (Ekstern), Höglund, E. (Intern), Omholt, S. W. (Ekstern), Våge, D. I. (Ekstern)
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Brain serotonergic activation in growth-stunted farmed salmon: adaption versus pathology

Signalling systems activated under stress are highly conserved, suggesting adaptive effects of their function. Pathologies arising from continued activation of such systems may represent a mismatch between evolutionary programming and current environments. Here, we use Atlantic salmon (Salmo salar) in aquaculture as a model to explore this stance of evolutionary-based medicine, for which empirical evidence has been lacking. Growth-stunted (GS) farmed fish were characterized by elevated brain serotonergic activation, increased cortisol production and behavioural inhibition. We make the novel observation that the serotonergic system in GS fish is unresponsive to additional stressors, yet a cortisol response is maintained. The inability of the serotonergic system to respond to additional stress, while a cortisol response is present, probably leads to both imbalance in energy metabolism and attenuated neural plasticity. Hence, we propose that serotonin-mediated behavioural inhibition may have evolved in vertebrates to minimize stress exposure in vulnerable individuals.

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Authors: Vindas, M. A. (Ekstern), Johansen, I. B. (Ekstern), Folkedal, O. (Ekstern), Höglund, E. (Intern), Gorissen, M. (Ekstern), Flik, G. (Ekstern), Kristiansen, T. S. (Ekstern), Øverli, Ø. (Ekstern)
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Cognitive appraisal of aversive stimulus differs between individuals with contrasting stress coping styles; evidences from selected rainbow trout (Oncorhynchus mykiss) strains

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Authors: Moltesen, M. (Intern), Vindas, M. A. (Ekstern), Winberg, S. (Ekstern), Ebbesson, L. (Ekstern), Ruiz-Gomez, M. L. (Ekstern), Skov, P. V. (Intern), Dabelsteen, T. (Forskerdatabase), Øverli, Ø. (Ekstern), Höglund, E. (Intern)
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Coping with a changing environment: The effects of early life stress

Ongoing rapid domestication of Atlantic salmon implies that individuals are subjected to evolutionarily novel stressors encountered under conditions of artificial rearing, requiring new levels and directions of flexibility in physiological and behavioural coping mechanisms. Phenotypic plasticity to environmental changes is particularly evident at early life stages. We investigated the performance of salmon, previously subjected to an unpredictable chronic stress (UCS) treatment at an early age (10 month old parr), over several months and life stages. The UCS fish showed overall higher specific growth rates compared with unstressed controls after smoltification, a particularly challenging life stage, and after seawater transfer. Furthermore, subjecting fish to acute stress at the end of the experiment, we found that UCS groups had an overall lower hypothalamic catecholaminergic and brain stem serotonergic response to stress compared with control groups. In addition, serotonergic activity was negatively correlated with final growth rates, which implies that serotonin responsive individuals have growth disadvantages. Altogether, our results may imply that a subdued monoaminergic response in stressful farming environments may be beneficial, because in such situations individuals may be able to reallocate energy from stress responses into other life processes, such as growth.

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Effects of acute and chronic stress on telencephalic neurochemistry and gene expression in rainbow trout (Oncorhynchus mykiss)

By filtering relevant sensory inputs and initiating stress responses, the brain is an essential organ in stress coping and adaptation. However, exposure to chronic or repeated stress can lead to allostatic overload, where neuroendocrinal and behavioral reactions to stress become maladaptive. This work examines forebrain mechanisms involved in allostatic processes in teleost fishes. Plasma cortisol, forebrain serotonergic (5-HTergic) neurochemistry, and mRNA levels of corticotropin-releasing factor (CRF), CRF-binding protein (CRFBP), CRF receptors (CRFR1 and CRFR2), mineralocorticoid receptor (MR), glucocorticoid receptors (GR1 and GR2) and serotonin type 1A (5-HT1A) receptors (5-HT1Aα and 5-HT1Aβ) were investigated at 1 h before and 0, 1 and 4 h after acute stress, in two groups of rainbow trout held in densities of 25 and 140 kg m⁻³ for 28 days. Generally, being held at 140 kg m⁻³ resulted in a less pronounced cortisol response. This effect was also reflected in lower forebrain 5-HTergic turnover, but not in mRNA levels in any of the investigated genes. This lends further support to reports that allostatic load causes fish to be incapable of mounting a proper cortisol response to an acute stressor, and suggests that changes in forebrain 5-HT metabolism are involved in allostatic processes in fish. Independent of rearing densities, mRNA levels of 5-HT1Aα and MR were downregulated 4 h post-stress compared with values 1 h post-stress, suggesting that these receptors are under feedback control and take part in the downregulation of the hypothalamic-pituitary-interrenal (HPI) axis after exposure to an acute stressor.

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Long-term tryptophan supplementation decreased the welfare and innate immune status of pikeperch juveniles

It has been demonstrated that short-term supplementation of L-tryptophan (TRP) can mitigate the primary neuroendocrine response to stress in some fish species, but such stress reduction was reported to be both dose- and context-dependent (Basic et al, 2013; Machado et al, 2015). So, the TRP responses may be species related or depend on the stress levels experienced by the fish. Since percid fish were reported to be more stress responsiveness than common aquaculture species such as rainbow trout (Jentoft et al, 2005), this study aimed (1) to determine to what extent a long-term dietary TRP mitigate the physiological response of pikeperch (Sander lucioperca) to emersion stress, and (2) to characterize the related immune status. Pikeperch juveniles of 10 g received four experimental diets: (CT) = control groups without any stress and any feed TRP supplement, (CTs) = control groups submitted to emersion stress but without any feed TRP supplement, 3TRPs = groups receiving 3-time TRP diet and submitted to emersion stress, 6TRPs = groups receiving 6-time TRP diet and submitted to emersion stress. Various organs were sampled on D7, D37 and D91 of TRP supplementation for evaluation of physiological and immune responses; samplings were done one hour after the emersion challenge stress. Specific growth rate (SGR) as well as food conversion rate (FCR) were also checked. Emersion stress induced a significant increase in plasma cortisol both after a single stress or repeated stress challenges. Dietary TRP significantly decreased cortisol levels in a dose related manner both after a single or repeated stress; but plasma glucose level was only affected after a single stress but not after long-term feeding. The two stress indicators measured showed that pikeperch displayed higher stress responsiveness as already demonstrated for European perch in comparison to...
salmonids (Jentoft et al, 2005). The reduction in physiological stress status by dietary TRP was associated to a significant decrease in plasma lysosomal activity, especially on D91; indicating negative interaction with the innate immune pathways. Growth rate was slowed by the long-term dietary TRP in association to an increase in FCR values. The available results indicate that long-term TRP supplementation has negative impact on the overall welfare status of pikeperch. Other analyses are ongoing and more results concerning key brain neurotransmitters such as serotonin, dopamine and their metabolites concentrations as well as on the expressions of key-immune genes (C3-1, TNF-α, IL-1β, etc) will be discussed.

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Authors: Mandiki, S. N. M. (Ekstern), Redivo, B. (Ekstern), Baekelandt, S. (Ekstern), Douxfils, J. (Ekstern), Lund, I. (Intern), Höglund, E. (Intern), Kestemont, P. (Ekstern)
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Effects of emergence time and early social rearing environment on behaviour of Atlantic salmon: Consequences for juvenile fitness and smolt migration

Consistent individual differences in behaviour have been well documented in a variety of animal taxa, but surprisingly little is known about the fitness and life-history consequences of such individual variation. In wild salmonids, the timing of fry emergence from gravel spawning nests has been suggested to be coupled with individual behavioural traits. Here, we further investigate the link between timing of spawning nest emergence and behaviour of Atlantic salmon (Salmo salar), test effects of social rearing environment on behavioural traits in fish with different emergence times, and assess whether behavioural traits measured in the laboratory predict growth, survival, and migration status in the wild. Atlantic salmon fry were sorted with respect to emergence time from artificial spawning nest into three groups: early, intermediate, and late. These emergence groups were hatchery-reared separately or in co-culture for four months to test effects of social rearing environment on behavioural traits. Twenty fish from each of the six treatment groups were then subjected to three individual-based behavioural tests: basal locomotor activity, boldness, and escape response. Following behavioural characterization, the fish were released into a near-natural experimental stream. Results showed differences in escape behaviour between emergence groups in a net restraining test, but the social rearing environment did not affect individual behavioural expression. Emergence time and social environment had no significant effects on survival, growth, and migration status in the stream, although migration propensity was 1.4 to 1.9 times higher for early emerging individuals that were reared separately. In addition, despite individuals showing considerable variation in behaviour across treatment groups, this was not translated into differences in growth, survival, and migration status. Hence, our study adds to the view that fitness (i.e., growth and survival) and life-history predictions from laboratory measures of behaviour should be made with caution and ideally tested in nature.

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Authors: Larsen, M. H. (Intern), Johnsson, J. I. (Ekstern), Winberg, S. (Ekstern), Wilson, A. D. M. (Ekstern), Hammenstig, D. (Ekstern), Thörnqvist, P. (Ekstern), Midwood, J. D. (Ekstern), Aarestrup, K. (Intern), Höglund, E. (Intern)
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Behaviour has been suggested as an underlying factor influencing how rearing density affects growth performance in Salmonid fishes. At low densities there is an elevated intensity of aggressive interactions and the formation of dominance hierarchies. As density increases, it is commonly assumed that aggression decreases, as the cost and effort required to establish and maintain dominance hierarchies increase. The increased energy expenditure associated with aggressive interactions has been identified as one mechanism causing a reduced efficiency in feed utilisation and therefore decreased growth performance. Manipulating aggressive behaviour through density may have advantages from a practical perspective. In the present study the energetic expenditure of rainbow trout held at three densities, 25, 80 and 140 kg m\(^{-3}\), were related to growth performance parameters. Measurements for growth performance and parameters of energetics were investigated at the three densities during a four week growth period. The results showed a significant increase in routine metabolism in fish reared at 25 kg m\(^{-3}\) compared to groups reared at higher densities. The study concludes that in fish reared at density of 25 kg m\(^{-3}\), a higher fraction of the dietary energy intake was used to fuel activity rather than growth, as evidenced by significantly higher routine metabolism, reduced feed utilisation efficiency and
a tendency for lower growth performance compared to fish reared at the higher densities. These results indicate a bioenergetic advantage of crowding. (C) 2015 Published by Elsevier B.V.
Natural selection constrains personality and brain gene expression differences in Atlantic salmon (Salmo salar)

In stream-spawning salmonid fishes, there is a considerable variation in the timing of when fry leave the spawning nests and establish a feeding territory. The timing of emergence from spawning nests appears to be related to behavioral and physiological traits, e.g., early emerging fish are bolder and more aggressive. In the present study, emerging Atlantic salmon (Salmo salar L.) alevins were sorted into three fractions: early, intermediate, and late emerging. At the parr stage, behavior, stress responses, hindbrain monoaminergic activity, and forebrain gene expression were explored in fish from the early and late emerging fractions (first and last 25%). The results show that when subjected to confinement stress, fish from the late emerging fraction respond with a larger activation of the brain serotonergic system than fish from the early fraction. Similarly, in late emerging fish, stress resulted in elevated expression of mRNA coding for serotonin 1A receptors (5-HT1A), GABA-A receptor-associated protein, and ependymin, effects not observed in fish from the early emerging fraction. Moreover, fish from the early emerging fraction displayed bolder behavior than their late emerging littermates. Taken together, these results suggest that the time of emergence, boldness, and aggression are linked to each other, forming a behavioral syndrome in juvenile salmon. Differences in brain gene expression between early and late emerging salmon add further support to a relationship between stress coping style and timing of emergence. However, early and late emerging salmon do not appear to differ in hypothalamus-pituitary-interrenal (HPI) axis reactivity, another characteristic of divergent stress coping styles.

