COVER PAGE

FELLOWSHIP SUMMARY REPORT

- Dr Mark J. Doubell (South Australian Research and Development Institute (SARDI), Australia)
- Subject title: Sustainable pre-infection solutions for mitigating parasitic infestations in salmon aquaculture.
- Theme number of the research fellowship: 1- Managing Natural Capital for the Future
- Host collaborator and Dr Pascal Klebert (SINTEF Fisheries and Aquaculture, Norway)
- Fellowship dates: 21 June 2017 to 02 August 2017
- I provide consent for this report to being posted on the Co-operative Research Programme's website.

1. What were the objectives of the research project? Why is the research project important?

The overarching objective of this research project was to assess to what extent Salmon aquaculture farm sea-cages create local hydrodynamic zones which support low and high concentrations of parasitic sea lice. To achieve this goal the specific aims were to;

1) Determine the 3-dimensionsal distribution of currents and microscale turbulence surrounding salmon farms, and

2) Use the measurements from 1) to develop a validated biophysical model for assessing how the hydrodynamics surrounding farms influence the abundance and distribution of sea lice.

This research is of global relevance because the prevalence, intensity, economic cost and ecological threat of parasitic diseases are expected to continue to increase as global finfish aquaculture production continues to grow. Hence, it is important that novel, sustainable and non-chemical mitigation measures to combat parasitic diseases in sea-cage based finfish aquaculture are developed. Owing to the generality of turbulence in aquatic systems and the pelagic life history of many parasitic disease species, new knowledge generated from this research project has provided an improved understanding of the interactions between aquaculture sea-cages and the surrounding environment. This knowledge will underpin the development of functional and sustainable tools (e.g. biophysical models) and solutions to lessen the impact of parasitic infestations in finfish aquaculture.

2. Were the objectives of the fellowship achieved?

If not, for what reasons? (The data or research is still ongoing or being analysed; technical reasons (e.g. equipment not working, adverse weather conditions, unexpected results, etc.; other reasons?)

Objective 1 has been achieved. Field observations mapping spatial and temporal variations in the hydrodynamics surrounding cages were successfully undertaken. This involved the use of an array of Nortek Acoustic Doppler Current Profilers (ADCP) to measure the advective component of flow and a Rockland MicroCTD turbulence profiler to measure vertical profiles of microscale shear. Results from the field studies showed a strong modification of the turbulence levels in the lee of aquaculture cages across a range of different background flow conditions. Specifically, turbulence levels over the upper 20 m of the water column (equivalent to the depth of cages) and in the lee adjacent to cages showed highly elevated rates of turbulence up to 2 orders of magnitude greater than those observed several hundred meters upstream of the cage (Figure 1). At equivalent distances downstream from the cage, elevated turbulence levels were also repeatedly measured over the upper 7.5 m of the water column compared to upstream values. Downstream measures of turbulence at depths between 7.5 m and 20 m showed a marked decrease, by around an order of magnitude, compared to those measured upstream at the same depths. In summary, these results show the presence of stocked aquaculture sea-cages significantly and consistently altered the intensity and distribution of turbulence levels, and hence the mixing regime, on the lee side of cages.

Objective 2 has been partially been achieved and is ongoing. All measurements collected from 1) have been analysed and have been made available for validation against simulations using the biophysical model. Fine-tuning and validation of the model simulations against the field observations is currently underway. Sampling of the spatio-temporal distribution of sea-lice surrounding cages were conducted separately to the physical measurements due to operational limitations (i.e. limited space on research vessel). Analysis of the collected water samples for sea-lice is labour-intensive and are still ongoing. Final validation and comparison of the biophysical model with the physical and biological observations is expected to be completed by late December 2017.

