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WEALTH

Welfare and health in sustainable aquaculture

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RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Contents

1 Objectives 3
2 Context 3
3 Main WEALTH results 4
4 Recommendations for future research 8
5 Recommendations for best practices in fish farming 10
6 Recommendations for legislation 11
7 Recommendations regarding education, training and dissemination of information 12
8 Conclusions 13

1 Objectives

The aim of the Policy Implementation Plan (PIP) is to provide a summary of the recommendations by the WEALTH consortium, and propose how these may be implemented through the European Fishery and Aquaculture policy. It describes the potential application of the results within the EU policy frameworks (e.g. research, legislation, guidelines), and provides ideas and suggestions for consideration and follow up by EU and national authorities.

2 Context

Despite continuous improvements in diagnoses, sanitary controls and proactive treatments methods such as vaccinations, the health of farmed fish still remains a major problem for the European aquaculture industry. Contributory factors are thought to be environmental conditions, husbandry practices and the genetic make-up of the stocks. These impacting parameters make up a complex matrix determining the health and welfare of the fish. Although some important components have been identified and studied, the current knowledge is incomplete and fragmented, and a holistic view of how health and welfare of farmed fish can be maximized is still lacking. **The main objectives of the WEALTH project were:**

1. To gain comprehensive knowledge on health and welfare of farmed fish by focusing on two of the major aquaculture species in Europe, Atlantic salmon and sea bass, not only to improve the farming situation for these fish, but to transfer the obtained knowledge to other important aquaculture species such as rainbow trout and sea bream.
2. To study a range of the most important environmental factors and husbandry practices in freshwater-, seawater- and recirculation-system aquaculture in order to identify how these may compromise welfare and health of farmed fish.
3. To gain an integrated understanding of the physiological and molecular mechanisms underlying the interactions of husbandry practices and environment on stress conditions affecting welfare and diseases resistance in farmed fish.
4. To identify innate and acquired immune parameters affected by environmental factors and husbandry practices resulting in compromised health, and to develop effective molecular tools to study and monitor the immune function, barrier functions and stress responses of farmed fish.
5. Based on the above objectives, the final goal of the WEALTH project was to develop and validate operational husbandry protocols for improved welfare and health of farmed fish, including methods for early prediction and management of disease outbreaks and compromised welfare.

The Wealth projects consisted of 5 interlinked work packages (Figure 1).

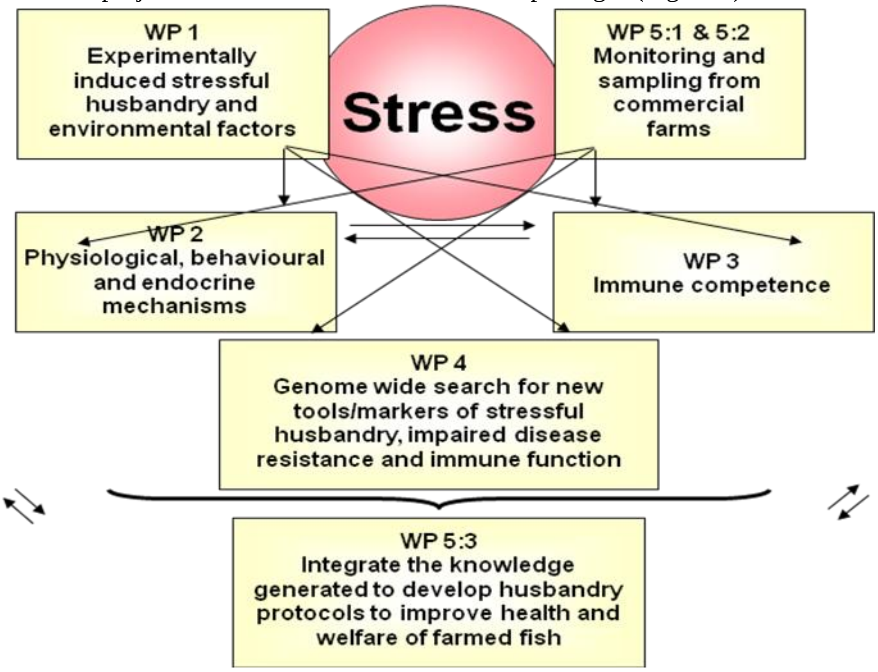

Figure 1. Structure of the Wealth project showing the links between WPs with monitoring and sampling on commercial fish farm, controlled experiments with potentially stressful environmental and husbandry conditions, the impact on physiological, endocrine and behavioural mechanisms, as well as immune function and competence, search for new markers for stress and impaired immune function, and integration into recommendations on welfare indicators and husbandry protocols.