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**Neuronal and neuroendocrine mechanisms of social rank and stress coping in teleost fish**

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Organisations: National Institute of Aquatic Resources, Section for Aquaculture, Uppsala University, University of Agder
Authors: Winberg, S. (Ekstern), Thörnqvist, P. (Ekstern), Dahlbom, J. (Ekstern), Roman, E. (Ekstern), Höglund, E. (Intern)
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Stress and fear responses in the teleost pallium

Evolution has resulted in behavioural responses to threat which show extensive similarities between different animal species. The reaction to predator cues is one example of such prevailing responses, and functional homologies to mammalian limbic regions involved in threat-sensitive behaviour have been found in the teleost telencephalon. The dorsolateral (Dl) and dorsomedial (Dm) regions of the pallium are thought to perform hippocampus and amygdala-like functions respectively. To what degree these regions are involved in the neuroendocrine responses to stress and predator cues however remains largely unknown. In the present study the involvement of Dl and Dm in such responses was investigated by exposing Nile tilapia (Oreochromis niloticus) to a standardized confinement stress and to skin extract from conspecifics. Nile tilapia develops a characteristic anticipatory behaviour to hand feeding, and effects of skin extract on this behaviour and locomotor activity were studied to characterise threat sensitive behaviour. Nile tilapia responded behaviourally to conspecific alarm cues by reducing feeding anticipatory behaviour. This may reflect a general elevation of alertness, and further studies combining skin extract with other challenges are needed to reveal neuroendocrine effects associated with this predator cue. Confinement stress resulted in an elevation of cortisol and serotonin (5-hydroxytryptamine, 5-HT) metabolism in both Dl and Dm. A similar tendency was observed in fish exposed to chemical alarm cues, but this effect did not reach the level of statistical significance. Hence, limbic responses to stress and fear, akin to those seen in extant mammals, are also present in the teleost lineage
Coping with unpredictability: Dopaminergic and neurotrophic responses to omission of expected reward in Atlantic salmon (Salmo salar L.).

Comparative studies are imperative for understanding the evolution of adaptive neurobiological processes such as neural plasticity, cognition, and emotion. Previously we have reported that prolonged omission of expected rewards (OER, or 'frustrative nonreward') causes increased aggression in Atlantic salmon (Salmo salar). Here we report changes in brain monoaminergic activity and relative abundance of brain derived neurotrophic factor (BDNF) and dopamine receptor mRNA transcripts in the same paradigm. Groups of fish were initially conditioned to associate a flashing light with feeding. Subsequently, the expected food reward was delayed for 30 minutes during two out of three meals per day in the OER treatment, while the previously established routine was maintained in control groups. After 8 days there was no effect of OER on baseline brain stem serotonin (5-HT) or dopamine (DA) activity. Subsequent exposure to acute confinement stress led to increased plasma cortisol and elevated turnover of brain stem DA and 5-HT in all animals. The DA response was potentiated and DA receptor 1 (D1) mRNA abundance was reduced in the OER-exposed fish, indicating a sensitization of the DA system. In addition OER suppressed abundance of BDNF in the telencephalon of non-stressed fish. Regardless of OER treatment, a strong positive correlation between BDNF and D1 mRNA abundance was seen in non-stressed fish. This correlation was disrupted by acute stress, and replaced by a negative correlation between BDNF abundance and plasma cortisol concentration. These observations indicate a conserved link between DA, neurotrophin regulation, and corticosteroid-signaling pathways. The results also emphasize how fish models can be important tools in the study of neural plasticity and responsiveness to environmental unpredictability.
This study examined whether dietary supply of DHA and phospholipids during early ontogeny affected the outcome of behavioural challenges in pike perch larvae and fry, and whether the history of lipid nutrition carried over in long-term effects on learning ability. Pike perch larvae were fed Artemia enriched with either refined olive oil high in oleic acid (A); refined olive oil supplemented with a low (B) or a high (C) level of DHA; or refined olive oil acid supplemented with fish oil with a high content of phospholipids (PL) and DHA (D). The enriched live diets were provided until 28 days post hatch (dph), at which time larval behavioural responses to visual and mechno-sensory stimuli were assessed. All dietary groups were subsequently fed an identical enriched live feed (diet D) and gradually weaned to an extruded dry feed, on which they were maintained for 112 days. At the end of this period, assessment of fry avoidance behaviour was repeated and individuals were tested for spatial learning ability in a maze. At the larval stage, individuals maintained on Artemia rich in DHA showed a 5–8 fold increase in swimming speed when subjected to a visually simulated predator test, a response that was not observed for larvae on diets low in DHA content. Independent of the predator simulation, larvae deficient or low in DHA exhibited significantly more time swimming along the edge of a test arena and had overall higher locomotor activities compared to larvae fed a diet with a high DHA content. Larvae on DHA rich diets showed an ability to achieve significantly higher peak acceleration rates during the escape response, which was maintained at 112 dph. Time spent locating the exit of a maze decreased with repetitious training sessions, although fish fed diets low in DHA spent longer
time in the maze, caused by extended periods of inactivity or “freezing” behaviour (time lag) prior to the onset of active searching behaviour. The consistency of behavioural responses to mechano-sensory stimuli in larvae and fry suggests long-term effects on the neuromuscular path-way involved in escape responses. A longer period of freezing in the learning test may reflect a more anxious and fragile behaviour profile in fish fed low levels of DHA. Further studies should aim at verifying whether this affects performance related traits, such as immune competence and robustness.

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Organisations: National Institute of Aquatic Resources, Section for Aquaculture, Uni Research AS
Authors: Lund, I. (Intern), Höglund, E. (Intern), Ebbesson, L. O. (Ekstern), Skov, P. V. (Intern)
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Feeding motivation as a personality trait in Nile tilapia (Oreochromis niloticus): role of serotonergic neurotransmission

Consistent individual variation in feeding motivation (i.e. feeding behaviour in novel environments) may be a central topic in many biological disciplines. Yet, underlying mechanisms of crucial personality traits like feeding behaviour in novel environments remain unclear. Comparative studies, however, reveal a strong degree of evolutionary conservation of neural mechanisms controlling such behaviour in teleost fishes. Previous studies have indicated duration of stress-induced anorexia as a consistent individual characteristic in teleost fishes. This study aims to determine serotonergic activity as a correlate to feed anticipatory behaviour and recovery of feed intake after transfer to a novel environment. Crucial to the definition of animal personality, a strong degree of individual consistency in different measures of feeding behaviour (feeding latency and feeding score) was demonstrated. Furthermore, low serotonergic activity in the hypothalamus was highly correlated with a personality characterized by high feeding motivation, with feeding motivation represented as an overall measure incorporating several behavioural parameters in a Principle Component Analyses (PCA). This study thus confirms individual variation in brain 5-HT neurotransmission as a correlate to complex behavioural syndromes related to feeding motivation.
Frustrative reward omission increases aggressive behaviour of inferior fighters

Animals use aggressive behaviour to gain access to resources, and individuals adjust their behaviour relative to resource value and own resource holding potential (RHP). Normally, smaller individuals have inferior fighting abilities compared with larger conspecifics. Affective and cognitive processes can alter contest dynamics, but the interaction between such effects and that of differing RHPs has not been adjudged. We investigated effects of omission of expected reward (OER) on competing individuals with contrasting RHPs. Small and large rainbow trout (Oncorhynchus mykiss) were conditioned to associate a light with reward. Thereafter, the reward was omitted for half of the fish prior to a contest between individuals possessing a 36–40% difference in RHP. Small control individuals displayed submissive behaviour and virtually no aggression. By contrast, small OER individuals were more aggressive, and two out of 11 became socially dominant. Increased aggression in small OER individuals was accompanied by increased serotonin levels in the dorsomedial pallium (proposed amygdala homologue), but no changes in limbic dopamine neurochemistry were observed in OER-exposed individuals. The behavioural and physiological response to OER in fish indicates that frustration is an evolutionarily conserved affective state. Moreover, our results indicate that aggressive motivation to reward unpredictability affects low RHP individuals strongest
Robustfish: New possibilities for growth and robustness in organic aquaculture

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Organisations: National Institute of Aquatic Resources, Section for Aquaculture, National Veterinary Institute, Section for Bacteriology, Pathology and Parasitology, Section for Ecosystem based Marine Management, University of Copenhagen, Dansk Akvakultur
Authors: Jokumsen, A. (Intern), Höglund, E. (Intern), Lund, I. (Intern), Madsen, L. (Intern), Pedersen, L. (Intern), Nielsen, M. (Ekstern), Nielsen, T. (Ekstern), Larsen, V. J. (Ekstern), Larsen, E. (Intern)
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Temperature and oxygen as determining factors in post-stress recovery profiles of Norwegian lobster Nephrops norvegicus

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Authors: Behrens, J. (Intern), Höglund, E. (Intern), Larsen, B. K. (Intern), Skov, P. V. (Intern)
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Changes in regional brain monoaminergic activity and temporary down-regulation in stress response from dietary supplementation with l-tryptophan in Atlantic cod (Gadus morhua)
The brain monoamines serotonin (5-hydroxytryptamine; 5-HT) and dopamine (DA) both play an integrative role in behavioural and neuroendocrine responses to challenges, and comparative models suggest common mechanisms for dietary modulation of transmission by these signal substances in vertebrates. Previous studies in teleosts demonstrate that 7 d of dietary administration with l-tryptophan (Trp), the direct precursor of 5-HT, suppresses the endocrine stress response. The present study investigated how long the suppressive effects of a Trp-enriched feed regimen, at doses corresponding to two, three or four times the Trp levels in commercial feed, last in juvenile Atlantic cod (Gadus morhua) when the fish are reintroduced to a diet with standard amino acid composition. We also wanted to determine whether Trp supplementation induced changes in brain monoaminergic neurochemistry in those forebrain structures innervated by DA- and 5-HTergic neurons, by measuring regional activity of DA and 5-HT in the lateral pallial regions (DI) of the telencephalon and nucleus lateralis tuberis (NLT) of the hypothalamus. Dietary Trp resulted in a dose-dependent suppression in plasma cortisol among fish exposed to confinement stress on the first day following experimental diet; however, such an effect was not observed at 2 or 6 d after Trp treatment. Feeding the fish with moderate Trp doses also evoked a general increase in DA and 5-HT-ergic activity, suggesting that these neural circuits within the NLT and DI may be indirectly involved in regulating the acute stress response.