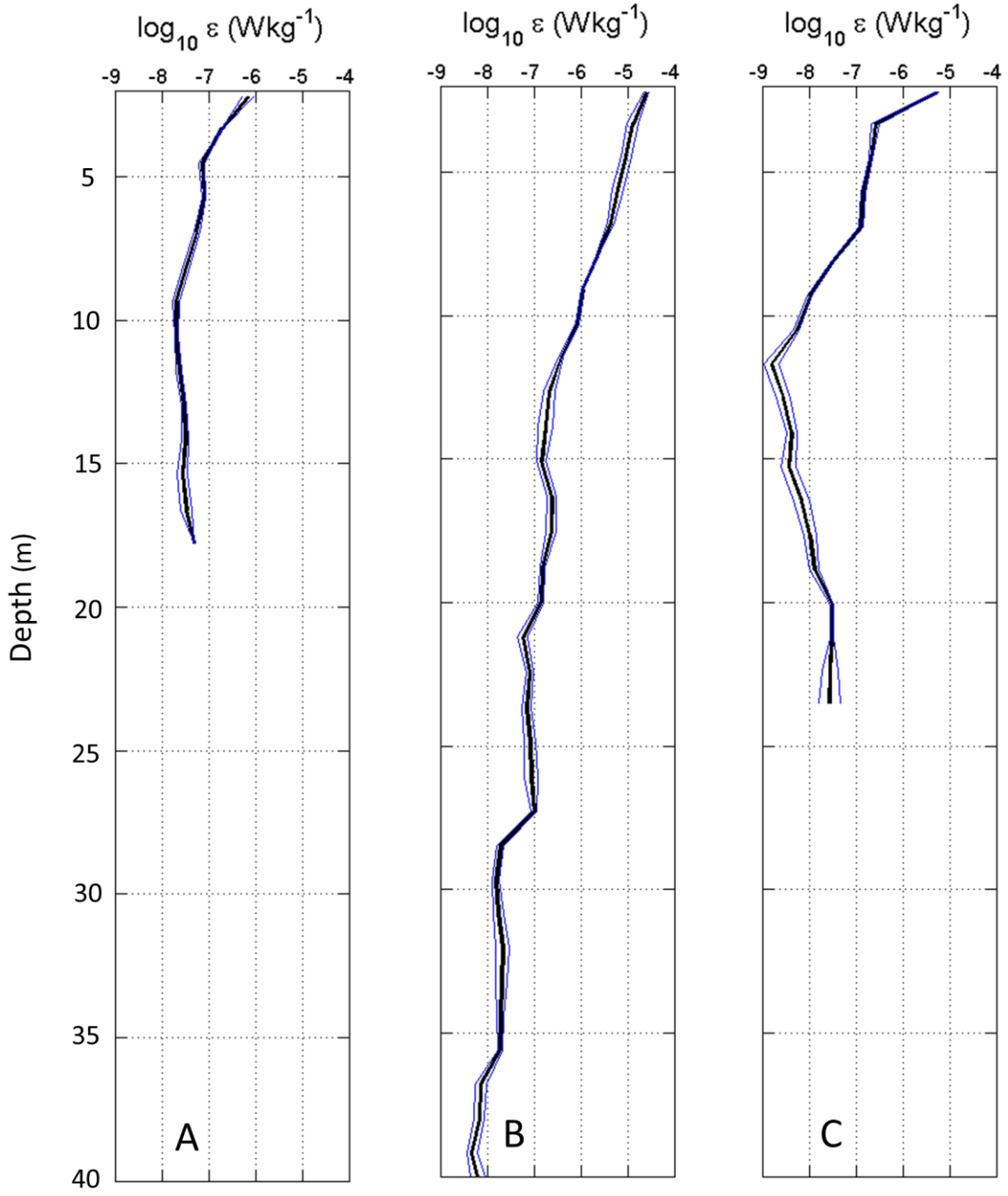

Figure 1. Mean (black line) and standard deviation (blue line) measures of the vertical distribution of the turbulent kinetic energy dissipation rate (ε, Wkg^{-1}) obtained from repeat profiling of microscale shear at (A) approximately 500 m upstream of a stocked aquaculture cage, (B) in the lee directly adjacent to a stocked cage and (C) approximately 500 m downstream of the cage. The aquaculture cage has a diameter of 50 m, extends from the surface to approximately 20 m depth and is located in a small basin of maximum depth 50 m. Measurements taken upstream and downstream of the cage were made outside of the basin in maximum water depths of 20 m and 25 m, respectively.