The WEALTH project has monitored environmental, health and welfare parameters in a range of commercial sea bass and salmon farms. Based on these observations, well controlled experiments have been conducted in tanks or small to medium scale sea cages, attempting to mimic critical situations found in commercial rearing systems, and investigating in detail how these affect various welfare and health indicators. A range of new molecular and physiological tools have been developed and tested in these experiments, both to reveal underlying mechanisms, and as possible welfare indicators. This Policy Implementation Plan explores how these results can be used as a basis for good practice guidelines, specific recommendations, and as a part of the basis for EU aquaculture policy including fish welfare.

3 Main WEALTH results

Good fish welfare comprises the maintenance of homeostasis and normal physiological and behavioural functions during all life-stages, indicating that the fish are coping in the farm environment. The WEALTH project has provided a range of new molecular and physiological tools and approaches that can serve as basis for new research projects targeting welfare in farmed fish. It has also provided baseline data on environment, behaviour, health status and welfare in commercial farming situations for Atlantic salmon and European sea bass that also can serve as a basis for new research projects.

The Wealth project has provided a large body of **baseline data from commercial farms** on environment and fish health (e.g. temperature, oxygen (O_2), carbon dioxide (CO_2), behaviour, fish densities, injuries, histopathological changes, status of immune parameters) with high relevance to fish welfare. We have identified and studied some limiting factors and key hazards in various productions systems (e.g. low or very high O_2, high CO_2 or stocking density).

The project has provided a range of **new research tools and approaches** to define indicators of fish welfare (e.g. methods to measure expression of immune or hypoxia related genes, cDNA micro arrays, *in vivo* and *in vitro* immune stimulation, intestinal primary barrier permeability, cortisol in water). The combined use of tank and sea cage studies has provided both control (experimental tanks and small experimental cages) and realism (a range of commercial tank and sea cages systems for salmon and sea bass). This approach has established links between environmental factors, stress physiology, immune responses and disease resistance.

The data provide a basis for further development of validated **welfare indicators** for use in research and on commercial farms (i.e. operational welfare indicators). The suggested welfare indicators include growth performance, feed intake, fin and skin injuries, cortisol in water, intestinal permeability, various measures of immune function, and assays to profile genes related to chronic stress and immune function, new techniques for *in vitro* and *in vivo* immune challenges, and various disease tests.

The project has provided **recommendations** for thresholds for environmental factors and stocking densities in cages and tanks. However these issues need further attention due to the complex interaction between different environmental factors, husbandry practices, different life-stages and the characteristics of various production systems. Recommendations on aquaculture protocols, environmental thresholds and optimum values need to take into account this complexity. Generally there is limited precise information of relevance for welfare in salmon and sea bass, in particular are there only few studies that have demonstrated continuous lines of evidence and clear links between environment, stress and immune function/disease resistance, or other key welfare aspects.

In short the WEALTH project has provided the following conclusions:

- Fish welfare can be affected by a range of hazards related to environmental factors and husbandry practices (see Table 1). In some cases exposure to these hazards also leads to increased susceptibility to infectious diseases, which in turn is a major fish welfare issue by its own. The WEALTH project has examined some of these factors, with particular focus on stress factors that can compromise immune function and potentially increase the risk of disease outbreaks.
- The key-limiting factors differ between production systems and life-stages; e.g. O_2 and temperature in sea cages, CO_2 and ammonia in recirculated tanks, and CO_2 and potentially high O_2 (super-saturation) in hyperoxygenated tanks.
- The sea cage environment is highly variable in time and space and needs close monitoring. Given their prevalent use in European aquaculture, there is an urgent need for more precise knowledge about such environments, their impact on the fish, and new monitoring technology providing measurements that also can serve as operational welfare indicators.
- Stocking density and water quality effects are difficult to assess separately (i.e. identify the effect of fish density per se independent of water quality). However, in monoparametrical experiments, no effect of stocking density on sea bass physiology and behaviour was demonstrated up to 70 kg/m^3 in flow through or recirculating system. At higher stocking densities (e.g. 100 kg/m^3 in sea bass tanks), space-limitations can affect swimming behaviour, feed intake and increase the risk of physical damage (e.g. fin erosion), either as a consequence of physical contact with the rearing unit or due to direct agonistic behaviour.
- There is a lack of validated welfare indicators – in particular those suitable for sea cage farming. A range of indicators needs to be applied to assess fish welfare (see table 2 for overview of some potential welfare indicators).
- Oxygen consumption is a sensitive immediate indicator of stress, and continuous oxygen monitoring may serve as one of several operational welfare indicators.
- Fish behaviour's (swimming, feeding response, vertical distribution etc) can also be useful operational welfare indicators, but interpretation can be difficult.
- The project has demonstrated links between stress and disease susceptibility – but not in all cases for various reasons (e.g. difficulties with disease challenge models such as nodavirus challenge). This needs to be further examined as "proof of concept", e.g. by using new *in vivo* and *in vitro* challenge/stimulation models.
- A range of new molecular and physiological tools have been developed and successfully tested on salmon and sea bass, e.g. cortisol in water, primary barrier tests, in vivo and in vitro immune challenges, as well as profiling of key immune and stress related genes after various challenges.
- These tools enable new studies to be designed to verify thresholds and optimum levels for a range of biotic and abiotic factors and various husbandry practices in terms for fish welfare and disease resistance. They will also be essential in validating welfare indicators, both in providing basic knowledge on underlying mechanisms essential for understanding the link between environment and welfare, and in measurement of coping costs when the individuals try to maintain their normal physiological and behavioural functions.