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Organisations: National Institute of Aquatic Resources, Section for Aquaculture, Norwegian School of Veterinary Science, BioMar A/S, Uppsala University
Authors: Basic, D. (Ekstern), Schjolden, J. (Ekstern), Krogdahl, A. (Ekstern), von Krogh, K. (Ekstern), Hillestad, M. (Ekstern), Winberg, S. (Ekstern), Mayer, I. (Ekstern), Skjerve, E. (Ekstern), Höglund, E. (Intern)
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Coupling between stress coping style and time of emergence from spawning nests in salmonid fishes: Evidence from selected rainbow trout strains (Oncorhynchus mykiss)

Correlations between behavioral and physiological traits, often referred to as stress coping styles, have been demonstrated in numerous animal groups. Such trait variations often cluster in two contrasting styles, with animals characterized as either proactive or reactive. In natural populations of salmonid fishes, emergence from spawning nests, when fry establish a territory and shifts from exogenous to endogenous feeding, is a crucial niche shift with a high selection pressure. The timing of this event is correlated to behavioral and physiological traits such as aggression, boldness/shyness, dominance, and metabolic rate; resembling those of proactive and reactive stress coping styles. In farmed fish populations, however the relation between emergence and stress coping styles seems to be absent, an effect which has been related to lack of selection pressure during emergence. In the present study two rainbow trout strains genetically selected as LR (low-responsive) and HR (high-responsive) trout, characterized with proactive (LR) and reactive (HR) stress coping traits, was used to further investigate the relationship between the time of emergence and stress coping style in salmonid fishes. For this task LR and HR larvae were hatched in mixed batches, and thirty individuals from the earliest and latest 25% of emerging larvae were randomly collected. Thereafter, a line specific genetic marker was used to distinguish the proportion of LR and HR occurring in early and late fractions. The result demonstrates a higher proportion of LR fry in the early fraction in comparison to the HR fry, which emerged at a higher proportion during the late period. Early emerging individuals had larger yolk reserves at emergence, lending further support to a relationship between emergence times, yolk reserves at emergence and stress coping styles in salmonids. Smaller larval bodies in early compared to late emerging individuals suggest that this difference in yolk size reflects differences in developmental stages at emergence. These data suggests that a genetic link between emergence time and stress coping style persists in captive salmonid fishes.

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Organisations: National Institute of Aquatic Resources, Section for Aquaculture, Norwegian University of Life Sciences
Authors: Andersson, M. Å. (Intern), Khan, U. W. (Ekstern), Øverli, Ø. (Ekstern), Gjøen, H. M. (Ekstern), Höglund, E. (Intern)
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High oxygen consumption rates and scale loss indicate elevated aggressive behaviour at low rearing density, while elevated brain serotonergic activity suggest chronic stress at high rearing densities in farmed rainbow trout *Oncorhynchus mykiss*

The effect of stocking density on indicators of welfare has been investigated by several studies on farmed rainbow trout *Oncorhynchus mykiss*. However, the densities at which welfare are compromised remain ambiguous. Here three different stocking density treatments were selected based on the results of a previous study, where levels of crowding where determined using the spatial distribution of fish in two-tank systems. An un-crowded low density of 25 kg m$^{-3}$, the highest density accepted by the fish without showing indications of crowding stress of 80 kg m$^{-3}$ as the intermediate density, and the highest density accepted by the fish showing indications of crowding stress of 140 kg m$^{-3}$ as the high density were investigated. The aim of the present study was to examine the effect of being held at these densities on indicators of welfare. This was achieved through oxygen consumption measurements using automated respirometry, recording fin erosion, determining scale loss and
analysing plasma cortisol and brain serotonergic activity levels. The results obtained in the present study indicated that at the lowest density the fish had the space and opportunity to display their natural aggressive behaviour and that the fish held at the highest density were exposed to a situation of confinement.

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Organisations: National Institute of Aquatic Resources, Section for Aquaculture, Universidade do Algarve
Authors: Laursen, D. C. (Intern), Silva, P. (Ekstern), Larsen, B. K. (Intern), Höglund, E. (Intern)
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Introduction of the stress hormone cortisol through food pellets induces cardiac remodelling in rainbow trout Oncorhynchus mykiss

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Authors: Johansen, I. B. (Ekstern), Lunde, I. G. (Ekstern), Vindas, M. A. (Ekstern), Skov, P. V. (Intern), Mayer, I. (Ekstern), Nilsson, G. E. (Ekstern), Höglund, E. (Intern), Øverli, Ø. (Ekstern)
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Linking development and growth to personalities in farmed rainbow trout (Oncorhynchus mykiss)
Individual variation in behavior and physiology has been described throughout the vertebrate phylum. Seemingly completely different behaviors can be related to each other and to physiological traits such as metabolism, hormone responses and brain neurochemistry. Stable suits of behavioral traits which are consistent between situations and over time, are often termed personalities. Moreover, the term stress coping style is used when trait correlations include individual differences in physiological responses to a stressor. Personalities and stress coping styles may vary along a continuum, where the extremes have been categorized as active versus passive and proactive versus reactive, respectively. The behavioral profiles of the active/proactive extreme include being more bold, aggressive, and socially dominant. In contrast passive/reactive individuals are shy and socially subordinate. Physiologically traits of proactive individuals include higher metabolic rate and a less pronounced cortisol response to a stressor, compared to their reactive counterpart. Providing information on the correlation of traits expressed early in ontogeny could give valuable insight on the physiological processes involved in the organization of behavioral and physiological traits. However, most research on trait correlations is performed relatively late in ontogeny and the information about expression of personalities/stress coping styles during early development is meager. In salmonid fishes, the timing of emergence from spawning nests is related to behavioral and physiological traits. Generally, early emerging individuals exhibit active/proactive traits. Later emerging individuals, on the other hand, display passive/reactive characteristics. Coherent to this, there are studies suggesting that selection pressures early in ontogeny promotes the co-existence of two energetically different strategies in salmonids. Early emerging fish have been demonstrated to have a higher metabolic rate compared to those individuals who emerge at a later stage during the emergence period. There is a growing interest in the presence of individual trait variation in aquaculture, however, elusive results have been presented, and whether personalities/stress coping styles are present in domesticated fish remains debated. The emphasis of this PhD work was to investigate the relationship between individual variation in developmental rate during early ontogeny, personality/stress coping styles, and growth potential in farmed rainbow trout. Two strains of rainbow trout selected for a low (LR) and high (HR) post stress plasma cortisol response have been shown to resemble proactive and reactive coping styles respectively. Results presented here showed that LR females produced large eggs that hatched into larvae with large yolk reserves. In comparison, HR females produced smaller eggs and offspring with smaller yolk reserves. Although no difference in larval growth and development was observed between the two lines a majority of the LR individuals emerged from artificial spawning nests early, prior to fully consuming their yolk reserves. In comparison a higher frequency of reactive HR fry emerged later after the yolk reserves had been fully depleted. This confirms proactive characteristics of early emerging fry. Moreover, the larger yolk in early emerging individuals was suggested to support a more energetically demanding proactive stress coping style during the initial social interaction and territory defense. This was further supported by newly emerged individuals with large yolk reserves showing a higher probability to obtain social dominance compared to individuals with smaller yolk reserves. Moreover, socially inexperienced individuals with large yolks, and a propensity for social dominance had lower brain concentrations of serotonin, suggesting a causative effect of this neurotransmitter on social dominance and aggression. Furthermore, the results demonstrated that farmed rainbow trout with an intermediate emergence time grew larger compared to both early and late emerging fry, suggesting that intermediate emerging individuals have a stress coping style lying in-between the
proactive-reactive continuum, and that the behavioral and physiological traits of these fish are beneficial in aquaculture settings. Taken together, the results presented in this thesis demonstrate a relationship between traits expressed early in development and differences in personalities/stress coping styles and growth later in ontogeny of farmed rainbow trout.

**Physiological and behavioral responses to stress in cultivated fish – Effects of selective breeding and exposure to cortisol and tryptophan**

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**Short- and long-term effects of dietary L-tryptophan supplementation on the neuroendocrine stress response in seawater-reared Atlantic salmon (Salmo salar)**

The essential amino acid L-tryptophan (Trp) is the immediate precursor of the neurotransmitter serotonin (5-HT). Supplementing Trp through diet has been shown to suppress the neuroendocrine stress response in vertebrates including teleosts. In salmonid fish, adjusting to the social environment as well as habituation to seawater involves the neuroendocrine stress response, suggesting that such environmental factors may modulate the stress-reducing effects of Trp. To date, studies that have investigated the neuroendocrine effects of dietary Trp have only been conducted in rainbow trout (. Oncorhynchus mykiss), a salmonid species, under conditions featuring social isolation in the freshwater environment. Here, we address the effects of dietary Trp on post-stress plasma cortisol and hypothalamic monoamines in seawater-adapted Atlantic salmon (. Salmo salar), reared at densities relevant for aquaculture. Fish were given feed containing 1, 2, 3 or 4 times the Trp content in normal feed for one week. Subsequently, the fish were reintroduced to feed containing the lowest Trp level, corresponding to standard commercial feed for a number of days prior to exposure to an acute confinement stressor. Basal plasma cortisol levels were lower among non-stressed fish at 1 and 10 days post dietary Trp supplementation. By comparison, stressed fish displayed stimulatory post-stress plasma cortisol responses at 1 and 2 days after the Trp regimen was terminated. However, a reversed pattern was observed among these fish at 10 days after Trp treatment. The overall effects of dietary Trp were more pronounced in dopamine (DA) neurochemistry compared to 5-HT in the hypothalamus. The results demonstrate both short- and long-term effects of elevated dietary Trp on the neuroendocrine stress response. These findings suggest that hypothalamic DA may be more involved than 5-HT in the stress reducing effects of Trp in seawater-adapted Atlantic salmon, reared at densities relevant for aquaculture.

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The effect of tryptophan supplemented diets on brain serotonergic activity and plasma cortisol under undisturbed and stressed conditions in grouped-housed Nile tilapia Oreochromis niloticus

Tryptophan (TRP) supplemented diets have been shown to have therapeutic effects in farmed animals including fish by modulating the activity of the neurotransmitter serotonin (5-hydroxytryptamine; 5-HT). The effects reported in fish have been obtained using individually-housed fish and include a reduction in stress response, aggression and stress-induced anorexia. In land farmed animals, TRP supplemented diets have also been shown to improve meat quality as a result of reduced stress during slaughter while in fish no data is currently available. This study aims at investigating whether short-term supplementation with TRP supplemented diets changes brain serotonergic activity and the stress response associated with slaughter handling in grouped-housed Nile tilapia Oreochromis niloticus. Adult fish (n. = 108, 490.6 ± 4.0 g, 12 individuals per tank) were exposed to one of the three treatments (triplicates per treatment were used): control (0.48 g/100 g), TRP 4 × (1.87 g/100 g) and TRP 10 × (4.45 g/100 g) diets during 7 days. Afterwards, half of the fish in each tank were subjected to an acute stressor consisting of a combination of crowding and chasing, just prior to slaughter. The other half of the fish represented undisturbed conditions. Blood and brain samples were collected for cortisol and serotonergic activity analyses, respectively. Flesh quality was also assessed in both undisturbed and stressed fish for all treatments by measuring muscle pH and rigor mortis over a 72 h period. Results showed that the highest TRP supplemented diet (TRP 10 ×) induced a significant reduction in undisturbed plasma cortisol (10.57 ± 2.71 ng/ml) as compared to TRP 4 × (24.93 ± 3.19 ng/ml) and control diets (18.69 ± 2.94 ng/ml) and no effect on post-stress cortisol levels. After stress, the major 5-HT metabolite (5-hydroxyindoleacetic acid, 5-HIAA) was higher in the TRP 10 × (471.31 ± 60.95 ng/g) as compared to the other diets (TRP 4 ×: 313.52 ± 30.12 ng/g; control: 260.36 ± 19.65 ng/g). Stress before slaughter induced a significant increase in plasma cortisol (from 18.40 ± 1.76 ng/ml under undisturbed conditions to 80.34 ± 7.16 ng/ml), however, it was not sufficient to cause a faster deterioration of flesh quality. TRP supplement diets had also no effect on muscle pH and rigor mortis during the 72 h observation period. In conclusion, this study showed that only the highest levels of supplementation (10 × the control diet) affect serotonergic activity. However, these levels did not result in reduced stress responsiveness or improved flesh quality when an acute stressor is applied before slaughter. Therefore, these results underline the fact that effects of TRP on cortisol production are dose- and context-dependent, and further experiments are needed to determine under which conditions the optimal effect is obtained.

