Submission

to the

Senate Environment and Communications

References Committee

Inquiry into Fin-fish Aquaculture in Tasmania

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EXECUTIVE SUMMARY

This submission comprehensively reviews research undertaken by the University of Tasmania's Institute for Marine and Antarctic Studies (IMAS) and its predecessors, commonly in collaboration with other organisations, over the last 20 years. This research has significantly contributed to knowledge of the environmental impacts and interactions of finfish aquaculture in Tasmania, and provides independent advice and understanding to support decisions regarding the management and regulation of the salmonid farming industry. To date IMAS researchers have played key roles in both identifying and responding to "knowledge gaps" and will continue to do so in the future. Summarised below are the key elements for each term of reference (TOR):

(a) the adequacy and availability of data on waterway health: Whether data currently available are adequate depends on the particular issue, as waterway health is a broad term. We focus on the adequacy of data vis-à-vis specific issues as they have arisen; considerable data are available through IMAS. Initially, local scale benthic impacts were the focus, and research was integral to developing management controls. Concern then shifted to broadscale effects of dissolved wastes because research suggested farming in the Huon River/D'Entrecasteaux Channel region was approaching capacity. A limit on further development was imposed, and a Broadscale Environmental Monitoring Program (BEMP) initiated that has since been highlighted as world's best practice. Concern now focuses on potentially adverse interactions between marine farming and reefs, and on declines in oxygen in Macquarie Harbour. IMAS is currently providing research advice on these issues as part of the adaptive management process.

(b) the impact on waterway health, including to threatened and endangered species: Initial research characterised local scale impacts of finfish farms and highlighted that these could be managed within acceptable guidelines. Emphasis then changed to broad scale interactions, and research to date suggests that water-column impacts can be managed. Interactions with threatened and endangered species have largely been addressed through zone assessments and appropriate site selection. In Macquarie Harbour, interactions with the endangered Maugean Skate are now being assessed..

(c) the adequacy of current environmental planning and regulatory mechanisms, and (d) the interaction of state and federal laws and regulation: Tasmania has specific systems in place addressing regulation and management of finfish aquaculture. The regulatory context needs to be responsive to change. The current governance systems were formulated in the industry's start-up phase, and these systems will be reviewed and researched in the context of the current industry.

(e) the economic impacts and employment profile of the industry: Most data relating to economic impacts of marine finfish farming in Tasmania have been collected by industry.

(f) any other relevant matters: Wider issues include IMAS research capability, climate change, food security, and options for expansion of the finfish aquaculture industry. IMAS has provided research support to industry and government on other developing issues to contribute to sustainability of the industry now and into the future. Relevant IMAS research capabilities are significant and will be enhanced with the new experimental aquaculture facility. Broad expertise in IMAS means that research support can come from a wide range of disciplines and perspectives.

INTRODUCTION

This submission has been prepared to provide the Committee with an understanding of the substantial body of research undertaken over the last two decades by the University of Tasmania's Institute for Marine and Antarctic Studies (IMAS) that has contributed to our knowledge of the environmental impacts and interactions of finfish aquaculture in Tasmania. Research generated by the University of Tasmania (both as IMAS and its predecessors, including the Tasmanian Aquaculture and Fisheries Institute (TAFI) and the State Department's Fisheries Laboratory, hereafter referenced as IMAS), has provided the knowledge base to support decisions regarding many issues relating to regulation of the marine aquaculture industry, and has been central to the development, implementation, and review of the aquaculture environmental monitoring programs currently employed in Tasmania. IMAS has also played a key role in providing the system understanding and recommendations that have supported ongoing development and management of the salmon industry in Tasmania. IMAS research has been responsive to issues and concerns raised by industry, government, and the broader community, and IMAS researchers have also identified matters directly. The focus of our research has been collaborative; acknowledging that marine and coastal ecosystems are a shared resource. Consequently, in making management recommendations we have sought to promote multiple-use management solutions and to provide advice that supports sustainable management practices for all stakeholders. IMAS aquaculture research is acknowledged as world class, and our environmental research has been identified as world's best practice in international standards (e.g. WWF: Salmon Aquaculture Dialogue, 2012) and is regularly cited in relation to the development of aquaculture management strategies globally (e.g. Reish et al., 2005; Nobre, 2009; Holmer, 2010; Steckbauer et al., 2011; Keeley et al., 2012; Bannister et al., 2015).

Research informs both marine farming development planning and the setting of regulations and understanding of their impacts. Research is required across multiple disciplines to understand key components of industry, including: improving production, use of technology, managing environmental change, animal welfare, and values that society places on regulation. IMAS is a significant and expanding research organisation with considerable research capacity directly applicable to finfish aquaculture; this capacity not only relates to our biological and environmental science capabilities, but also incorporates expertise in social science, economics, and law. Integrated organisational structures facilitate a team approach to addressing important issues, including the expansion of finfish aquaculture in Tasmania.

In considering the terms of reference (TOR), it was challenging to separate our research outputs along the lines proposed since most of our research projects address a number of these elements simultaneously; for example, research focused on impacts on waterway health (TOR (b)) will also be relevant to the adequacy and availability of data on waterway health (TOR (a)). Consequently, whilst there may appear to be some overlap in the research presented in each section, the relevance and specific focus of the research to each TOR will differ. Furthermore, TOR (f) has been used to provide comments on wider issues relating to the expansion of finfish aquaculture in Tasmania.

<u>Terms of Reference:</u>

This submission addresses the following Terms of Reference:

(a) the adequacy and availability of data on waterway health;

(b) the impact on waterway health, including to threatened and endangered species;

(d) the interaction of state and federal laws and regulation;

(e) the economic impacts and employment profile of the industry; and

(f) any other relevant matters.