3. What were the major achievements of the fellowship? (up to three)

The fellowship has allowed for several major achievements to be made in regards to understanding the impact of sea-cage based finfish aquaculture on the surrounding hydrodynamics, and the potential consequences for the health of farmed fish and the ecology of the surrounding marine system. These achievements include;

1. The successful application of novel oceanographic measurement technologies to demonstrate, to our knowledge for the first time, the modification of the *in-situ* hydrodynamic regime in the lee of sea-cage aquaculture farms. This included quantification of the magnitude and spatial distribution of turbulence levels associated with to sea-cage aquaculture and changes in background flow in a tidally driven coastal system.
2. The application of *in-situ* measures of turbulence microstructure surrounding aquaculture sea-cages to the development and validation of high-resolution biophysical Computational Fluid Dynamic (CFD) model to better understand how farms influence the surrounding hydrodynamics and the abundance and distribution of problematic sea lice.
3. The strengthening of international collaborative bonds between myself and my host and our respective institutions.

4. Will there be any follow-up work?

Is a publication envisaged? Will this be in a journal or a publication? When will it appear?

Two manuscripts, based on the Fellowship objectives, are being prepared for publication in leading international peer-reviewed journals.

The first publication will focus on the results of the field measurement program achieved under Objective 1. This work will detail, to our knowledge for the first time, the spatial and temporal extent and magnitude of changes in turbulence in the vicinity of sea-cages in relation to changes in the background flow regime. This manuscript by Doubell and Klebert titled "Evidence for enhanced turbulent mixing in the lee of aquaculture sea-cages" is currently in preparation with the aim of submitting to the journal 'Aquaculture' in December, 2017.

The second publication will be based on results comparing of the magnitude and spatio-temporal distribution turbulence and sea-lice concentrations measured *in-situ* with the biophysical CFD model simulations achieved under Objective 2. As previously mentioned, analysis of the collected water samples for sea-lice, tuning of the biophysical model and the subsequent comparison with the physical and biological observations are still ongoing. Following this a manuscript will be prepared for publication with the aim of submitting to a leading Aquaculture or Oceanographic modelling journal in February 2018. To our knowledge, this work will be the first to validate high-resolution CFD models with *in-situ* observations of turbulence and plankton (sea-lice).

A third, opportunistic publication resulting from the field program has the potential for publication as a 'Methods' paper. This work will be, to our knowledge, the first to compare estimates of the turbulent kinetic energy dissipation rate measured directly and in high-resolution by microstructure profiling against bulk estimates provided by new technology ADCP current meters used in this project. This work is of lowest priority in the following work but would be a significant relevance to the oceanographic community. An appropriate target journal would be 'Limnology and Oceanography: Methods'.

Is your fellowship likely to be the start of collaboration between your home institution and your host?

Owing to the strong results delivered through this Fellowship and the ubiquitousness of parasitic diseases problems facing sustainable aquaculture growth in our respective countries, and globally, my host and I are actively pursuing further funding opportunities to continue and deepen the collaboration between our institutions.

Is your research likely to result in protected intellectual property, novel products or processes?

Outcomes from the biophysical CFD modelling have the potential to result in protected intellectual property for the host institution if novel designs in sea-cage design and layout are found to have an effect in providing sustainable and non-chemical mitigation measures to combat parasitic diseases in sea-cage based finfish aquaculture.

5. How might the results of your research project be important for helping develop regional, national or international agro-food, fisheries or forestry policies and, or practices, or be beneficial for society?

Please express this in terms of environmental/food security/food safety/economic/health (human and livestock and plant) benefits, etc.

Globally, the development of sea-cage based aquaculture is being challenged by ever increasing stresses in the form of parasitic diseases as well as consequences resulting from negative impacts on water quality and the natural ecological systems they are contained within. Results from this research have improved our knowledge of interactions between aquaculture sea cages, the physical environment and parasitic diseases. This knowledge is fundamental to the development of new tools (i.e. biophysical models) and practices to optimise sea-based aquaculture at regional, national and international scales by;

1. replacing current post-infection chemical control and parasite removal methods through the development of natural and sustainable solutions to mitigate parasite infections, thereby reducing operational costs, environmental impacts and improving product quality
2. improving sea-cage design and farm siting and layout to minimize environmental impacts (e.g. eutrophication) and maximise production (disease infection and transfer) and economic returns (improved product quality)
3. optimise holistic aquaculture practices such as Integrated Multi-Trophic Aquaculture (IMTA) to increase production, value add and reduce impacts on the receiving environment
4. improve and optimise aquaculture ecosystem monitoring practices and policies

Hence, the outcomes from this research are beneficial to industry and the governing bodies responsible for regulation, legislation and policy, by providing knowledge based solutions to improve the quality, productivity and sustainability of marine aquaculture practices. Moreover, since sea-cage based aquaculture is undertaken in the natural environment, improvements in the sustainability of aquaculture practices have flow on effects by ensuring the surrounding ecosystem services (e.g. recreation, tourism, fisheries) are maintained for benefit the broader society.