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Authors: Martins, C. (Ekstern), Silva, P. (Ekstern), Costas, B. (Ekstern), Larsen, B. K. (Intern), Santos, G. (Ekstern), Concicao, L. (Ekstern), Dias, J. (Ekstern), Øverli, T. (Ekstern), Höglund, E. (Intern), Schrama, J. (Ekstern)
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BFI (2014): BFI-level 2
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The relationship between emergence from spawning gravel and growth in farmed rainbow trout Oncorhynchus mykiss

The relationship between the timing of emergence from spawning gravel and growth after emergence was investigated in farmed Oncorhynchus mykiss. A relationship between the time of emergence and growth became evident after 6 months of rearing, where individuals with an intermediate emergence time had grown larger compared with early and late emerging individuals.

General information
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Organisations: National Institute of Aquatic Resources, Section for Aquaculture, Universidade do Algarve
Authors: Åberg Andersson, M. (Intern), Laursen, D. C. (Intern), SILVA, P. (Ekstern), Höglund, E. (Intern)
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Scopus rating (2016): CiteScore 1.57 SJR 0.741 SNIP 0.882
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.951 SNIP 0.935 CiteScore 1.64
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.944 SNIP 0.934 CiteScore 1.76
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.049 SNIP 1.118 CiteScore 1.98
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.93 SNIP 1.035 CiteScore 1.88
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.895 SNIP 0.946 CiteScore 1.66
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.774 SNIP 0.834
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.773 SNIP 0.891
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.883 SNIP 0.968
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.996 SNIP 1.06
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.897 SNIP 1.051
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.827 SNIP 0.898
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.945 SNIP 1.148
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.937 SNIP 1.096
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 0.949 SNIP 1.056
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 0.874 SNIP 1.1
Utilising spatial distribution in two-tank systems to investigate the level of aversiveness to crowding in farmed rainbow trout Oncorhynchus mykiss

In aquaculture, fish are exposed to a range of unfavourable environmental conditions. Amongst these, stocking density has attracted considerable attention as inappropriate densities may compromise welfare and negatively impact production. However, the recommendations for stocking remain elusive. The aim of the present study was to apply a novel method to investigate a level of crowding that indicated aversiveness in rainbow trout (Oncorhynchus mykiss). In a two-tank system, where two identical tanks were connected via a doorway, it was observed that social behaviour controlled the distribution of the fish between the tanks. Fish were stocked at equal quantities in each tank of the system. The doorway was opened and the fish moved between the two tanks. Typically, this resulted in one tank being occupied by a few highly aggressive dominant individuals (“dominant” tank) and the majority of the fish occupying the second tank (“crowded” tank). Here, the potential of this unequal spatial distribution for quantifying aversion to crowding was explored. Fish were stocked in three two-tank systems at a total density of 20, 40 and 80kgm$^{-3}$ respectively. The number of fish in each tank was determined every three days throughout the duration of the experiment and the percentage of fish in the “crowded” tank was used as an indicator of the distribution pattern in the two-tank systems. The results indicated a negative relationship between the total density stocked (20, 40 and 80kgm$^{-3}$) and the percentage of fish in the “crowded” tank. A subsample of individuals was sacrificed for blood and brain samples every three days from the “crowded” tank, prior to the fish count. The neuroendocrine indicators of stress, elevated serotonergic activity levels which were not associated with high plasma levels of cortisol, suggested chronic stress in the fish at the highest total density stocked (80kgm$^{-3}$). Taken together, these results indicated that a level of aversiveness to crowding had been reached at the highest density stocked, where the mean absolute density, irrespective of time of day, observed in the “crowded” tank was 126.5±3.7kgm$^{-3}$. 

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BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.018 SNIP 1.297 CiteScore 2.08
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.075 SNIP 1.342 CiteScore 2.17
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Scopus rating (2013): SJR 0.823 SNIP 1.16 CiteScore 1.85
ISI indexed (2013): ISI indexed yes
Welfare aspects of stocking density in farmed rainbow trout, assessed by behavioural and physiological methods

There is an increasing amount of interest in the welfare of fish from aquaculture. There are several aquaculture practices that may act as chronic stressors and therefore have the potential to negatively impact welfare. Stocking density has been highlighted as a particular welfare concern, from both an ethical and practical point of view. A quantity of research has been conducted on the relationship between stocking density and indicators of welfare in farmed rainbow trout Oncorhynchus mykiss. The studies to date have revealed that both low and high densities have the potential to detrimentally affect welfare in rainbow trout. Several studies have endeavoured to make specific recommendations for maximum stocking density limits for rainbow trout. However, wide discrepancies exist, highlighting the fact that it has been a challenge to identify density limits that promote optimal welfare and production in rainbow trout. This emphasises the significance of developing alternative methods that provide insight into the potential density limits that are optimal for welfare and performance in rainbow trout. Here, a behavioural method using two-tank systems was developed and applied. The twotank systems consisted of two identical tanks which were attached to each other with a doorway allowing the fish to move freely between the two tanks. By studying the spatial distribution of fish in two-tank systems stocked with different densities and the neuroendocrine stress levels of the fish, a density level was established that showed indications of crowding. The results revealed that a level of aversion to crowding had been reached at an absolute density of approximately 140 kg m–3. Additionally, the influence of the established density limit on physiological indicators of welfare and performance were investigated. At this density of 140 kg m–3, the lower oxygen consumption rates and lower quantity of scale loss collected from the tanks suggested reduced levels of social hierarchy related aggressive encounters. Higher brain serotonergic activity in the brain stem of individuals held at this density indicated elevated stress levels, despite low concentrations of plasma cortisol. The reduced energetic expenditure at 140 kg m–3 resulted in a better utilisation of ingested feed and hence growth performance. Taken together, despite the chronic stress levels at this density, the results showed that at this density the reduced energy expenditure, attributed to reduced agressive social interactions, resulted in a better growth performance. Therefore, it may be concluded that application of the method using the two-tank systems provided new insight into an optimal stocking density limit for rainbow trout. Furthermore, the method presented here provides a promising tool for investigating stocking density levels in rainbow trout. Further development of the current method would consider it applicable for determining limits for a range of culture situations.
Brain activation and appraisal of hypoxia in two strains of rainbow trout (Oncorhynchus mykiss) displaying divergent stress coping styles

Context-dependent responses to novelty in Rainbow trout (Oncorhynchus mykiss), selected for high and low post-stress cortisol responsiveness

Previous studies in a rainbow trout model, selectively bred for high (HR) and low (LR) post stress plasma cortisol levels, have yielded data that are indicative of contrasting stress coping styles. Fish from the HR line have been suggested to display a more diverse behavioral repertoire in challenging situations than the LR counterpart. The present study addressed whether such variation in behavioral flexibility traits was evident in different experimental settings using these selection lines. The fish were subjected to three sets of challenges (novel object test, resident–intruder test and confinement stressor test), all which were repeated a week later. Introducing a novel object evoked a divergent behavioral response in association with feeding: fish from the LR line displayed consistently suppressed feed intake while the HR fish remained unaffected. This observation was found to be repeatable along with attack latency and movement activity from the resident–intruder and confinement stressor tests. These results indicate that the behavioral responses in this animal model are context-dependent and shed new light on the expression of behavioral flexibility.
Effects of stocking density and sustained aerobic exercise on growth, energetics and welfare of rainbow trout

Two stocking densities, “low” (L, between ~19 and ~25 kgm−3) and “high” (H, between ~75 and ~100 kgm−3) were compared for effects on specific growth rate (SGR), feed conversion, energetics and welfare of rainbow trout reared at 14 °C either in static water (S) or swimming in a gentle current of ~0.9 bodylengths s−1 (C). Trout (initial mass ~110 g) were reared for 9 weeks in circular tanks (volume 0.6 m3), in triplicate of four conditions (LS, LC, HS, HC). Fish were fed ad libitum daily; waste pellets were swirl-collected at the outflow to calculate feed intake. SGR was measured each three weeks for the last six weeks of the trial. The tanks functioned as intermittent-stopped flow respirometers, to permit metabolic rate to be measured as instantaneous oxygen uptake once per hour. Mean (±SD) SGR was significantly lower at H than L (1.51±0.03 vs 1.44±0.04% day−1, respectively, n=6) and lowest in HC. When compared over a similar interval of mass gain, H groups had approximately 25% higher metabolic rates than L, with the highest rates in the HC condition. As a result, fish in the H groups dissipated a greater amount of feed energy as metabolism and, across all groups, there was a direct negative relationship between the quantity of energy dissipated and their SGR. There was no evidence of a neuroendocrine stress response, plasma cortisol was around 1 ng ml−1 in all conditions. An acute crowding stress increased plasma cortisol to above 120 ng ml−1 in all groups, but C groups recovered to control levels within 8 h whereas S groups required 20 h. Respirometry on individuals revealed that H fish had approximately 14% higher metabolic rates than L fish, indicating that increased metabolic rate in rearing tanks was in part physiological. The H groups had approximately 15% lower critical
swimming speeds than the L groups which, together with their raised metabolic rate, indicated a physiological impairment. Thus, high density reduced SGR by raising energy dissipation, at least partially as a physiological response by the fish, although there was no evidence of an endocrine stress response. The only beneficial effect of C was in recovery from acute stress.
Hormonal modulation of the heat shock response: insights from fish with divergent cortisol stress responses

Acute temperature stress in animals results in increases in heat shock proteins (HSPs) and stress hormones. There is evidence that stress hormones influence the magnitude of the heat shock response; however, their role is equivocal. To determine whether and how stress hormones may affect the heat shock response, we capitalized on two lines of rainbow trout specifically bred for their high (HR) and low (LR) cortisol response to stress. We predicted that LR fish, with a low cortisol but high catecholamine response to stress, would induce higher levels of HSPs after acute heat stress than HR trout. We found that HR fish have significantly higher increases in both catecholamines and cortisol compared with LR fish, and LR fish had no appreciable stress hormone response to heat shock. This unexpected finding prevented further interpretation of the hormonal modulation of the heat shock response but provided insight into stress-coping styles and environmental stress. HR fish also had a significantly greater and faster heat shock response and less oxidative protein damage than LR fish. Despite these clear differences in the physiological and cellular responses to heat shock, there were no differences in the thermal tolerance of HR and LR fish. Our results support the hypothesis that responsiveness to environmental change underpins the physiological differences in stress-coping styles. Here, we demonstrate that the heat shock response is a distinguishing feature of the HR and LR lines and suggest that it may have been coselected with the hormonal responses to stress.
Linking personality to larval energy reserves in rainbow trout (Oncorhynchus mykiss).