(a) the adequacy and availability of data on waterway health.

Numerous research projects over the last 15 years have specifically sought to describe the interactions between salmon farming and the environment, with a view to providing both baseline data and system understanding to inform management and monitoring, as well as support effective regulation. Many of the research projects have been undertaken in conjunction with state government and industry partners, and these have often had quite specific management objectives (see summaries of projects below). The research quantum has been progressive and additive in its development, with each project building from the understanding of previous studies, and the research directly responding to the evolving information needs and concerns. There are many ways we could present a review of the adequacy and availability of data on waterway health generated by IMAS through research focused on both salmon interactions and more broadly, the approach taken was to consider the contributions chronologically and look at the salmon specific data first and then research from other sources. As a result there is likely to be considerable overlap between this section and the next (b. the impact on waterway health, including to threatened and endangered species); hopefully). We hope it serves to emphasise the value of the information.

Many studies involving University of Tasmania researchers have sought to define the nature and extent of the environmental impacts associated with salmon farming in Tasmania (see project summary below). However, the first study that really focused on how we might translate an understanding of impacts to management was undertaken by Crawford et al. (2002). This study was specifically aimed at supporting the development of an industry wide monitoring program by determining the most reliable and cost-effective monitoring approaches for management of the Tasmanian industry. At this stage the research was focused on local-scale benthic impacts and sought to compare approaches employed in other areas of the world for monitoring of fish farms to determine those that would be most effective under Tasmanian conditions. The findings suggested that a combined package of measures that would identify changes in the sediments as well as in the associated infauna was the best approach, and that video recordings would also be a valuable inclusion because they provide relatively inexpensive, instant, permanent records of sediment conditions that are readily interpreted by stakeholders. The findings of this report played a key role in the development of the current Marine Farm Monitoring program regulated by DPIPWE.

The next stage in the developing understanding regarding management of the environmental interactions of salmon farming was to consider how areas affected by salmon farming might recover both after farming ceased and as part of the ongoing farming process. An opportunity to study this was provided when a lease in North West Bay was vacated in 2000 (Macleod et al., 2002). This showed that sediments can recover once farming is removed and that there was potential to manage recovery (Macleod et al., 2004a). This prompted further research to establish farm-based indicators for management of sediment condition, such that conditions beneath cages can be maintained at a level that ensures ongoing farming sustainability (Macleod et al., 2004b). The research found a clear relationship between farm management practices and level of impact, and identified nine distinct stages of sediment condition that could be used to enable farmers to easily classify sediment condition and manage accordingly (Macleod et al., 2004b). This research highlighted regional differences in the sediments' ability to assimilate organic material, and showed that although the fundamental stages of degradation and recovery were consistent, the rate at which these processes occurred differed depending on the prevailing environmental conditions (Macleod et al., 2007). However, farm management regimes could be manipulated to compensate for this (Macleod et al., 2006). Although the protocols proposed through this research were developed specifically in relation to on-farm monitoring and management, and were not intended for regulatory or compliance purposes, the findings have informed regulatory processes both in Tasmania and internationally (Woods et al., 2004, Keeley et al, 2014).

The field guide produced as part of the local-scale benthic research (Macleod et al., 2004b) details in highly specific terms how to undertake the monitoring approaches proposed, and as such has helped to ensure the monitoring is consistent and accurate and therefore that the monitoring results are reliable. As a consequence, the resultant data can be used for broader scale analyses of ecological impact and interactions, with independent studies using the collective monitoring data to assess the broad-scale effects of marine salmonid aquaculture on the sediment environment and the distribution of introduced pests in Tasmania (Edgar et al. 2005, Edgar et al., 2009). The value of these data in supporting our understanding of broader spatial and temporal changes across Tasmania should be acknowledged.

Having established a clear understanding of the local-scale benthic impacts of salmon farming, the next area of research focus was to examine the potential for broader-scale environmental interaction, and in particular the potential for adverse impacts associated with excess water column nutrients as a result of farming activities. This was the focus of a major research initiative through the Sustainable Aquaculture of Finfish CRC (Aquafin CRC; Volkman et al., 2009), and built on the findings of the integrated evaluation of water quality in the Huon Estuary undertaken by CSIRO (CSIRO Huon Estuary Study Team, 2000). A project commenced in 2001 to undertake a whole-of-ecosystem assessment of environmental issues for salmonid aquaculture. The project was led by Dr John Volkman from CSIRO and was a multidisciplinary partnership involving researchers and students from a broad range of disciplines (e.g. biologists, ecologists, biochemists, microbiologists, hydrodynamic and biogeochemical modellers) and agencies (UTAS, IMAS, CSIRO), as well as stakeholder representatives from the salmon farming industry and the government. This project set out to characterise the broader environmental conditions in the Huon Estuary and D'Entrecasteaux Channel (the main farming area at the time) and to design a monitoring program with the capacity to detect the effects of those processes judged to be most threatening at the whole-of-ecosystem level. The detailed dataset that has resulted from this research provides a comprehensive baseline, not only for assessment of salmon farming, but also with respect to informing of the potential interactions associated with any other development or inputs into this system.