Table 1. Some key fish welfare issues in farming associated with abiotic and biotic environmental factors, feed and feeding, and management. Issues in *italics* have been studied in the Wealth project with focus on the factors in the yellow boxes (***bold***). Fish requirements and tolerance differs between species and life-stages, and the limiting factors and hazards for fish welfare also differs between production systems such as flow trough tanks, hyperoxygenated tanks, recirculated tanks, fresh water cages and sea cages.

Abiotic	**Biotic**	**Feed & Feeding**	**Management**
Temperature	***Stocking density***	Balance major nutrients	*Sorting and handling*
Salinity	Aggression/agonistic behaviour	Vitamins, minerals and additives	Biomass monitoring
Oxygen	Predators	Pellet size/type	***Health monitoring***
Metabolites *(e.g.* CO_2 *and* NH_3*)*	***Pathogens***	*Feeding regime*	Disease/parasite treatments
Water current	Toxic algae	Feed amount	*Vaccination*
Waves	Jelly fish etc	Starvation periods	***Environment monitoring***
Light	Bio-fouling (affecting flow)	Alternative diets (e.g. Soya-based)	Net change and cleaning
Enclosure size/ Cage distortion	*Ability for schooling*	Medicines and vaccines in feed	Transport
Pressure		Dietary toxins (e.g. fungal toxins)	Emergency killing
Access to air (salmonids)			Removal of dead fish

Table 2. Suggested welfare indicators and their usefulness in fish farming (for research and on farms).

Welfare indicator	Time aspect for detection (typical)	Comment
Appetite/feed intake	Rapid (hours)	Decrease under unfavourable conditions such as hypoxia, but show often large natural/unexplained meal to meal variation
Growth rate	Slow to (weeks/months)	Lower growth rate is often a sensitive sign of unfavourable conditions, but high growth rate do not always guarantee high welfare (e.g. growth related skeletal disorders)
Condition factor	Slow (weeks/months)	Decreasing and/or very low condition factor can indicate unfavourable conditions, but show large natural/seasonal variation. Very high condition may also be indicative of problems.
Feed Conversion Rate	Slow (weeks/months)	Sensitive to increased coping costs, but show large variation and can be difficult to measure
Size variability	Slow (weeks/months)	Increased size variation can be indicative of antagonistic behaviour, under/uneven feeding, or other unfavourable conditions
Changes in oxygen consumption	Rapid (minutes/hours)	Sensitive indicator of stress and various disturbances, but increases also with general activity, e.g. related to feeding
Behaviour surveillance (displays, avoidance, panic reactions, preferences, swimming activity, crowding, schooling, feeding activity...)	Rapid (seconds, minutes)	Respond to various disturbances (e.g. environmental, social, predators etc), preferences can be indicative of optimum values/situations, some behaviours can be difficult to monitor in some systems, depends on the ability of the animal to perceive the hazard.
Fin damages	Slow (days/weeks/months)	Integrative over time, indicative of agonistic behaviour, physical trauma, poor water quality, sunburn, inappropriate feeding regime and stocking density. Difficult to differentiate active (i.e. due to present conditions) from historical damage.
(Skeletal) Deformities	Slow (weeks/months)	Integrative over time, sensitive to various environmental disturbances, especially at early life-stages or related to broodstock management/gamete quality
Eye damages	Slow (days/weeks/months)	Integrative over time, indicative of agonistic behaviours, physical damages, inappropriate feeding regime and to high stocking density.
Cataracts	Slow (weeks/months)	May be indicative of some environmental disturbances and feed related problems
Mortality	Variable (minutes to days)	Often unspecific and difficult to establish cause; increased mortality rate verifies problems
Disease outbreaks	Variable (days to weeks)	Disease outbreaks are a big welfare problem on their own right, but can also be indicative of unfavourable environmental or husbandry conditions
Skin colour	Rapid or variable (minutes, hours, days)	Dark skin colouration can be indicative of stress, disease or parasite load in some species
Stress hormones (in blood and water)	Rapid (minutes)	Indicative of physiological stress, difficult to sample in blood under farming conditions. Water samples can provide information on cortisol and stress level in tanks. Chronic stress (weeks) may not be reflected in sustained increase of hormone levels.
Other stress parameters (plasma ions, osmolality, NEFA)	Variable (hours to days)	Reliable stress indicators that require standardized blood sampling procedure and availability of physiological basal levels. Sensitive indicators of physiological status of fish in relation to acute and chronic stressful conditions.
Immune parameters	Slow (days/weeks/months)	Integrative over time, indicative of welfare and health status in relation to chronic exposure of stressful environmental and husbandry conditions.
Histopathological	Slow	Indicative of diseases, tissue damage either caused by