6. How was this research relevant to:

The objects of the CRP?

Results of this research have improved scientific knowledge on biophysical couplings between aquaculture sea cages and farms and the distribution of parasitic pelagic plankton through measurements and modelling. Owing to the generality of turbulence in aquatic systems and the pelagic life history of many parasitic disease species, the international collaborative research supported through this fellowship has provided new baseline knowledge required for the development of functional, pre-infection mitigation solutions to reduce parasitic infection risks across a range of parasitic diseases, aquaculture species and marine systems. This is an emerging global imperative as sea-cage based aquaculture continues to grow around the world.

Specifically, results from this research will provide knowledge and information of global relevance to;

1) The scientific community, through scientific publications, conferences and seminars, by providing benchmark results to build future research and modelling into microscale couplings related to dispersion processes and disease mitigation in sea-cage aquaculture.

2) Aquaculture operators and managers by facilitating the development of natural, functional sea-cage siting, layout and designs to reduce parasitic infection and environmental impacts (i.e. chemical free methods, eutrophication), thereby improving the quality, productivity and sustainability.

3) Provide aquaculture policy makers and legislators (i.e. government) with knowledge based information and tools (i.e. models) to guide future policy decisions for sustainable aquaculture development.

4) The outcomes will ultimately provide consumers with a 'cleaner' more sustainable end product free of chemicals.

The CRP research theme?

Results from this fellowship directly address the 'Managing natural capital for the future' theme, through its focus on providing knowledge to support the sustainable development of aquaculture by providing increased knowledge of aquaculture interactions with the environment. Specifically, results from the field measurements have provided new knowledge on the extent and modification of microscale biophysical couplings due to aquaculture sea cages. These findings will underpin the development of functional and environmentally 'clean' disease management solutions. Additionally, the field results support the development of an advanced biophysical CFD model which will provide a tool to optimise how the spatial layout of sea cages within farms may reduce parasite infestation risks. This will be advantageous as it will reduce the use of post-infection treatments against sea lice, which are challenging in terms of operation, costs and fish welfare and maybe environmentally hazardous. Hence, the project results provide knowledge critical for improving our understanding of how to optimise aquaculture practices in natural systems to mitigate disease, minimize impacts on the receiving environment in order to improve productivity, quality and sustainability.

7. Satisfaction

Did your fellowship conform to your expectations?

Yes. The fellowship provided me with an opportunity to establish new international collaborations and, in doing so, undertake novel applied research with other international experts. The new

knowledge resulting directly from the fellowship will be used as a springboard to leverage research funds to further develop innovative and collaborative multidisciplinary scientific solutions to common problems facing the sustainable expansion of global aquaculture.

Will the OECD Co-operative Research Programme fellowship increase directly or indirectly your career opportunities? Please specify.

Yes. The fellowship has provided me with the opportunity to expand and apply my capabilities in the field collection, analysis and interpretation of ocean microstructure to provide novel solutions of international relevance to the sustainable development of aquaculture. The fellowship has also provided me with the opportunity to broaden and strengthen collaborative research connections on personal, institution and international levels. Publication of the results supported by this fellowship will strengthen my academic standing, improve my chances for promotion and will be used to leverage future research funding. Collectively, the benefits I have gained from the fellowship have only strengthened my career opportunities.

Did you encounter any practical problems?

Yes. The high cost of living in the host country was initially an issue. This was overcome through communication with the OECD. I am grateful for the support given to me by the OECD.

Please suggest any improvements in the Fellowship Programme.

Potential adjustment the fellowship stipend based on the cost of living in the destination country.

8. Advertising the Co-operative Research Programme

How did you learn about the Co-operative Research Programme?

I was advised by my host.

What would you suggest to make it more "visible"?

Increased visibility at key, relevant Australian national conferences. Increased advertising through national funding bodies whose programs would benefit by applicants leveraging funds to undertake collaborative research via the OECD fellowships.

Are there any issues you would like to record?

No.