The monitoring program proposed as part of the Aquafin CRC program was specifically designed to provide an understanding of how the ecosystem is coping with the existing nutrient load and to allow any significant temporal trend(s) in ecological indicators to be detected (Thompson et al., 2008). The proposed monitoring program represents world's best practice for "broad-scale" monitoring of salmon aquaculture; few countries have anything comparable and this approach has been showcased as an aspirational goal in the development of such programs both nationally and overseas. The monitoring program was implemented in 2009 as an interim regulatory compliance requirement, with the intention that the outcomes would be reviewed and the program adjusted where necessary as part of an adaptive management framework. An initial review of this Broadscale Environmental Management Program(BEMP) was undertaken in 2013 by IMAS (Ross and Macleod, 2013), and comprised an evaluation of the first three years of data (2009-2012) in which recommendations were made both on the system condition (see next section) and on the adequacy of the associated data. Significant findings from this study are detailed in the next section, but it is clear that this dataset provides an important and highly reliable body of information on the conditions in the Huon Estuary and D'Entrecasteaux Channel that has been independently authenticated and therefore can be used by regulators, industry, and other stakeholders to assess ecological condition and to support adaptive management strategies. The monitoring program is now an active component of this adaptive management process and the next stage is to review the monitoring itself (in the light of the BEMP review) to assess whether the parameters and approaches remain "fit for purpose" for current management objectives.

The findings of the Aquafin CRC project indicated that in general the environmental conditions within this system were good with occasional localised periods of high phytoplankton abundance and low dissolved oxygen (DO). A suite of 3-dimensional hydrodynamic and biogeochemical models of the region were also developed by CSIRO as part of this project that capture the main physical and biological processes. The results obtained from both the field measurements and the modelling suggested that the nutrient contributions from the salmonid industry to this region had in all likelihood led to increases in phytoplankton abundance and that the industry was approaching the size where significant further expansion in the same region could lead to adverse environmental effects. It was on the basis of these findings, in combination with the industry's projections for salmon production in 2009, that the Marine Farming Planning Review Panel decided to recommend that a limit be imposed on the salmonid industry in the Huon Estuary and D'Entrecasteaux Channel. A feed cap was subsequently imposed by DPIPWE in 2008, under the management controls provided in the marine farming development plans. This limit controls the nutrient outputs of the industry, and meant that for the industry to expand they needed to look to other regions outside of the Huon Estuary and D'Entrecasteaux Channel or find ways to reduce or ameliorate nutrient inputs.

Clearly, the progression has been to explore other areas for development, and as a result, several projects have been undertaken to address the range of additional information needs and concerns associated with that goal. In the first instance this has involved mapping of potential new sites. IMAS has significant spatial analysis capability in the SeaMap Tasmania research team (http://seamap.imas.utas.edu.au - Lucieer et al., 2009) and has provided zone assessments under contract to DPIPWE to support State Government in developing new or amending existing marine farming development plans (MFDPs) for salmonid aquaculture. Zone assessments are undertaken prior to any new development (or zone extension) being approved, and provide a broad characterisation of the seabed in the area of focus; these include photographic, acoustic, biological, and sediment sampling. The resultant habitat maps identify any sensitive or unsuitable environments (e.g. reefs) within the proposed development area, and the associated sediment samples and video are designed to identify ecological risk factors (e.g. threatened species such as the Tasmanian screwshell, *Gazameda gunni*). The zone assessment process is well documented, standardised, and consistent, and as such the resultant maps represent extremely valuable baseline datasets that can be used to monitor for changes in habitat extent and structure over time. The broad coastal habitat maps are available online through SeaMap Tasmania (http://seamap.imas.utas.edu.au/maps/) whilst the individual marine farming planning zone assessments can be accessed through DPIPWE.

Storm Bay and the lower D'Entrecasteaux Channel are perhaps the most obvious areas for expansion of the aquaculture industry in SE Tasmania. Crawford et al. (2011; Fisheries Research and Development Corporation (FRDC) 2009-067) collected water quality data at a suite of sites in Storm Bay from 2009-10. IMAS has since maintained the sampling program, with FRDC funding supporting the program for 2014-15 (FRDC 2014-031). This data set provides crucial baseline scientific information to support ecologically sustainable development of salmonid aquaculture in the region. In particular, this research sought to better understand the complex oceanography of this region and describe the resultant spatial and temporal changes in temperature, salinity, and nutrients with a view to enhancing the various risk and decision support systems being developed for management of salmon farming in the Storm Bay region. In particular, describing interactions among temperature, wind, and rainfall patterns, how these might influence nutrient concentrations and plankton dynamics (e.g. harmful algal blooms (HABs)), and how gelatinous species around farms and *Neoparamoeba perurans* (the causative agent of amoebic gill disease (AGD)) relate to broader environmental conditions. It is also important to note that this research provides data to support long-term monitoring in this system by repeating the sampling conducted at a site in central Storm Bay by CSIRO from 1985-89.

Establishing the BEMP was a natural progression in the development of our understanding of the environmental interactions of salmonid farming, and the clearly stated intention of the BEMP was to provide "*a monitoring program with the capacity to detect the effects of those processes judged to be most threatening to the Huon and D'Entrecasteaux ecosystem at the whole-of-ecosystem level …. to provide knowledge of how well the ecosystem is functioning with an increased nutrient load and to allow any significant temporal trend(s) in ecological indicators to be detected*". However, the key focus of the BEMP was on water-column and benthic effects on soft sediments within this system, the primary concern being the potential for eutrophication. The possibility of adverse interactions between salmonid aquaculture and reef systems was not specifically addressed by the BEMP, and this has since been highlighted as an area of concern.