There is a surging interest in the evolution, ecology and physiology of personality differences. However, most of the studies in this research area have been performed in adult animals. Trait variations expressed early in development and how they are related to the ontogeny of an animal's personality are far less studied. Genetic differences as well as environmental factors causing functional variability of the central serotonergic system have been related to personality differences in vertebrates, including humans. Such gene-environment interplay suggests that the central serotonergic system plays an important role in the ontogeny of personality traits. In salmonid fishes, the timing of emergence from spawning nests is related to energy reserves, aggression, and social dominance. However, it is currently unknown how the size of the yolk reserve is reflected on aggression and dominance, or if these traits are linked to differences in serotonergic transmission in newly emerged larvae. In this study we investigated the relationship between yolk reserves, social dominance, and serotonergic transmission in newly emerged rainbow trout (Oncorhynchus mykiss) larvae. This was conducted by allowing larvae with the same emergence time, but with different yolk sizes, to interact in pairs for 24 h. The results show that individuals with larger yolks performed more aggressive acts, resulting in a suppression of aggression in individuals with smaller yolks. A higher brain serotonergic activity confirmed subordination in larvae with small yolks. The relationship between social dominance and yolk size was present in siblings, demonstrating a link between interfamily variation in energy reserves and aggression, and suggests that larger yolk reserves fuel a more aggressive personality during the initial territorial establishment in salmonid fishes. Furthermore, socially naïve larvae with big yolks had lower serotonin levels, suggesting that other factors than the social environment causes variation in serotonergic transmission, underlying individual variation in aggressive behavior.
Lower brain levels of serotonin in rainbow trout larvae with a propensity for social dominance

There is general consensus that low levels of brain serotonin are associated with aggression and social dominance. However, most of the studies investigating the relationship between serotonin (5-HT) and aggressive behavior have been performed in animals with previous social experience. Studies performed on socially naive animals, predisposed to different levels of aggression, are needed to investigate to which extent inherited differences in 5-HTeric transmission underlie this behavioral variability. In this work we show that rainbow trout larvae, having a large yolk during emergence from the spawning nests, also have higher probability to become social dominant. Furthermore, newly emerged socially naïve individuals with larger yolk also had lower brain 5-HT levels. This demonstrates a propensity to social dominance, which is associated with lower brain serotonin levels, in larvae that emerge from the spawning nests with a big yolk. Further studies utilizing this animal model may reveal inherited differences in 5-HTeric transmission underlying individual variation in aggressive behavior.

Neural plasticity is affected by stress and heritable variation in stress coping style

Here we use a comparative model to investigate how behavioral and physiological traits correlate with neural plasticity. Selection for divergent post-stress cortisol levels in rainbow trout (Oncorhynchus mykiss) has yielded low- (LR) and high responsive (HR) lines. Recent reports show low behavioral flexibility in LR compared to HR fish and we hypothesize that this divergence is caused by differences in neural plasticity. Genes involved in neural plasticity and neurogenesis were investigated by quantitative PCR in brains of LR and HR fish at baseline conditions and in response to two different stress paradigms: short-term confinement (STC) and long-term social (LTS) stress. Expression of proliferating cell nuclear antigen (PCNA), neurogenic differentiation factor (NeuroD) and doublecortin (DCX) was generally higher in HR compared to LR fish. STC stress led to increased expression of PCNA and brain-derived neurotrophic factor (BDNF) in both lines, whereas LTS stress generally suppressed PCNA and NeuroD expression while leaving BDNF expression unaltered. These results indicate that the transcription of neuroplasticity-related genes is associated with variation in coping style, while also being affected by STC – and LTS stress in a biphasic manner. A higher degree of neural plasticity in HR fish may provide the substrate for enhanced behavioral flexibility.
Omission of expected reward sensitizes the brain dopaminergic system of classically conditioned Atlantic salmon

For several reasons, such as easy maintenance, rapid generation times, and increasingly mapped genomes, teleost fishes are emerging as an alternative to small mammals in biomedical, neural, and behavioral research. Behavioral, genetic, and physiological screening of high numbers of individuals across treatments and generations is one particularly attractive feature of fish model systems. Both animal welfare considerations and fundamental scientific questions regarding the evolution of learning and memory have directed particular attention towards possible cognitive and emotional processes in fishes. Here we show that the omission of expected reward (OER) leads to increased aggression towards conspecifics in classically conditioned Atlantic salmon (Salmo salar). Furthermore, in response to an acute stressor, OER fish displayed increased dopaminergic (DA) neurotransmission compared to controls. There was also a general downregulation of dopamine receptor D1 gene expression in the telencephalon of OER groups, which suggests a coping mechanism in response to unbalanced DA metabolism. These results indicate that animals subjected to unpredictable reward conditions develop a sensitization of the DA signalling system, manifest as a potentiated response to novel, stressful stimuli. Similarities between fish and mammals in this response to unpredictability illustrates a role for teleost fish as models to understand the development of different types of DA dysfunction.

General information
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Organisations: National Institute of Aquatic Resources, Section for Aquaculture, Institute of Marine Research, University of Oslo, Norwegian University of Life Sciences
Authors: Vindas, M. (Ekstern), Höglund, E. (Intern), Folkedal, O. (Ekstern), Johansen, I. (Ekstern), Braastad, B. (Ekstern), Stien, L. (Ekstern), Kristiansen, T. (Ekstern), Overli, O. (Ekstern)
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Behavioural responses to hypoxia provide a non-invasive method for distinguishing between stress coping styles in fish

Two divergent behavioural and physiological response patterns to challenges have been identified in mammals and birds, frequently termed the proactive and reactive coping styles. In recent years, individually distinct coping styles have also been observed in several species of fish. These individual differences may result in suboptimal production and compromised welfare in aquaculture. An approach to overcome these problems could be to sort fish and optimise rearing conditions according to coping style. It has been previously demonstrated that the proactive and reactive coping styles in
fish can be characterised by contrasting behavioural responses to hypoxia. Two rainbow trout (Oncorhynchus mykiss) strains, bred for a low- (LR) and high- (HR) cortisol response to a standardized stressor, are suggested to resemble the proactive and reactive coping styles respectively. Therefore, these fish provided an opportunity for verifying a method for sorting fish with respect to coping style by exposure to hypoxia. Groups consisting of 24 individually tagged fish, 12 HR and 12 LR were exposed to hypoxia in a two choice system. The system consisted of a "home" tank provided with cover connected to a second brightly "illuminated" tank via a closable doorway. During the experiment, the doorway between the two tanks was opened and hypoxic conditions were gradually induced in the "home" tank by bubbling with nitrogen. The latency time to move away from hypoxic conditions to normoxic conditions in the second tank was recorded for each individual. The oxygen saturation in each tank was measured every 30 min. The experiment consisted of two trials. Each trial was carried out in two sessions, switching the "home" tank and "illuminated" tank between Sessions 1 and 2. The results indicated that the response to hypoxia differed significantly between LR and HR individuals in both Session 1 (P <0.05) and Session 2 (P ≤ 0.001). Furthermore, a higher number of HR individuals left hypoxic conditions compared to LR individuals in both Session 1 (P = 0.001) and Session 2 (P ≤ 0.001). Taken together, the findings of the present study demonstrate a repeatable difference in behavioural response to hypoxia between the two strains. The method presented could be utilized as a non-invasive method for sorting fish according to stress coping style.

General information
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Authors: Laursen, D. C. (Intern), Olsén, H. L. (Ekstern), Ruiz-Gomez, M. D. L. (Ekstern), Winberg, S. (Ekstern), Höglund, E. (Intern)
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BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.94 SNIP 1.177 CiteScore 1.98
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.018 SNIP 1.297 CiteScore 2.08
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.075 SNIP 1.342 CiteScore 2.17
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 0.823 SNIP 1.16 CiteScore 1.85
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 0.866 SNIP 1.2 CiteScore 1.73
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.032 SNIP 1.309 CiteScore 2.1
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 0.867 SNIP 1.175
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.901 SNIP 1.244
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.816 SNIP 1.397
Scopus rating (2007): SJR 0.702 SNIP 1.262
Consistent boldness behaviour in early emerging fry of domesticated Atlantic salmon (Salmo salar): Decoupling of behavioural and physiological traits of the proactive stress coping style

Individual variation in the way animals cope with stressors has been documented in a number of animal groups. In general, two distinct sets of behavioural and physiological responses to stress have been described: the proactive and the reactive coping styles. Some characteristics of stress coping style seem to be coupled to the time to emerge of fry from spawning redds in natural populations of salmonid fishes. In the present study, behavioural and physiological traits of stress coping styles were compared two and five months after emergence in farmed Atlantic salmon (Salmo salar), using individuals with an early or late time to emerge. Initially, compared to late emerging individuals, early emerging individuals showed a shorter time to resume feeding after transfer to rearing in isolation. Resumption of feeding after isolation was suggested to be related to boldness behaviour, rather than hunger, in the present study. This observation was repeated five months after emergence, demonstrating behavioural consistency over time in this trait. However, in other traits of proactive and reactive stress coping styles, such as social status, resting metabolism or post stress cortisol concentrations, early and late emerging individuals did not differ. Therefore, this study demonstrates that boldness in a novel environment is uncoupled from other traits of the proactive and reactive stress coping styles in farmed salmonids. It is possible that this decoupling is caused by the low competitive environment in which fish were reared. In natural populations of salmonids, however, the higher selection pressure at emergence could select for early emerging individuals with a proactive coping style.

General information
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Organisations: Section for Aquaculture, National Institute of Aquatic Resources, Norwegian University of Life Sciences, UAEMéx, Mexico, Facultad de Ciencias, University of Glasgow
Authors: Vaz-Serrano, J. (Ekstern), Ruiz-Gomez, M. L. (Ekstern), Gjøen, H. M. (Ekstern), Skov, P. V. (Intern), Huntingford, F. A. (Ekstern), Øverli, Ø. (Ekstern), Höglund, E. (Intern)
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Scopus rating (2016): CiteScore 2.53 SJR 1.05 SNIP 0.856
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.286 SNIP 1.006 CiteScore 2.92
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Effects of maternal stress coping style on offspring characteristics in rainbow trout (Oncorhynchus mykiss)

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Organisations: National Institute of Aquatic Resources, Section for Aquaculture
Authors: Åberg Andersson, M. (Intern), Silva, P. (Ekstern), Steffensen, J. (Ekstern), Höglund, E. (Intern)
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Is batch variability in hatching time related to size heterogeneity and cannibalism in pikeperch (Sander lucioperca)?

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State: Published
Organisations: Section for Aquaculture, National Institute of Aquatic Resources
Authors: Steenfeldt, S. J. (Intern), Lund, I. (Intern), Höglund, E. (Intern)
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Linking fearfulness and coping styles in fish

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Authors: Martins, C. I. (Ekstern), Silva, P. I. (Ekstern), Conceicao, L. E. (Ekstern), Costas, B. (Ekstern), Höglund, E. (Intern), Øverli, Ø. (Ekstern), Schrama, J. W. (Ekstern)

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BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.283 SNIP 1.046
Scopus rating (2007): SJR 1.162 SNIP 1.033
Scopus rating (2006): SJR 1.094 SNIP 1.055
Scopus rating (2005): SJR 1.045 SNIP 0.922
Scopus rating (2004): SJR 1.066 SNIP 1.006
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.898 SNIP 0.833
Scopus rating (2002): SJR 0.725 SNIP 0.744
Scopus rating (2001): SJR 0.567 SNIP 0.746
Web of Science (2001): Indexed yes
Scopus rating (2000): SJR 0.606 SNIP 0.763
Scopus rating (1999): SJR 0.673 SNIP 0.771
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The two-choice system is a non-invasive method for identifying socially dominant individuals from a group of fish

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Yolk reserves predicts social status in rainbow trout (Oncorhynchus mykiss) larvae

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Main Research Area: Technical/natural sciences
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Avoidance behaviour of rainbow trout (Oncorhynchus mykiss) to hypoxia: a non-invasive method for sorting fish according to stress coping style

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Differences in post hatch metabolic rate and developmental rate in Atlantic salmon (Salmo salar L.): Evidence for compensatory growth?