changes (e.g. gill & intestinal damages)	(days/weeks/months)	pathogens, vaccine damages or environment/social stress
Primary barriers and physiological changes (e.g. intestinal permeability)	Rapid and slow (hours, days/weeks/months)	A two phased response; acute transient response within hours, but also sensitive to chronic physiological stress such as moderate hypoxia, can potentially be indicative of increased disease risk. Also sensitive to a prior history of stress, i.e. in an earlier life stage.
Immune parameters after stimulation/challenges	Variable (hours to days)	Compromised immune function is believed to be associated with severe physiological stress, but can be difficult to assess (i.e. due to lack of knowledge of mode of action)
Gene expression profiles (e.g. Micro arrays)	Variable (hours to days)	Stressed fish show an altered gene expression profile, which could affect the response of fish to infections. Can indicate affected mechanism and identify genes of interest. Signatures may be established that can indicate severe chronic stress or other situation with compromised welfare
Molecular markers	Variable (hours to days)	The functional characterization of several genes and expression studies by quantitative PCR can provide clues about the mechanisms of disease and stress resistance of fish. These candidate genes could be used for diagnostic and therapeutic purposes in aquaculture.
Disease challenge tests (mortality and pathogen persistence/prevalence after challenge)	Variable (hours to days)	Can show physiological cost of coping under severe/chronic stress condition, but can be difficult to conduct (high variability, lack of good disease models) and are ethically problematic
Acute stress test	Rapid (minutes, hours)	Acute stress test (e.g. cortisol measurements) after periods with chronic stress can be indicative of costs of coping and limitations in scope of further stress resistance.
Indirect assessment by environment monitoring of key parameters (e.g. O_2, CO_2, ammonia, temperature, salinity, pH)	Rapid (minutes, hours)	It is often easier to monitor the environment than the fish's response, but interpretations should be based on knowledge on safe thresholds for different parameters at different life-stages and interaction between parameters. Some parameters can be difficult/costly to monitor continuously (e.g. CO_2, ammonia)

By March 2008, the WEALTH project has contributed with 117 different dissemination activities including oral presentations on scientific meetings and targeted workshops, posters on scientific meetings, peer reviewed scientific papers and popular articles. Summary of results, conclusions and list of publications and other dissemination activities from the WEALTH project are available at the project web site: http://wealth.imr.no/

4 Recommendations for future research

In the WEALTH project a range of new physiological and molecular tools have been developed and tested to study the welfare of sea bass and salmon. These new tools have proved to provide valuable new knowledge, and may in some cases also serve as welfare indicators. It is recommended that such tools are further applied in well controlled experimental set-ups to explore underlying mechanisms of fish welfare, and to determine safe limits for environmental conditions. This could include tests on how various husbandry protocols and farming conditions affect the immune response following various tests representing viral and bacterial challenges – to further increase our knowledge on the impacts of such protocols and conditions on fish health, and ultimately overall fish welfare.

There is generally limited published information directly targeting fish welfare and notably safe thresholds for maintaining acceptable welfare in fish farming. The concept of fish welfare and welfare indicators is still developing, and further research is needed to provide the scientific basis for welfare criteria in fish farming.