IMAS has a number of ongoing research projects that seek to improve our understanding of the potential interactions among salmon farming, macroalgae, and reefs, and in particular the effect of increased nutrients on reef ecology and dynamics. Proliferation of intertidal "nuisance" algae in response to increased nutrients was initially assessed in 2003, and the results at that stage suggested no obvious causal links to salmonid farming (Crawford et al., 2004). A reassessment of these sites 11 years after the initial assessment has recently been funded (FRDC CC035 Reassessment of intertidal macroalgal communities near to and distant from salmonid farms and an evaluation of using drones to survey macroalgal distribution) given concerns that the abundance of opportunists has increased in recent years as a result of the overall expansion of the salmonid aquaculture industry. Crawford et al. (2006) undertook an analysis of changes in abundance of macroalgae based on long term data sets (1992-2002) at the Ninepin Point and Tinderbox Marine Protected Areas (MPAs) to assess whether broadscale impacts of effluent from marine farming activities could be detected. The report found no apparent patterns of changes in macroalgal community composition over the 10 year time period. Similarly, this assessment is currently been repeated with the inclusion of an additional 11 years (2003-2014) of MPAMPA data from Tinderbox and Ninepin Points given recent concerns raised regarding the potential impacts of salmon farming on rocky reef assemblages. In 2009 an IMAS honours project examining macroalgal communities data at varying distance from twelve active salmon farming leases found that sub-tidal opportunistic and epiphytic algae increased at sites close to fish farms (100m) but noted that this effect was localised, i.e. sites at 400m varied in their response to farms, with some sites showing characteristics similar to 100m sites.

Two student projects currently approaching completion are specifically focused on determining the effects of nutrients on sub-tidal macroalgae. The first of these is looking at the potential to utilise the nutrients produced by salmon aquaculture to grow algae, and has modelled the effects of growing algae alongside salmon farming on local nutrient dynamics, both as a secondary culture species and/or explicitly for nutrient extraction (i.e. integrated multi-trophic aquaculture (IMTA)). The results suggest some potential to use this approach to mitigate nutrient outputs of salmon farming and improve environmental conditions, but that location of the macroalgae within the system is critical and depends on the end result required (i.e. whether growing for profit or for nutrient mitigation) (Hadley et al., 2014). The second student project (due to complete by the end of 2015) is looking at the effect of adding nutrients directly to reef systems in the D'Entrecasteaux Channel on reef ecology and dynamics. The data so far suggest little evidence of any major effect on reef structure or complexity, although there is evidence of changes at the physiological level. Opportunistic algae responded to the increase in transient nutrients, but this response does not seem to have any major influence on the dominant or keystone species. Location of the reef systems within the Estuary (particularly in relation to exposure/ light regimes) would seem to be the most significant determinant of algal community changes and associated sensitivity/ resilience. Both of these student projects have generated information to advance our understanding of salmon farming interactions and the environmental condition of the receiving waters. Data included in the IMTA modelling have been used to inform and improve the CSIRO biogeochemical modelling suite for the Huon River,Estuary and D'Entrecasteaux Channel as well as Storm Bay.

In addition, a new research collaboration is due to commence at the end of July 2015 (FRDC 2015-024 - Managing ecosystem interactions across differing environments: building flexibility and risk assurance into environmental management strategies). This study will look not only to further inform our understanding of reef interactions, but also to consider whether the impacts and interactions of salmon farming may have changed markedly over the last 15 years, given the significant changes in farming technology and the new areas in which farming has occurred since that time, i.e. when the benthic monitoring protocols were established. IMAS has developed this project in conjunction with collaborators at CSIRO and a broad range of stakeholders from government, the community, the salmon industry, and also with representatives from the commercial fishing industry (abalone and rock lobster) and the recreational fishing community. The project recognises that the salmonid industry in Tasmania has changed over the last 10 years, and is proposing to change further in order to double production by 2030.

It is clear from discussions with various resource users (i.e. fish farmers and both commercial and recreational fishers) that the perception of potential risks differs between Macquarie Harbour and the southern farming regions. In Macquarie Harbour a critical issue is whether the current on-farm monitoring (and local scale impact indicators are "fit for purpose" i.e. do they support sustainable management by providing an accurate understanding of sediment conditions? Whilst in the new farming areas in the southern regions (Lower Channel/ Storm Bay), the key concern is whether there may be adverse effects on reef health (i.e. off-site interactions) as a result of increased marine farming activities.

This study has been designed to target the different research priorities and concerns in each new farming region (Lower Huon Estuary / D'Entrecasteaux Channel, Storm Bay, Macquarie Harbour). In Macquarie Harbour the emphasis will be on validating local scale monitoring approaches (on-site focus), and whilst this will also be an important element in the southern regions, a key element of the research in the south will be defining cost-effective and risk appropriate approaches for assessment of reef health (off-site interactions). An important component of this study will be to use the empirical monitoring data to calibrate and validate sediment deposition and nutrient dispersion models. Dispersion modelling will be used to link the reef assessment information to the local scale studies, specifically looking to identify the exposure of reef systems to nutrients and sediments from fish farms. Nutrient diffusive gel technology (DGT) and sediment trap measurements will be critical for model calibration and validation. Ultimately, the deposition and dispersion models will provide an important predictive tool for determining risk to the ecology of soft sediment and reef habitats in new farming regions. Overall, the project research and outputs will be specifically developed to align with the broad-scale monitoring and management measures currently in place, and to connect with and build upon broader ecosystem based management and research currently underway (e.g. existing DPIPWE and industry spatial planning processes, INFORMD2 project, Storm Bay project, intertidal algal monitoring, current abalone spatial mapping initiatives, and any local/regional hydrodynamic modelling) and particularly any other research aligned to the broader stakeholders' key concerns. Importantly, the proposed study builds on existing research and management understanding, seeking to inform and improve practices rather than replace current approaches. The findings and data from this research will be discussed with the relevant project steering committees. This project has two steering committees associated with it: one to discuss and inform the research on local-scale interactions and one associated with the reef interactions. These reference groups have been selected on the basis of their particular stakeholder interests and expertise, and therefore are well positioned to review and assess the data.