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State: Published
Organisations: Section for Aquaculture, National Institute of Aquatic Resources
Authors: Vaz-Serrano, J. (Ekstern), Åberg, M. (Intern), Gjøen, H. (Ekstern), Steffensen, J. (Ekstern), Höglund, E. (Intern)
Publication date: 2010
Event: Poster session presented at 9th International Congress on Biology of Fish, Barcelona, Spain.
Main Research Area: Technical/natural sciences
Links:
http://www.fishbiologycongress.org/

Relation between stress coping style, larval development and time to emergence in rainbow trout (Oncorhynchus mykiss)

General information
State: Published
Organisations: Section for Aquaculture, National Institute of Aquatic Resources
Authors: Åberg, M. (Intern), Khan, U. W. (Ekstern), Øverli, Ø. (Ekstern), Gjøen, H. M. (Ekstern), Steffensen, J. F. (Intern), Höglund, E. (Intern)
Publication date: 2010
Event: Poster session presented at 9th International Congress on Biology of Fish, Barcelona, Spain.
Main Research Area: Technical/natural sciences

Stress coping styles in farmed tilapia (Oreochromis niloticus): Consistent individual behavioral differences and response to conspecific alarm cues

General information
State: Published
Organisations: Section for Aquaculture, National Institute of Aquatic Resources
Authors: Silva, P. (Ekstern), Martins, C. (Ekstern), Höglund, E. (Intern), Øverli, Ø. (Ekstern)
Publication date: 2010
Event: Poster session presented at 9th International Congress on Biology of Fish, Barcelona, Spain.

Stress responsiveness, energetics and life history traits in salmonid fish

General information
State: Published
Organisations: National Institute of Aquatic Resources, Section for Aquaculture
Authors: Höglund, E. (Intern)
Publication date: 2010

Host publication information
Title of host publication: Book of Abstracts
Main Research Area: Technical/natural sciences
Conference: 9th International Congress on Biology of Fish, Barcelona, Spain, 05/07/2010 - 05/07/2010
Links:
http://www.fishbiologycongress.org/

Effects of stocking density on the energetics and welfare of rainbow trout

General information
State: Published
Organisations: National Institute of Aquatic Resources, Section for Aquaculture
Authors: McKenzie, D. (Intern), Höglund, E. (Intern), Jokumsen, A. (Intern)
Number of pages: 140
Publication date: 2009

Host publication information
Title of host publication: Comparative Biochemistry and Physiology A-Molecular & Integrative Physiology
Volume: 153A (2): Suppl. 1
Main Research Area: Technical/natural sciences
Conference: Society for Experimental Biology Conference : Session "The respiratory physiology of fish in aquaculture", Glasgow, UK, 01/01/2009

Larval developmental rate, metabolic rate and future growth performance in Atlantic salmon

General information
State: Published
Organisations: Section for Aquaculture, National Institute of Aquatic Resources
Authors: Serrano, J. V. (Ekstern), Åberg, M. (Intern), Gjoeen, H. M. (Ekstern), Steffensen, J. F. (Ekstern), Höglund, E. (Intern)
Pages: S140-S140
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Comparative Biochemistry and Physiology. Part A: Molecular & Integrative Physiology
Volume: 153A
Issue number: 2
ISSN (Print): 1095-6433
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
Consistent and heritable individual differences in reaction to challenges, often referred to as stress coping styles, have been extensively documented in invertebrates. In fish, selection for divergent post-stress plasma Cortisol levels in rainbow trout (Oncorhynchus mykiss) has yielded a low (LR) and a high responsive (HR) strain. A suite of behavioural traits is associated with this physiological difference, with LR (proactive) fish feeding more rapidly after transfer to a new environment and being socially dominant over HR (reactive) fish. Following transport from the UK to Norway, a switch in...
behavioural profile occurred in trout from the 3rd generation: HR fish regained feeding sooner than LR fish in a novel environment and became dominant in size-matched HR-LR pairs. One year after transport, HR fish still fed sooner, but no difference in social dominance was found. Among offspring of transported fish, no differences in feeding were observed, but as in pre-transported 3rd generation fish, HR fish lost fights for social dominance against size-matched LR opponents. Transferred fish and their offspring retained their distinct physiological profile throughout the study; HR fish showed consistently higher post-stress cortisol levels at all sampling points. Altered risk-taking and social dominance immediately after transport may be explained by the fact that HR fish lost more body mass during transport than did LR fish. These data demonstrate that some behavioural components of stress coping styles can be modified by experience, whereas behavioural plasticity is limited by genetic effects determining social position early in life story. (C) 2008 Elsevier Inc. All rights reserved.
Effects of antalarmin, a CRF receptor 1 antagonist, on fright reaction and endocrine stress response in crucian carp (Carassius carassius)

The corticotrophin-releasing factor (CRF) receptors show striking homogeneity throughout the vertebrate subphylum. In mammals, the CRF1 receptor (CRFR1) plays an important role in mediating behavioral and endocrine responses to fear and stress. The specific roles of this receptor subtype in fear and stress reactions in non-mammalian vertebrates are largely unknown. Crucian carp displays the olfactory-mediated fright reaction, a stereotypic behavioral response to waterborne cues from damaged skin of conspecifics. This reaction shows several similarities to basic components of avoidance behavior in mammals. In the present study, we applied the non-peptide CRFR1 antagonist, antalarmin, to crucian carp 1 h before exposure to conspecific skin extract. This treatment resulted in a suppression of the fright reaction. After skin extract exposure, antalarmin treatment also lead to lower plasma cortisol values, as compared to vehicle treatment. This suppression of the behavioral fright reaction and the stress induced rise in plasma cortisol in crucian carp suggests that the functions of the CRFR1 are conserved by evolution.
Female crucian carp, Carassius carassius, lose predator avoidance behavior when getting ready to mate

In predator-prey interactions, the prey often have to compromise fitness-related behaviors such as feeding, courting, and territorial defense in order to avoid predators. In these trade-off situations, some behaviors have priority over others. These priorities are not rigid, and may be context-dependent; for instance, many animals show increased risk-taking during courtship behavior by paying less attention to potential predators. We investigated whether the fright reaction, a stereotypical avoidance response to olfactory cues from injured conspecifics, may be affected by reproductive status in a teleost fish, the crucian carp. We demonstrate that among individuals not responding to alarm substances with a fright reaction, the majority were ovulated or spermiated. In females, mean plasma concentrations of 17 beta-estradiol and testosterone, gonadal steroids known to decrease during the later stages of sexual maturation, were lower in the individuals not responding with a fright reaction compared to those responding. In males, there were no differences between responsive and non-responsive individuals in mean plasma levels of androgens (testosterone and 11-ketotestosterone) involved in spermatogenesis and male sexual behavior. As the fright reaction in crucian carp consists of behavior incompatible with spawning behavior, we hypothesize that this short-term suppression of the alarm response has evolved so that spawning can occur uninterrupted.

**General information**

State: Published
Organisations: Section for Aquaculture, National Institute of Aquatic Resources
Authors: Lastein, S. (Ekstern), Höglund, E. (Intern), Mayer, I. (Ekstern), Overli, O. (Ekstern), Doving, K. (Ekstern)
Pages: 1487-1491
Publication date: 2008
Main Research Area: Technical/natural sciences

**Publication Information**

Journal: Journal of Chemical Ecology
Volume: 34
Issue number: 11
ISSN (Print): 0098-0331
Ratings:
- BFI (2018): BFI-level 1
- Web of Science (2018): Indexed yes
- BFI (2017): BFI-level 1
- Web of Science (2017): Indexed Yes
- BFI (2016): BFI-level 1
- Scopus rating (2016): SJR 1.187 SNIP 1.176 CiteScore 2.67
- BFI (2015): BFI-level 1
- Scopus rating (2015): SJR 1.533 SNIP 1.156 CiteScore 2.94
Larval developmental rate, stress responsiveness and life history traits in salmonids

General information
State: Published
Organisations: Section for Aquaculture, National Institute of Aquatic Resources
Authors: Höglund, E. (Intern), Serrano, J. (Ekstern)
Pages: S209-S209
Publication date: 2008
Main Research Area: Technical/natural sciences

Publication information
Journal: Comparative Biochemistry and Physiology. Part A: Molecular & Integrative Physiology
Volume: 150
Issue number: 3
ISSN (Print): 1095-6433
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
Parental stress-coping styles affect the behaviour of rainbow trout Oncorhynchus mykiss at early developmental stages

This work examined behavioural responses in yolk-sac rainbow trout Oncorhynchus mykiss larvae originating from strains selected for high (HR) or low (LR) plasma cortisol response to a standardized stressor. The results showed that yolk-sac larvae originating from the HR strain were more sensitive to environmental stressors, in that they showed a shorter reaction time to low oxygen levels. Previous studies on adult and juvenile individuals from these strains demonstrated a number of correlated physiological and behavioural differences. In yolk-sac larvae, growth and development depended...
mainly on internal factors, which suggest that at least some aspects of stress-coping styles are inherent to the individual, before factors such as social experience or variable access to food resources could modify behavioural strategy.

**General information**

State: Published
Organisations: Section for Aquaculture, National Institute of Aquatic Resources
Authors: Höglund, E. (Intern), Gjoen, H. (Ekstern), Pottinger, T. (Ekstern), Overli, O. (Ekstern)
Pages: 1764-1769
Publication date: 2008
Main Research Area: Technical/natural sciences

**Publication information**

Journal: Journal of Fish Biology
Volume: 73
Issue number: 7
ISSN (Print): 0022-1112
Ratings:
- BFI (2018): BFI-level 1
- Web of Science (2018): Indexed yes
- BFI (2017): BFI-level 1
- Web of Science (2017): Indexed yes
- BFI (2016): BFI-level 1
- Scopus rating (2016): CiteScore 1.57 SJR 0.741 SNIP 0.882
- Web of Science (2016): Indexed yes
- BFI (2015): BFI-level 1
- Scopus rating (2015): SJR 0.951 SNIP 0.935 CiteScore 1.64
- Web of Science (2015): Indexed yes
- BFI (2014): BFI-level 1
- Scopus rating (2014): SJR 0.944 SNIP 0.934 CiteScore 1.76
- Web of Science (2014): Indexed yes
- BFI (2013): BFI-level 1
- Scopus rating (2013): SJR 1.049 SNIP 1.118 CiteScore 1.98
- ISI indexed (2013): ISI indexed yes
- Web of Science (2013): Indexed yes
- BFI (2012): BFI-level 1
- Scopus rating (2012): SJR 0.93 SNIP 1.035 CiteScore 1.88
- ISI indexed (2012): ISI indexed yes
- Web of Science (2012): Indexed yes
- BFI (2011): BFI-level 1
- Scopus rating (2011): SJR 0.895 SNIP 0.946 CiteScore 1.66
- ISI indexed (2011): ISI indexed yes
- Web of Science (2011): Indexed yes
- BFI (2010): BFI-level 1
- Scopus rating (2010): SJR 0.774 SNIP 0.834
- Web of Science (2010): Indexed yes
- BFI (2009): BFI-level 1
- Scopus rating (2009): SJR 0.773 SNIP 0.891
- Web of Science (2009): Indexed yes
- BFI (2008): BFI-level 2
- Scopus rating (2008): SJR 0.883 SNIP 0.968
- Web of Science (2008): Indexed yes
- Scopus rating (2007): SJR 0.996 SNIP 1.06
- Web of Science (2007): Indexed yes
- Scopus rating (2006): SJR 0.897 SNIP 1.051
- Web of Science (2006): Indexed yes
- Scopus rating (2005): SJR 0.827 SNIP 0.898
Attenuation of stress-induced anorexia in brown trout (Salmo trutta) by pre-treatment with dietary L-tryptophan