Based on the experience in the WEALTH project, and the general state-of-the-art we propose high priority to the following research areas:

1. **Validated welfare indicators for use in research and on farms**

The concept of fish welfare is still under discussion, and firm definitions and appropriate welfare indicators are currently being discussed both in the research community (e.g. in the COST ACTION 867 "Welfare of fish in European Aquaculture"; http://www.fishwelfare.com/) and in relation to welfare legislation (e.g. Working Group "Concerning animal welfare aspects of husbandry systems for farmed fish in relation to Atlantic salmon" under the Animal Health and Welfare Panel in the European Food Safety Authority; http://www.efsa.europa.eu/EFSA/).

Based on the results from the WEALTH project we recommend further development and validation of fish welfare indicators – both for use in research and as operational indicators for use on farms (see also FASTFISH project for development of Operational Welfare Indicators; http://fastfish.imr.no/).

2. **Further insight in physiological links between environment, husbandry protocols, stress and health/welfare**

It is generally believed that there is a clear link between physiological stress and disease resistance in fish. However, there is still very limited scientific information on to what degree acute or chronic stress impairs innate and acquired immune function in fish, and the underlying mechanisms. The recent development of a range of new molecular and physiological tools to study such processes in farmed fish such as salmon, trout, sea bass and sea bream open new possibilities to explore in detail the relationship between environment, stress and immune function in fish. New *in vivo* and *in vitro* challenge tests enable testing of immune function without running traditional disease challenge tests, and may provide a more sensitive as well as more ethically sound way of establishing links between environment, stress and health. The WEALTH project has provided "proof-of-concept" in a few cases for direct links between suboptimal rearing conditions and disease resistance (e.g. following hyperoxygenation and hypercapnina in both salmon and sea bass). However, disease challenge tests were unable to reveal the impact of suboptimal rearing conditions in other cases. Thus, we recommend further in depth approaches using the new molecular and physiological tools to explore these relations in combination with the use of *in vivo* and *in vitro* immune challenge tests.

3. **Threshold values for limiting factors and physiological models**

The WEALTH project has provided a basis for evaluation of **safe threshold levels** for some water quality parameters, such as CO_2 in sea bass on-growing and hypoxia in salmon postsmolts using a range of morphological, physiological and immunological parameters. However, we suggest that the issue of threshold values for both salmon and sea bass should be further explored with the new tools that have been developed, e.g. to study impact on immune related genes following *in vivo* immune stimulation. The studies should take into account the variation between species, life-stages and production systems. Also, the interaction between water quality parameters should be studied in more detail, e.g. the relative importance of high CO_2, pH and high total gas pressure under hyperoxygenated situations. This should also take into account additive or synergistic effects of different factors and stressors; i.e. "stress on stress", and the ability of the fish to cope with these additional stressors. These results should be incorporated into quantitative physiological models that can be used to simulate real situations on farms, and also provide a basis for risk assessment related to fish welfare.

4. **Discrimination of stress and environmentally induced diseases**

Disease outbreaks in fish are generally blamed upon stress and/or poor environmental conditions. However, this sweeping generalisation is unlikely to be true for all diseases. There needs to be a better discrimination between pathogenic diseases 1) that only occur when the fish are in a poor state (i.e. facultative), 2) that will occur even if the fish are in prime condition (obligate), and 3) that are more prevalent/severe when the fish are in a poor condition. Better recognition of "stress-mediated" diseases and non-pathogenic "diseases of indicators of poor environmental quality" (e.g. nephrocalcinosis, gas bubble disease) could provide valuable welfare indicators, and facilitate improvements in the overall health of farmed stocks.

5. **Integrated knowledge of how farming conditions impact on disease susceptibility**

The WEALTH project has examined the effects of those environmental factors deemed most important, on selected parameters within the stress, immune and barrier systems of fish. It was beyond the scope of the project to examine the complete suite of the immune and barrier systems. For example, only gut integrity was examined, while environmental conditions may also affect the barrier functions of the gills and skin, and injuries may provide a portal for pathogen entry. Environmental conditions may also affect disease incidence through simple physical processes. For example, higher densities may aid pathogen transmission within a stock; lower oxygen levels, which are compensated for by increasing "breathing" rate in fish, will increase the volume of (potentially pathogen infected) water passing over the gills (an important infection route). Further research is needed to gain a more holistic view of the multitude of factors and levels that affect disease prevalence and severity. Laboratory experiments are needed to understand the processes, while field epidemiological studies are the most likely means to identify the husbandry and environmental factors that are the key risk factors for disease in farmed fish.