Many questions and concerns have been raised over the years with respect to salmon farming and the potential for adverse interactions of this activity in the marine environment. IMAS has actively sought to engage with government, industry, and the broader community to develop collaborative research projects that seek to address these concerns and provide risk appropriate management advice. Issues are captured in a number of ways; the Sustainable Marine Research Collaboration Agreement (SMRCA) is a mechanism by which State Government engages IMAS directly to address research needs, and several research projects have been undertaken this way ((e.g. the initial assessment of monitoring approaches (Crawford et al., 2002) and recovery studies (Macleod et al., 2002)). Research issues can also be raised through Research Advisory Groups (RAGs), which are state based reference groups made up of a broad range of stakeholders (industry, government, and community) and which provide an overview each year of state based research priorities across a range of topics. The RAG process and associated annual report provides an important strategic reference for a range of independent funding agencies, but most importantly to the FRDC, as each year the RAGs identify the most significant research needs in relation to fisheries and aquaculture for Tasmania. IMAS is committed to ensuring our research collaborations are aligned to the needs identified through this RAG process and are therefore relevant to current stakeholder expectations. Many of our research projects over the last 10 years have been generated from, and responded to, issues identified through this process (e.g. the current FRDC project 2015-024 Managing ecosystem interactions across differing environments: building flexibility and risk assurance into environmental management strategies - see summary below).

However, not all research is driven through specific stakeholder engagement; several projects and initiatives have come directly through research organisations. INFORMD (Inshore Network For Observation and Regional Management: Derwent-Huon) is a research collaboration between the CSIRO and IMAS first established in 2009 with the aim of developing an advanced coastal information system for south-east Tasmania that is comprehensive, useful, and accessible to a wide range of users, and which will lead to shared knowledge and understanding, and better choices and outcomes in regional coastal development. The vision of INFORMD is to turn research capacity to observe, understand, and predict the coastal environment into better "hands-on" management approaches, improving both the information base available and the delivery of advice to policy makers and regulators. Consequently a key objective of all of the research under the INFORMD banner is to enable the broader community and resource stakeholders to access research and particularly environmental data more effectively, but also in a way that will allow them to interpret it in a meaningful context.

The first funded INFORMD project sought to specifically support integrated planning, management and development of the marine and coastal ecosystems of south east Tasmania by developing and demonstrating practical and science-based methods for predicting, assessing, and monitoring environmental condition in the Derwent, Huon Estuary and Bruny Bioregion. This region represents a microcosm of the issues facing coastal development and management throughout Australia. A range of remote sensing and modelling tools were developed and tested in this region with a view to developing practical approaches to coastal planning that can be used both by individual industries and for the region as a whole. Several of the methods, models, and management approaches developed through INFORMD are now being applied elsewhere in Australia.

INFORMD2 was funded by FRDC in 2012 and sought to build on the work done in the previous study by developing a new computer model, based on and linked to the existing hydrodynamic and biogeochemical models, but simplified, to enable communities and aquaculture industries to more easily assess the potential for environmental and human impacts in south east Tasmania. The project focuses on the estuarine and marine environments of the Huon River, D'Entrecasteaux Channel, and around Bruny Island, and is particularly relevant to the management of salmonid farms. The computer-based tool will in essence be a simulator, which allows management ideas to be tested before implementation. The project will help industry, regulators, and local communities to better understand how changes in farming practices or spatial deployment, the expansion of other industries, or coastal urbanisation might impact key aspects of the marine and estuarine environments (i.e. those aspects critical to ecosystem function and/ or which are most valued by the community).

The first stage of this research involved engaging with key stakeholder groups to identify regionally relevant environmental values, clarifying how people relate to marine farming and how they relate to farm management practices and monitoring of the marine environment. This component was published separately in a document called "Your Marine Values" (http://www.imas.utas.edu.au/__data/assets/pdf_file/0003/535908/Your-Marine-Values-Document_WEB-FULL.pdf) and provides a valuable community resource outlining the values of all stakeholders, how those values relate among stakeholders, and to current management requirements and legislation. The integration of community values with environmental understanding via computer modelling has the potential to help government agencies better manage risks facing coastal marine environment and communities, and this latter component is due for completion in 2016.

Similarly, the Centre for Marine Socio-ecology (CMS) is a collaborative partnership involving the University of Tasmania, CSIRO, and Australian Antarctic Division, established earlier this year, which seeks to broaden our understanding of the connectivity of all aspects of our coastal systems, and particularly to better define the interaction of humans with each other and with their environment. The CMS aims to draw together research across complex biophysical and human systems with the intention of supporting industries, ecosystems, livelihoods, and communities to be sustainable, and to improve the balance between competing marine uses and values. Several developing research projects relevant to ensuring waterway health are anticipated to fit into this agenda. One of the key research areas currently proposed for the CMS (including two potential PhDs and a post-doc through IMAS) is how to improve data access and availability, and sharing of information to improve spatial planning and decision making in the coastal zone - the CMS is further discussed in Section (e). Another project that IMAS is involved with which has sought to improve data access and availability is Seafood CRC (Project 2011-735). This project comprised three stages; the first two stages were associated with development of an industry decision support framework (described in more detail in section (e)). But the final stage of this project is relevant here as it aims to provide a ready reference of the key factors to consider with respect to spatial planning for marine farming development and a simple planning and decision support framework. The outputs should provide a functional but effective mechanism for community engagement and communication that will be useful in supporting future marine farming development application processes and improve planning outcomes.