General Information
State: Published
Organisations: Section for Aquaculture, National Institute of Aquatic Resources
Authors: Höglund, E. (Intern), Sørensen, C. (Ekstern), Bakke, M. (Ekstern), Nilsson, G. (Ekstern), Øverli, Ø. (Ekstern)
Pages: 786-789
Publication date: 2007
Main Research Area: Technical/natural sciences

Publication Information
Journal: British Journal of Nutrition
Volume: 97
Issue number: 4
ISSN (Print): 0007-1145
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 3.46 SJR 1.983 SNIP 1.533
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.583 SNIP 1.446 CiteScore 3.52
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.468 SNIP 1.278 CiteScore 3.18
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 2.72 SNIP 2.521 CiteScore 3.61
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 2.263 SNIP 2.484 CiteScore 3.12
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Differences in oxygen consumption, yolk adsorption and behaviour in early life stages of rainbow trout strains selected for high or low stress responsiveness

General information
State: Published
Organisations: Section for Aquaculture, National Institute of Aquatic Resources
Authors: Höglund, E. (Intern), Gjøen, H. (Ekstern), Øverli, Ø. (Ekstern)
Publication date: 2007
Event: Poster session presented at Annual Main Meeting Society of Experimental Biology, Saturday 31st - 4th April, .
Main Research Area: Technical/natural sciences

Bibliographical note
Poster
Source: orbit
Source-ID: 225873
Publication: Research - peer-review › Journal article – Annual report year: 2007

Effect of dietary bacterial protein or L-tryptophan supplementation on welfare and growth performance in silverfox
The suitability of bacterial protein meal as a feed ingredient in silver fox diets was examined in an experiment comprising 72 juvenile silver foxes. Bacterial protein meal has a high content of tryptophan, which is the precursor for the neurotransmitter serotonin. The biological hypothesis on which this study was premised was that increased brain serotonin production reduces the fear response, which may lead to better welfare and performance through lower energy
expenditure related to fear-induced defensive responses. The effect of substituting 15% fish meal with bacterial protein meal was measured by two behavioural tests, growth performance and fur quality, by comparison with a control diet and a diet supplemented with a high level of synthetic tryptophan. The welfare of the foxes fed the diet supplemented with synthetic tryptophan was considered to be improved, as they used shorter time to approach feed in the presence of a person; thus displayed less fear, than the other two groups after treatment. Weight gain of the foxes during 55 d did not differ among diets, and feed consumption was similar. Live grading of the foxes showed that the dietary treatments did not affect fur quality (P > 0.05). It is concluded that 15% bacterial protein meal can replace fish meal in dry silver fox diets and that a large supplement of tryptophan reduces fear of silver foxes kept in cages.

**General information**

State: Published
Organisations: Nova Scotia Agricultural College, Norwegian University of Life Sciences
Authors: Faaland Schoyen, H. (Ekstern), Rouvinen-Watt, K. (Ekstern), Höglund, E. (Intern), Stone, K. P. (Ekstern), Skrede, A. (Ekstern)
Pages: 93-102
Publication date: 2007
Main Research Area: Technical/natural sciences

**Publication information**

Journal: Canadian Journal of Animal Science
Volume: 87
Issue number: 1
ISSN (Print): 0008-3984
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.507 SNIP 0.823 CiteScore 1.08
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.523 SNIP 0.591 CiteScore 0.7
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.753 SNIP 0.94 CiteScore 1.35
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.506 SNIP 0.741 CiteScore 1.02
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.64 SNIP 0.661 CiteScore 0.84
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.599 SNIP 0.584 CiteScore 0.92
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.631 SNIP 0.6
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.547 SNIP 0.464
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.421 SNIP 0.557
Scopus rating (2007): SJR 0.534 SNIP 0.706
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.576 SNIP 0.787
Scopus rating (2005): SJR 0.435 SNIP 0.641
Scopus rating (2004): SJR 0.377 SNIP 0.669
Scopus rating (2003): SJR 0.467 SNIP 0.701
Scopus rating (2002): SJR 0.472 SNIP 0.675
Scopus rating (2001): SJR 0.529 SNIP 0.738
Memory of opponents is more potent than visual sign stimuli after social hierarchy has been established

During agonistic interactions between male Anolis carolinensis, perception of a visual sign stimulus (darkened eyespots) not only inhibits aggression and promotes initial attainment of dominant social status, but also evokes distinct neuroendocrine responses in each opponent. This study was designed to examine the effect of eyespot manipulation on behavior and social rank during a second interaction between opponents that had previously established a natural dyadic social hierarchy. Prior to a second interaction, eyespots of familiar size-matched combatants were manipulated to reverse information conveyed by this visual signal. Eyespots on the previously dominant male were masked with green paint to indicate low aggression and social status. Previously subordinate males had their eyespots permanently marked with black paint to convey high aggression and status. Opponents were then re-paired for a second 10 min interaction following either 1 or 3 days of separation. Aggression was generally decreased and social status between pairs remained reasonably consistent. Unlike rapidly activated monoaminergic activity that occurs following the initial pairing, most brain areas sampled were not affected when animals were re-introduced, regardless of visual signal reversal or length of separation between interactions. However in males with "normal" eyespot color, dominant males had reduced serotonergic activity in CA3 and raphe, while subordinate males exhibited elevated CA3 dopaminergic activity. Reversing eyespot color also reversed serotonergic activity in raphe and dopaminergic activity in CA3 after 3 days of separation. The results suggest that males remember previous opponents, and respond appropriately to their previous social rank in spite of eyespot color.
Antalarmin inhibits alarm reaction in crucian carp (Carassius carassius)

**General information**
State: Published
Organisations: Norwegian University of Life Sciences
Authors: Lastein, S. (Ekstern), Overli, O. (Ekstern), Døving, K. (Ekstern), Höglund, E. (Intern)
Publication date: 2006

**Host publication information**
Title of host publication: Chemical Senses
Volume: 31
Main Research Area: Technical/natural sciences
Conference: Annual Meeting of the European Chemoreception Research Organisation, 01/01/2006
Source: orbit
Source-ID: 267687
Publication: Research › Conference abstract in proceedings – Annual report year: 2006

A review on the chemical and physiological basis of alarm reactions in cyprinids

**General information**
State: Published
Organisations: University of Oslo
Authors: Døving, K. (Ekstern), Hamdami, E. (Ekstern), Höglund, E. (Intern), Kasumyan, A. (Ekstern), Tuvikene, A. (Ekstern)
Number of pages: 356
Pages: 133-163
Publication date: 2005

**Host publication information**
Title of host publication: Fish Chemosenses
Place of publication: Enfield, NH
Publisher: Science Publishers
Editors: Reutter, K., Kapoor, B.
Avoidance behavior and brain monoamines in fish

General information
State: Published
Organisations: Uppsala University, University of Oslo, University of Bergen
Authors: Höglund, E. (Intern), Weltzien, F. (Ekstern), Schjolden, J. (Ekstern), Winberg, S. (Ekstern), Ursin, H. (Ekstern), Døving, K. B. (Ekstern)
Pages: 104-110
Publication date: 2005
Main Research Area: Technical/natural sciences

Publication information
Journal: Brain Research
Volume: 1032
Issue number: 1-2
ISSN (Print): 0006-8993
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 2.75
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 2.74
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 3.013 SNIP 2.52 CiteScore 3.04
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 4.518 SNIP 2.957 CiteScore 3.22
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 4.622 SNIP 3.836 CiteScore 3.2
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 4.932 SNIP 2.763 CiteScore 2.89
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 4.748 SNIP 2.621
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 4.448 SNIP 2.031
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 3.492 SNIP 1.879
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 3.629 SNIP 2.078
Web of Science (2007): Indexed yes
Scopus rating (2005): SJR 3.916 SNIP 2.428
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 3.957 SNIP 2.741
Scopus rating (2003): SJR 4.369 SNIP 2.626
Scopus rating (2002): SJR 4.072 SNIP 2.259
Does serotonin influence aggression? Comparing regional activity before and during social interaction

Serotonin is widely believed to exert inhibitory control over aggressive behavior and intent. In addition, a number of studies of fish, reptiles, and mammals, including the lizard Anolis carolinensis, have demonstrated that serotonergic activity is stimulated by aggressive social interaction in both dominant and subordinate males. As serotonergic activity does not appear to inhibit agonistic behavior during combative social interaction, we investigated the possibility that the negative correlation between serotonergic activity and aggression exists before aggressive behavior begins. To do this, putatively dominant and more aggressive males were determined by their speed overcoming stress (latency to feeding after capture) and their celerity to court females. Serotonergic activities before aggression are differentiated by social rank in a region-specific manner. Among aggressive males baseline serotonergic activity is lower in the septum, nucleus accumbens, striatum, medial amygdala, anterior hypothalamus, raphe, and locus ceruleus but not in the hippocampus, lateral amygdala, preoptic area, substantia nigra, or ventral tegmental area. However, in regions such as the nucleus accumbens, where low serotonergic activity may help promote aggression, agonistic behavior also stimulates the greatest rise in serotonergic activity among the most aggressive males, most likely as a result of the stress associated with social interaction.
Effects of L-DOPA on aggressive behavior and central monoaminergic activity in the lizard Anolis carolinensis, using a new method for drug delivery

General information
State: Published
Organisations: University of South Dakota
Authors: Höglund, E. (Intern), Korzan, W. J. (Ekstern), Forster, G. L. (Ekstern), Watt, M. J. (Ekstern), Johannessen, H. F. (Ekstern), Summers, C. H. (Ekstern)
Pages: 53-64
Publication date: 2005
Main Research Area: Technical/natural sciences

Publication information
Journal: Behavioural Brain Research
Volume: 156
ISSN (Print): 0166-4328
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 1.51 SNIP 0.92 CiteScore 3.17
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.523 SNIP 0.895 CiteScore 3.19
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.626 SNIP 0.985 CiteScore 3.32
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.835 SNIP 1.069 CiteScore 3.6
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Suppression of aggressive behavior in juvenile Atlantic cod (Gadus morhua), by L-tryptophan supplementation

General information
State: Published
Organisations: University of Oslo, Norwegian University of Life Sciences, Uppsala University
Authors: Höglund, E. (Intern), Jørgensen Bakke, M. (Ekstern), Øverli, Ø. (Ekstern), Winberg, S. (Ekstern), Nilsson, G. E. (Ekstern)
Pages: 525-531
Publication date: 2005
Main Research Area: Technical/natural sciences

Publication information
Journal: Aquaculture
Volume: 249
ISSN (Print): 0044-8486
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.75 SJR 1.101 SNIP 1.524
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.103 SNIP 1.254 CiteScore 2.12
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.002 SNIP 1.34 CiteScore 2.16
Visual sympathetic signals influence behavior and catecholaminergic response in previously established social hierarchies