5 Recommendations for best practices in fish farming

Environmental monitoring in commercial sea bass and salmon farms (both tanks and sea cages) in the WEALTH project has revealed large temporal and spatial (in cages) variations in water quality in these rearing system. Such environmental monitoring with high resolution in time (and space in sea cages) can serve as operational welfare indicators in two ways: 1) Oxygen consumption has been shown to be very sensitive to activity, stress and various disturbances, hence close monitoring of oxygen may be a rapid indicator of impending problems in fish farms. 2) Continuous monitoring can help to ensure that environmental conditions are maintained within safe levels, and assist in the management on fish farms.

Actions to be taken will depend on the production system:
In tanks both flow and water quality can be controlled in a more efficient way than in sea cages, ensuring sufficient oxygen supply and removal of waste products such as ammonia and CO_2. However, we have also indications that the common practice of hyperoxygenation to maintain sufficient oxygen levels in tanks with limited water flow can be stressful to both salmon and sea bass, and result in increased susceptibility to infectious diseases. On the other hand, with proper water quality, stocking density up to 70 kg/m^3 had no detrimental effect on sea bass in flow through or in recirculation system.

In sea cages, there is less possibility to control water flow and oxygen levels. The primary management solutions to maintain good water quality in sea cages is to keep stocking density at moderate levels, to carefully select sites with sufficient water currents, and a set-up of cages that facilitate good water exchange and proper cleaning of the nets. Use of deeper cages can provide the fish with better possibilities to select optimal environmental conditions, such as avoiding extreme temperatures or reduce the impact of biotic factors such as algal blooms or jelly fish strikes that are confined to specific depths. On the other hand, we have seen that salmon tend to aggregate at specific depths presumably due to environmental preferences, hence, the resultant observed fish density is often much higher than the theoretical stocking density. Moreover, at some sites oxygen saturation can be low in the surrounding water, thus the above mentioned approaches will not be sufficient to provide sufficient oxygen levels within the cages. Under such situations, artificial addition of oxygen may be a possible solution.

*Some specific recommendations are developed from the **WEALTH** results:*

1. Improved **monitoring regimes** should be implemented in salmon and sea bass farms to provide a better overview of variation in the sea cage environment - and to take actions to avoid situations with high risk of impaired welfare. This was warranted by the findings of suboptimal and sometimes critical environmental conditions in commercial salmon and sea bass farming systems.

2. **Variable hypoxia** in the range of 50-70% oxygen saturation was found to reduce appetite, growth and feed conversion efficiency in salmon in seawater. Thus, improved growth performance can be expected by avoiding such low oxygen levels in commercial cages. Improved oxygen conditions can be achieved by lowering stocking density, by cleaning of cages, and by improving the design and orientation of sea cages and initial site selection.

3. **Hypoxia** around 55% of oxygen saturation was indicated to negatively affect the primary barrier functions and the innate immune response following *in vivo* and *in vitro* challenges that simulates virus and bacterial infection. This suggest that exposure of salmon to such oxygen levels may increase the susceptibility to infectious diseases. Maintaining oxygen levels at a higher level in sea cages may thus reduce the risk of

infectious diseases outbreaks. However, further research is needed to corroborate these indications.

4. **Hyperoxygenation** of around 150% O_2 saturation combined with low specific water flow in freshwater gave both acute and long-lasting stress responses and a subsequent increased susceptibility to IPN virus challenge after seawater transfer of salmon postsmolts. Hyperoxygenation is a common practice in salmon smolt farming, and the results suggest that this can increase the risk of disease outbreaks. Hyperoxygenation and high carbon dioxide was also found to increase mortality in sea bass after bacterial challenge. These results suggest that the combination of high O_2 and CO_2 levels have detrimental effects on disease susceptibility in both salmon and sea bass farming – and this common procedure should be revised. Further studies are needed to clarify if this is due to CO_2 or high O_2 – or a combination of these and other water quality parameters.

5. **Chronic hypercapnia** (over 25-30 mg/l CO_2) affects both physiology and immune system of sea bass reared in recycling systems under experimental conditions. The results suggest elevated CO_2 concentrations should be avoided to preserve good welfare and health of fish, but further studies are needed on commercial sea bass farms to determine threshold CO_2 levels in relation to different rearing systems.

6. Controlled tank experiments with sea bass indicated that **stocking densities** up to 70kg/m^3 had no negative effect on growth performance or other welfare indicators examined – provided that the water quality was maintained at non-limiting levels. However, these findings were contrasted with poor environmental conditions found in some commercial sea bass tank and sea cage systems together with histopathological changes on the fish. Further studies are therefore needed on commercial sea bass farms to verify safe levels of environmental factors and stocking densities to secure fish welfare.