Growth of the Tasmanian salmonid industry over recent years has been further development in Macquarie Harbour. Whilst salmonid farming has occurred in the harbour for many years, in mid-2012 approval was granted for a substantial (>60%) increase in lease area in the harbour. IMAS conducted the zone assessments for these new lease areas. Several concerns have been raised both during the approval process and since on the potential for adverse interactions between salmonid farming and the environment at this scale. Consequently, IMAS has been and is currently involved in multiple research projects to better understand the environmental interactions of salmon aquaculture in Macquarie Harbour, and to help inform monitoring and management strategies.

A key concern for Macquarie Harbour was the lack of specific data on sediment dynamics, and as a result whether the environmental model used to assist decision making accurately captured this process. Consequently in 2012-13 IMAS undertook research to determine sediment - water column nutrient fluxes at both the farm (local) and harbour (regional) scales. These data have been used to re-calibrate the environmental model and identified status level indicators of sediment condition (FRDC 2012-047; Ross et al., 2014). The study identified clear relationships between farming activity and sediment condition, and suggested that further research could provide valuable management information. Bottom water oxygen declined markedly at the end of this study and it was recommended that this event (and the potential causes) be further investigated.

In February 2014 the Tasmanian Salmonid Growers Association (TSGA) established the Macquarie Harbour Dissolved Oxygen Working Group (MHDOWG) to consider the DO reductions in bottom waters of Macquarie Harbour and to investigate likely causes. IMAS (Ross and Macleod) were invited to participate in the working group given their experience working on salmonid aquaculture -environment interactions and expertise with respect to the water column and benthic processes responsible for the cycling of nutrients (including oxygen) and organic matter both in Macquarie Harbour specifically (Ross et al., 2015) and in other coastal systems (e.g., Bissett et al., 2007; Banks et al., 2012;; Ross et al., 2013; Oakes et al., 2013; MacLeod et al., 2014).

Another notable and related concern with respect to Macquarie Harbour is whether techniques for monitoring developed in south eastern Tasmania can be reliably applied to the harbour. One of the key issues is whether the opportunistic indicator taxa most commonly observed in Macquarie Harbour (i.e. Dorvilleids) fit the same functional role as the taxa previously defined as a relevant environmental trigger in the south (i.e. Capitellids). IMAS has commenced a project (FRDC 2014-038) to review the current understanding of Dorvilleid ecology, and in particular, their response to organic enrichment as well as their current use as indicator of the impacts of finfish farming. The project will also undertake targeted field surveys at selected leases to clarify the relationship between Dorvilleids and sediment condition, and define the environmental conditions associated with changes in Dorvilleid abundance. This project is about half way through and preliminary results suggest that Dorvilleids can be effective indicators of sediment condition in Macquarie Harbour, although some considerations need to be taken into account when using them for monitoring. This data will be extremely important in refining the Macquarie Harbour monitoring program for salmonid farming and will extend directly into FRDC project 2015-024 (Managing ecosystem interactions across differing environments) to provide a comprehensive assessment of whether the current on-farm monitoring approach and local scale impact indicators are “fit for purpose” in Macquarie Harbour.

In the Macquarie Harbour expansion proposal it was noted that the anticipated increase in production would affect overall nutrient inputs to the system (i.e. increasing nitrogen and phosphorous). Whilst it was noted that this could potentially adversely impact primary production in the Harbour, the reduced light penetration (as a result of the darkly coloured tannin waters) suggested that such impacts might be restricted to the intertidal zone. Consequently, Crawford et al., (2013; FRDC 2011-086) surveyed macroalgal composition and abundance throughout the Harbour in 2012 to provide a baseline for assessment of future changes.

Several other issues have been raised with respect to potential impacts of current and proposed marine farming operations in Macquarie Harbour. One particular concern relates to the possibility for adverse interactions with the endangered Maugean Skate, and IMAS has an ongoing research project (FRDC 2013/008) specifically investigating the movement, habitat utilisation, and population status of this species in Macquarie Harbour. The spatial and temporal dispersal patterns of salmonid escapees in the harbour are also being investigated. Acoustic tagging has been used to track the movements (location and depth) of both skates and escaped salmonids. This project is providing data on the biology, ecology, habitat preferences, and environmental sensitivities of the Maugean skate that can be used to not only understand the potential risks to the species associated with salmon farming but also to provide a better understanding of other environmental risk factors. For example there is a concern that fishing (gillnetting) in the harbour may have an adverse effect on the Maugean skates, and because one of the main species targeted in gillnet fishing is salmonid escapees, this study will evaluate strategies to reduce the probability of encountering skates whilst fishing. Similarly, the underlying environmental data and details of recreational fishing activity and fish interactions collected through this study will markedly improve our overall understanding of conditions in Macquarie Harbour.

Clearly a large body of research has been undertaken with the specific purpose of establishing the effects of finfish farming on the marine environment, and whilst this research has often been specifically targeted at providing management advice and recommendations for either the industry directly or resource regulators, the underlying data also provide a substantial resource for understanding broader ecosystem processes and function. Likewise, several studies undertaken by IMAS staff and students over the last two decades have been focused on other issues and interactions, and provide a more general understanding of the ecology, system processes, and ecosystem services associated with our coastal and marine communities, but which in turn also represent baselines against which the interactions of aquaculture and other broader anthropogenic influences can be assessed. Identifying and better connecting researchers and data sources are foci of several current and ongoing research projects. For example, these are key aims of the CMS project described earlier, and are foci of FRDC project 2015-024 (Managing ecosystem interactions across differing environments) where a research advisory group has been established to better engage the broader research community (academic, industry, and government) with a view to sharing knowledge and value-adding to the research program wherever possible.