General information
State: Published
Organisations: Unknown
Authors: Korzan, W. (Ekstern), Lukkes, J. (Ekstern), Watt, M. (Ekstern), Forster, G. (Ekstern), Øverli, Ø. (Ekstern), Höglund, E. (Intern), Summers, C. (Ekstern)
Publication date: 2004

Host publication information
Title of host publication: Hormones and Behavior
Volume: 46(1)
Behavior in established social hierarchies are influenced by visual sympathetic signals

Behavioral and neuroendocrine effects of environmental background colour and social interaction in Arctic charr (Salvelinus alpinus)
Stimulatory and inhibitory effects of 5-HT1A receptors on adrenocorticotropic hormone and cortisol secretion in a teleost fish, the Arctic charr (Salvelinus alpinus)

General information
State: Published
Organisations: University of Nijmegen, Uppsala University
Authors: Höglund, E. (Intern), Balm, P. H. M. (Ekstern), Winberg, S. (Ekstern)
Pages: 193-196
Publication date: 2002
Main Research Area: Technical/natural sciences

Publication information
Journal: Neuroscience Letters
Volume: 324
Issue number: 3
ISSN (Print): 0304-3940
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Stress-induced changes in brain serotonergic activity, plasma cortisol and aggressive behavior in Arctic charr (Salvelinus alpinus) is counteracted by L-DOPA

General information
State: Published
Organisations: Uppsala University
Authors: Höglund, E. (Intern), Kolm, N. (Ekstern), Winberg, S. (Ekstern)
Pages: 381-389
Publication date: 2001
Main Research Area: Technical/natural sciences

Publication information
Journal: Physiology & Behavior
Volume: 74
Issue number: 3
ISSN (Print): 0031-9384
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
Skin darkening, a potential social signal in subordinate Arctic charr (Salvelinus alpinus): The regulatory role of brain monoamines and pro-opiomelanocortin-derived peptides

General information
State: Published
Organisations: University of Nijmegen, Uppsala University
Authors: Höglund, E. (Intern), Balm, P. H. M. (Ekstern), Winberg, S. (Ekstern)
Pages: 1711-1721
Publication date: 2000
Main Research Area: Technical/natural sciences
Feeding behaviour, brain serotonergic activity levels, and energy reserves of Arctic char (Salvelinus alpinus) within a dominance hierarchy

General information
State: Published
Organisations: Swedish University of Agricultural Sciences, Uppsala University
Authors: Alanärä, A. (Ekstern), Winberg, S. (Ekstern), Brännäs, E. (Ekstern), Kiessling, A. (Ekstern), Höglund, E. (Intern), Elofsson, U. (Ekstern)
Pages: 212-220
Publication date: 1998
Main Research Area: Technical/natural sciences

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ISI indexed (2011): ISI indexed yes
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Spatial and temporal distribution of brown trout redds in a small temperate stream

General information
State: Published
Organisations: Section for Population- and Ecosystem Dynamics, National Institute of Aquatic Resources, Section for Aquaculture
Authors: Olofsson, H. (Ekstern), Mosegaard, H. (Intern), Höglund, E. (Intern)
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Main Research Area: Technical/natural sciences

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Projects:

Development of filtering technologies for microalgae and sustainable high quality feed for fry (FIMAFY) (39115)
There is an urgent need for alternative resources to fishmeal and fish oil for the production of fish feed to the aquaculture industry. The resource problem is due to a combination of the rapid growth of the aquaculture, and the fact that catches of fish for the feed industry is stagnating.

The idea to use microalgae as fish feed originated from an on-going EU-project, which aims at demonstrating that algae can be grown on process water from the industry.

The partners in the project will develop, test and demonstrate new technologies for harvesting and refining microalgae. The project will develop a technology to open the cell walls of the microalgae in order to make it possible to extract micro- and macronutrients for use as an alternative resource to fish oil and fishmeal in the production of fish feed for the aquaculture industry.

The project is coordinated by the National Food Institute, Technical University of Denmark.

The project is funded by the Danish Ministry of Food, Agriculture and Fisheries through the Green Development and Demonstration Program (GUDP).

National Institute of Aquatic Resources
Section for Aquaculture
National Food Institute
BioMar A/S
LiqTech International A/S
IFAU
Ecolipids A/S
Period: 01/10/2013 → 31/03/2017
Number of participants: 2
Research area: Aquaculture
Project participant:
Höglund, Erik (Intern)
Project Manager, organisational:
Lund, Ivar (Intern)
Project

**Stress coping Styles’ effect on fitness and life history choice in wild salmonids**

National Institute of Aquatic Resources
Period: 01/12/2011 → 02/09/2015
Number of participants: 7
Phd Student:
Larsen, Martin Hage (Intern)
Supervisor:
Höglund, Erik (Intern)
Skov, Christian (Intern)
Main Supervisor:
Aarestrup, Kim (Intern)
Examiner:
Koed, Anders (Intern)
Lucas, Martyn (Ekstern)
Thorstad, Eva (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

**Fish welfare aspects of individual variation in cognition, physiology and behavior**

National Institute of Aquatic Resources
Period: 01/11/2011 → 01/05/2015
Number of participants: 2
Phd Student:
Moltesen, Maria (Intern)
Main Supervisor:
Höglund, Erik (Intern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: 1/3 FUU, 1/3 inst 1/3 Andet
Project: PhD

**Fish welfare aspects of individual variation in cognition, physiology and behaviour (Cope Well) (38813)**
The project targeted welfare aspects of individual variability fish. Such differences include both behavioural and physiological traits, which are often clustered in separate stress coping styles. These stress coping styles seem to be coupled to fundamental differences in how information is processed. The aim of this project was to develop methods for separating fish with respect to stress coping styles, and investigate how fish with contrasting stress coping styles differs in cognitive evaluation of challenges. Moreover, the neural mechanism separating fish with contrasting stress coping styles was investigated. The project was part of a large scale collaborative project, funded by the European Commission FP 7 (Cope Well), aiming to establish, evaluate, and further develop, a new scientific framework for the understanding and
application of the concept of animal welfare in farmed fish.

The project was coordinated by Havforskningsinstituttet (IMR), Norway.
The project was funded by EU, Framework Programme 7.

National Institute of Aquatic Resources
Section for Aquaculture
Havforskningsinstituttet
Uni Research AS
Partnership Transnational Consulting Partnership
Instituto Superior de Psicologia Aplicada
University of Stirling
University of Patras
University of Crete
Katholieke Universiteit
NOFIMA
Centro de Ciências do Mar do Algarve
Universidad Autonoma de Barcelona
University of Oslo
Stichting Dienst Landbouwkundig Onderzoek
Uppsala University

IFREMER
Period: 01/01/2011 → 31/12/2015
Number of participants: 2
Research area: Aquaculture
Project participant:
Moltesen, Maria (Intern)
Project Manager, academic:
Höglund, Erik (Intern)
Project

Welfare in farmed rainbow trout, social and environmental preferences
National Institute of Aquatic Resources
Period: 01/03/2010 → 03/07/2013
Number of participants: 6
Phd Student:
Laursen, Danielle Caroline (Intern)
Supervisor:
Skov, Peter Vilhelm (Intern)
Main Supervisor:
Höglund, Erik (Intern)
Examiner:
Jokumsen, Alfred (Intern)
Kristiansen, Tore S. (Ekstern)
Sneddon, Lynne U. (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 FUU, 1/3 inst 1/3 Andet
Project: PhD
Integrative Fish Behavioural Neuroscience Network (BIFINE) (38812)

The aim of the network was to encourage exchange of ideas and stimulate collaboration across disciplines. A multitude of disciplines were represented, each offering distinct and powerful tools for the study of behavioral neuroscience of fishes.

The network included leading groups in Denmark, Norway, Sweden and Finland, representing the following research fields: general fish physiology (both at the phenotypic and genotypic level), genetic modification, genotype-phenotype interactions, molecular biology, biomedicine, evolutionary ecology, stress responses and neurotransmitter mechanisms, neuroanatomy and developmental neurobiology.

The integration of the above mentioned disciplines aimed at meeting the growing need to understand underlying mechanisms of fish behavior and how it is affected by environments change, including anthropogenic disturbance and climate changes and at improving our understanding and tackling of key issues associated with fish aquaculture, welfare, restoration and climate change.

The project was coordinated by DTU Aqua.

The project was funded by Nordforsk, Nordic Council of Ministers.

National Institute of Aquatic Resources
Section for Aquaculture
Norwegian School of Veterinary Science
Uni Research AS
University of Gothenburg
Uppsala University
Lund University
University of Helsinki
University of Bergen
Norwegian University of Life Sciences
Period: 01/01/2010 → 31/12/2012
Number of participants: 1
Research area: Aquaculture
Project Manager, academic: Höglund, Erik (Intern)
Individual variation in developmental rate in rainbow trout larvae; implications for welfare and production aspects in modern aquaculture
National Institute of Aquatic Resources
Period: 01/02/2009 → 28/02/2013
Number of participants: 6
Phd Student: Åberg Andersson, Madelene (Intern)
Supervisor: Steffensen, John Fleng (Intern)
Main Supervisor: Höglund, Erik (Intern)
Examiner: Skov, Peter Vilhelm (Intern)
Metcalfe, Neil Benedict (Ekstern)
Winberg, Svante (Ekstern)
Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 FUU, 1/3 inst 1/3 Andet
Project: PhD
Animal welfare: social and environmental preferences of reared rainbow trout (38697)
The principle objective of this project is to evaluate the effect of rearing densities, current and cover on animal welfare. We will use preference test to investigate behavioral and environmental needs of farmed rainbow trout. Furthermore, for investigating the effects of not fulfilling these needs we will use neurophysiological and endocrine responses involved in the stress reaction as biomarkers for compromised welfare. The obtained knowledge is expected to contribute to a scientific based governmental guideline for welfare based intensive fish rearing.

National Institute of Aquatic Resources
Section for Aquaculture
Period: 01/01/2009 → 31/03/2013
Number of participants: 2
Research area: Aquaculture
Project participant:
Laursen, Danielle Caroline (Intern)
Project Manager, academic:
Höglund, Erik (Intern)

Strategies to improve health and welfare in rainbow trout farming (38193)
The main aim of the project is the developing of sustainable strategies for improving the health, welfare and quality of cultured rainbow trout by implementing three interrelated approaches: management, immune prophylactics, and selective breeding. The management approach determines how increased water current at given rearing densities and water temperatures can reduce the stress of trout. The immune prophylactic approach determines the relationship between immune response profiles and induction of protective immunity at different water temperatures and hereby establishing efficient strategies for use of vaccination and feed stimulants in prevention of diseases. The selective breeding approach determines how physiological and immunological traits can improve the genetically basis for resistance of trout to stress and disease.

The project is coordinated by DTU Aqua.

National Veterinary Institute
National Institute of Aquatic Resources
Section for Aquaculture
University of Copenhagen
Aarhus University
Period: 01/01/2007 → 31/12/2010
Number of participants: 5
Research area: Aquaculture
Project participant:
Höglund, Erik (Intern)
Larsen, Bodil Katrine (Intern)
Skov, Peter Vilhelm (Intern)
McKenzie, David D. (Ekstern)
Project Manager, organisational:
Jokumsen, Alfred (Intern)