6 Recommendations for legislation

The WEALTH project has started to explore the impact of some key environmental factors and husbandry practices such as oxygen, CO_2, stocking density and light treatments on fish welfare and health in fish farming. We have documented large variability of these key environmental factors in various commercial production systems for sea bass and salmon, have revealed periods with theoretical critical values and documented associated effects on various welfare parameters such as fin damage, other histopathological changes or reduced growth performance or appetite. We have seen that the limiting factors can differ among the different productions systems (flow trough tanks, hyperoxygenated tanks, recirculated tanks, sea cages of different shapes and sizes) and life-stages. However, due to the complexity of these issues, we still lack precise knowledge to set safe threshold values for factors such as oxygen, CO_2 and stocking density in the various production systems and for the different life stages. The observed complexity of the interaction between water flow, water quality, stocking density and fish behaviour in the various production systems preclude simple recommendations on e.g. maximal allowed stocking density for salmon and sea bass. Also, stocking densities that appear to be acceptable under strictly controlled experimental conditions with good water quality may not be applicable to commercial situations with much more variable water conditions. However, we can draw some preliminary conclusions for legislation and good husbandry practices based on the WEALTH results:

<u>Monitoring of environment and behaviour</u>

High resolution monitoring of environment and fish behaviour in farming systems have proved to be a valuable source of information both to detect critical environmental situations that can pose a threat to welfare and health of the fish, as well as to provide the farmer with information to take the appropriate management actions (e.g. stop feeding, clean nets, lower stocking density). We recommend that improved monitoring systems should become standard in fish farms, and robust and simple monitoring systems and associated models should be developed to ensure adequate surveillance of the environment and associated fish welfare.

<u>Stocking density</u>

Sea cage studies combined with experimental tank studies in this project suggest that the current limit of 25kg/m^3 in salmon cages in Norway is set too high. Approaching this limit can increase the risk of impaired salmon welfare due to the increased risk of reduced water quality. It could be considered to lower this limit e.g. to 20 kg/m^3, to reduce the risk of undesired oxygen conditions in the sea cages that in turn can impair welfare and potentially increase the likelihood of disease outbreaks.

Controlled tank experiments with sea bass indicated that stocking densities up to 70kg/m^3 had no negative effect on growth performance or other welfare indicators tested - provided that the water quality was maintained at non-limiting levels. However, these findings were contrasted with poor environmental conditions found in commercial sea bass tank and sea cage systems together with histopathological changes on the fish. Further studies are therefore needed on commercial sea bass farms to verify safe levels of stocking density in the context of variable water quality.

Hypoxia

Low and variable oxygen saturations (around 50%) were found to negatively affect feed intake, growth performance, primary barrier integrity and other physiological parameters in salmon in seawater. Some negative effects were also indicated on the innate immune response following *in vivo* and *in vitro* immune stimulations potentially suggesting inflammation and compromised disease resistance. Further research is needed to set safe threshold levels for oxygen in salmon, but legislation could incorporate a requirement for close monitoring of oxygen in farming systems to ensure welfare and health.

Hyperoxygenation

Hyperoxygenation is often used in commercial fish farms to reduce water usage, or increase production from a limited water supply. This can lead to build up of metabolites such as CO_2 and ammonia as well as very high oxygen saturation in the tanks. The current project has documented negative effects on physiology and disease resistance in both salmon and sea bass following hyperoxygenation combined with a high total gas pressure and reduced water flow. Thus, it is recommended to revise this common procedure and establish safe limits for hyperoxygenation in combination with other water quality parameters such as CO_2, ammonia and pH.

Hypercapnia

Carbon dioxide can be the limiting water quality parameter in some production systems, e.g. in recirculated tanks or hyperoxygenated tanks. Some negative effects of high CO_2 (over 25-30 mg/l CO_2) were noted on immune parameters and other physiological parameters in sea bass experiment in recirculated tanks. Thus we recommend further research to find safe levels for CO_2 in commercial sea bass farms.

The results from the WEALTH project should have direct relevance for the ongoing work in the European Food Safety Authority (EFSA) concerning the scientific opinion on welfare aspects of husbandry systems for farmed fish, and in national authorities working with fish welfare issues and the World Organisation of Animal Health (OIE).