Some notable examples of projects that have not specifically focused on the effects of marine farming, but where the findings have proven useful in developing our understanding of aquaculture interactions, include are:

- Understanding the condition and dynamics of Tasmanian estuaries, interactions with human uses of the coastal zone, and the implications for monitoring and management has been the focus of a significant body of IMAS research over the past two decades. Edgar and colleagues (e.g. Edgar et al., 1999, Edgar et al., 2000; Edgar and Barrett 2000, 2002) undertook an estuarine bioregionalisation study, providing a classification and conservation assessment of 111 Tasmanian estuaries based on ecological and physical attributes, population, and land use characteristics. Murphy et al., (2003) extended this work, providing an assessment of estuarine health based on status and indicators of water quality. Over the past decade, IMAS has continued this work, further developing water quality monitoring programs, estuarine health indicators and conducting estuarine health assessments across a range of Tasmanian estuaries (e.g. Hirst et al., 2005; Crawford 2006; Mount et al., 2006; Beard et al., 2008; Crawford et al., 2008; Temby et al., 2008). Most recently, Ross et al. (2012b) developed an estuarine decision support system to assist estuarine monitoring and management, and this includes recommended indicators of the thresholds levels for potential concern. In addition, several studies have investigated specific issues, for example the environmental water requirements of estuaries (Crawford et al. 2006; Ross et al., 2012a), the impacts of point source discharges of nutrients and organic matter (Oakes et al., 2011; 2012), and the suitability for shellfish aquaculture (Crawford and Mitchell 1999). This body of work provides the critical background understanding required when assessing the implications of development such as marine farming in Tasmanian estuaries.
- The Bruny Bioregion assessment (Barrett et al., 2001) has provided detailed (100m scale) inshore habitat maps of this region, identifying the extent of reef/ sand/seagrass habitat, areas of particular conservation significance, and the broad-

scale relationships between habitat features and biological assemblages which have been extremely valuable in spatial planning.

- The long-term studies of MPAs from the east coast of Tasmania and the D'Entrecasteaux Channel have provided an excellent and unique time series, over many years of standardised data for reef communities around Tasmania. This dataset provides a benchmark against which to detect system-wide changes in reef biota which incorporates interannual and decadal variation, thus enabling the changes to be placed in the context of a range of different possible long-term drivers, such as the effects of nutrient enhancement, fishing, climate change, and introduced species (Barrett et al., 2007, Barrett et al., 2009).
- The Reef Health project has provided comprehensive data on the algal and macroinvertebrate communities associated with ~120 reef sites around Tasmania. These assessments were initially undertaken in 1993, and all sites were revisited again in 2005; the resultant dataset provides both baseline ecological data from a broad range of environments from all around Tasmania, and is also an excellent resource for assessment of temporal change over that period. This information can help us better understand the ecological processes and environmental issues that structure spatial and temporal patterns in reef communities, including the effects of marine farming (Edgar and Stuart-Smith, 2009, Stuart-Smith et al., 2010).
- Some of these broader ecological studies have proven to be of direct relevance to the assessment of aquaculture impacts. For example, the study of the soft sediment community structure in the Huon and Derwent estuaries undertaken in 2002-3 (Macleod and Helidoniotis, 2005) - primarily to assess the effect of metal contaminants on the Derwent Estuary biota - has proven extremely useful in providing background copper loadings for assessing the environmental impacts of antifoulant usage associated with salmon farming (FRDC Project 2011-041; Macleod et al, 2014)
- SeaMap Tasmania has been discussed already, but it is worth highlighting the importance of having detailed habitat maps for all of the main farming regions and also for other areas where there may be concerns regarding the potential for adverse interactions (i.e. North West Bay, Huon Estuary and D'Entrecasteaux Channel, Storm Bay, The Actaeon Islands, theDerwent Estuary, Macquarie Harbour). These maps define the types of marine habitats and biological communities in these areas and provide an excellent reference point for assessment of risk potential.
- Recent funding under the Sense-T program (http://www.sense-t.org.au/) has provided resources for two key aquaculture optimisation projects.
  - The Oyster Biosensors project will see IMAS and CSIRO working together to progress research started under Sense-T's Stage 1 Aquaculture project. Individual oysters at three pacific oyster growing areas in Tasmania (Pittwater, Moulting Bay, and Duck Bay) will be fitted with a network of environmental- and bio-sensors to monitor and connect physiological variables (such as oyster heart-rate and production) with environmental conditions. The data collected on the health of oysters and on-farm conditions will inform real-time production decisions and help the industry to become more competitive, efficient and sustainable.
  - The Macquarie Harbour Salmon project brings together the Tasmanian Salmonid Growers Association, IMAS, and CSIRO to collect and analyse data from salmon farms in Macquarie Harbour. Data on fish behaviour will be collected from sensors deployed on individual 'sentinel' fish in pens and compared with environmental

sensor data (i.e. conditions such as water temperature, DO, and depth). This will provide information that can help to reduce feed wastage by ensuring feeding occurs when environmental conditions are most suitable. It will also enable information to be collected about the specific impact of salmon farming on variables such as oxygen levels (something that we have previously been unable to obtain). Together these data will not only improve the salmon industry's efficiency and productivity by providing real-time data to support decision-making, but also highlight any areas where the industry could improve environmental practices.

- Finally IMAS research data have contributed to improved understanding of coastal ecosystems Tasmania, and it has also been made available more broadly to a range of other combined environmental reports – for example the State of the Derwent reports (Green & Coughanowr, 2003; Whitehead et al., 2009; Whitehead et al., 2015) and the State of the Channel report (Parsons, 2012).