7 Recommendations regarding education, training and dissemination of information

Monitoring the environment, fish behaviour, production performance, fish welfare and health can be very demanding in fish production systems. This is particularly the case in large commercial sea cage systems where appropriate monitoring technologies are currently lacking and representative samplings of the fish are difficult. This situation demands high skills and knowledge of the staff on fish farms, both the staff involved in daily husbandry and monitoring, and more specifically involved in fish health and general welfare monitoring. This suggests a need for increased skills and knowledge in fish biology, fish behaviour, signs of disease or other signs of impaired welfare, as well as increased skills and knowledge regarding various technological solutions for monitoring fish (e.g. behaviour, appetite or mortality) and appropriate measures to compensate for unwanted conditions. Thus, to assure the best welfare and health of farmed fish it is essential to provide good opportunities for education/training of staff associated with fish farms.

Several ongoing and completed European research projects deal with various aspects of fish welfare and fish health (e.g. WEALTH, Seafoodpluss, FASTFISH, BENEFISH and COST ACTION 867). Specific measures should be established to ensure efficient transfer of knowledge from these projects to the industry, e.g. by targeted workshops and meetings for fish health services and other personnel working on fish farms. Specific projects could be initiated to ensure such dissemination of results towards the industry, including the establishment and maintenance of specific web sites for fish welfare and health information. This should also facilitate interactions between fish farming personnel, scientists and legislators to further the appreciation of the different stakeholder groups of the drivers for, and the practical problems associated with investigating, monitoring and assuring fish welfare on farms, and the implementation of technology and procedures in commercial farming situations.

The results from the WEALTH project are of direct relevance to fish welfare legislation, and results should be specifically disseminated towards the European Food Safety Authority (EFSA) for their ongoing work concerning the scientific opinion on welfare aspects of husbandry systems for farmed fish. The results are also relevant for national authorities working with fish welfare, and for the World Organisation of Animal Health (OIE).

Specifically, we suggest a **policy assessment workshop** to disseminate and discuss results from relevant ongoing and completed European fish welfare projects such as WEALTH, Seafoodpluss, FASTFISH, BENEFISH and COST ACTION 867 “Welfare of fish in European Aquaculture”, together with representatives from relevant European policy makers regarding fish welfare such as EFSA, DG Fisheries and Costal Affairs and DG SANCO, as well as representatives from the fish farming industry such as the Federation of European Aquaculture Producers (FEAP). This should focus on the status on fish welfare indicators and the state-of-the-art regarding threshold values for environmental factors and other hazards of relevance for welfare in fish farming. Moreover, the discussions could also focus on the transfer of knowledge from these research projects into practical guidelines and possible best practices in fish farming and as basis for aquaculture legislation.

8 Conclusions

The WEALTH project has provided baseline data on key environmental factors, health and welfare in commercial salmon and sea bass farms. The impact of some of these environmental factors and some common husbandry practices has been investigated in more detail in controlled experimental systems. A range of new physiological and molecular tools have been developed and tested in these experiments. The project has revealed some of the complexity in providing specific guidelines and recommendations on safe thresholds for environmental parameters with importance for welfare and fish health. This is partly due to the variability between the production systems, variable sensitivity at different life-stages, and the complex interactions between different environmental parameters affecting the fish. Potential welfare indicators are suggested, and have to some extent been tested in the WEALTH project.

The baseline data from commercial farms and the new tools that have been developed provide opportunities for new research targeting: 1) validation of welfare indicators, 2) further insight into links between environment, husbandry protocols, stress, physiological performance, immune function and health, 3) determination of safe thresholds for key environmental factors at different life-stages and in different production systems to ensure maintenance of good fish welfare, 4) discrimination of stress and environmentally induced diseases, and 5) integrated knowledge of how farming conditions impact on disease susceptibility.

The WEALTH project can provide basis for best practices in aquaculture and potential legislation and guidelines, e.g. related to oxygen saturation, carbon dioxide levels and maximum stocking densities. Specifically these results should have high relevance for the ongoing work concerning the scientific opinion on welfare aspects of husbandry systems for farmed fish in EFSA. We suggest improved monitoring regimes in fish farms in terms of environmental factors, fish behaviour, health and welfare. Monitoring is required in fish farms, in particular in large sea cages, which will require the development of monitoring technology suitable for commercial operations, as well as education and training of fish farming personnel.

There is a great need for improved dissemination of research results on fish welfare and health to the industry. Additionally, there is a need for increased interaction between fish farming personnel, scientists and legislators, amongst others to appreciate the difficulties in studying fish welfare and in implementing relevant measures on farms. Specific project measures should be developed to facilitate this.

Specifically we suggest a policy assessment workshop to disseminate and discuss results from relevant ongoing and completed European fish welfare projects with relevant European policy making representatives and aquaculture industry representatives.

Bergen, 24.04.2008 Geir Lasse Taranger