In concluding, it is worth noting that the research understanding outlined in this document represents two decades of accumulated knowledge and that this has been developed through a broad range of research collaborations both with other research providers (notably CSIRO) and in collaboration with industry, government, various not for profit organisations, funding agencies (particularly FRDC, Natural Heritage Trust/National Resource Management, various CRCs), and the community. The research has been progressive, with each question answered leading quite naturally to further questions. The transition in our understanding of the interaction of marine farming (and therefore monitoring requirements) has similarly progressed from a need to understand local-scale impacts, to a need to define broader-scale impacts, to the situation where ecosystem interactions and multiple-use management are now the focus. It is to be expected that as the current research evolves other questions will need to be addressed.

All IMAS research data is subject to the terms and conditions outlined in the University of Tasmania Management of Research Data Policy (http://www.utas.edu.au/__data/assets/pdf_file/0008/412001/Management-of-Research-Data-Procedure.pdf). Metadata is generally available through The University of Tasmania and more detailed information may be available upon request, providing there are no ethical or confidentiality considerations and that appropriate acknowledgements/ attributions are obtained.

(b) the impact on waterway health, including to threatened and endangered species

As identified in the previous section, several studies have specifically focused on determining the impacts and interactions of marine farming on waterway health, and several of these have implications for threatened/endangered species. The key findings of these projects are described below.

To minimise the potential for impacts, proposed marine farming zones are first assessed for their suitability for marine farming activities. This includes a zone assessment conducted by IMAS that details the habitat extent, depth, and details of the substrate, including dominant flora and fauna and the presence of threatened and endangered species. After farming has commenced, routine monitoring of the lease areas is required and the marine farming development plan management controls stipulate “there must be no unacceptable impacts 35 m outside the boundary of the marine farming lease area’.

The 35 m point from the boundary was based on studies from Europe where particulate farm wastes were generally found to be concentrated within 35 m of the edge of the cage, and preliminary research conducted in Tasmania (Ye et al. 1990). There has since been extensive research in Tasmania documenting the extent of benthic affects associated with particulate farm waste (e.g. Ritz et al., 1989; McGhie et al., 2000; Crawford et al., 2002; MacLeod et al., 2004; Edgar et al., 2005) which confirm a distinct gradient of impact: from significant signs of enrichment immediately adjacent to cages to minor farm effects evident at sites 35 m from the lease boundary. Research conducted at IMAS also established scientifically credible and cost effective environmental variables and techniques for monitoring the effects of particulate organic waste from fish farms that have been incorporated into regulatory requirements (e.g. Crawford et al., 2002). Subsequent work developed novel approaches for farm based monitoring of environmental condition which have since been used to improve farm management protocols and to maximize sustainable usage of the lease area (Macleod & Forbes 2004)

In the early years management and research of salmon farm wastes focused on local scale impacts associated with particulate deposition (i.e. excess fish feed and faeces). With continued expansion in existing growing areas because of a shortage of new sites in the southeast, government and industry became increasingly concerned about broadscale cumulative effects, particularly due to increased nutrient inputs from dissolved salmon farm wastes in the Huon Estuary where most salmon were grown. This triggered an intensive investigation of environmental quality by CSIRO (CSIRO Huon Estuary Study Team, 2000). This included examination of the physics, cycling of nutrients, and phytoplankton dynamics culminating in the development of hydrodynamic and water quality models of the Estuary. The modelling predicted that the Estuary could assimilate a doubling of production. Investigation of system wide environmental issues for sustainable salmonid aquaculture in southeast Tasmania then became the focus of a major seven year collaborative (IMAS & CSIRO) R&D program under the Aquafin CRC. With expansion into the nearby D'Entrecasteaux Channel, hydrodynamic and water quality models were developed for the whole Huon Estuary/ D'Entrecasteaux Channel region to evaluate the effects of current and projected farming loads to the system in addition to detailed investigation of water column nutrients, phytoplankton and zooplankton dynamics, and benthic biogeochemistry (Volkman et al., 2009). The study provided an extensive set of environmental data for the region, and demonstrated good environmental conditions with occasional localised periods of high phytoplankton abundance and low DO. The data were used to calibrate and validate sophisticated 3D hydrodynamic and biogeochemical models utilized to evaluate the environmental impacts of the salmonid fish farms in the region, contrasting the environmental footprint based on 2002 farm inputs with projected 2009 farm inputs. Informed by the modelled predictions of likely effects on phytoplankton populations based on projections of salmon farming in 2009, the Marine Farming Planning Review Panel and the Secretary of DPIPWE imposed a limit (via a nitrogen feed cap) of the salmonid industry in the Huon/D'Entrecasteaux region. To ensure that the water column and sedimentary environment remained in a satisfactory condition as farming continued to develop in the region, BEMP was initiated in 2009 as a regulatory compliance requirement. BEMP provides a comprehensive assessment of ecological condition measuring a broad suite of parameters capturing the physical, chemical, and biological characteristics of the system at fifteen sites throughout the region. In 2013, IMAS (Ross & Macleod 2013) evaluated the first three years of monitoring data (2009-2012) in the context of the major system drivers (including salmon farming), previous environmental data sets, and broader ecosystem performance measures.

The key findings of the review were:

- Catchment inflows, fish farms, and oceanic inputs are the major sources of nutrients, particularly nitrogen, but they vary in the form of nitrogen they input to the system. Catchments inputs are predominately organic nitrogen, fish farms are the most significant source of ammonium, and oceanic inputs are the major source of nitrate and nitrite.
- A comparison of the BEMP data set (2009-2012) with historical data sets collected in the D'Entrecasteaux Channel (Aquafin CRC: 2002-2005) and Huon Estuary (HES: 1996-1998 and Aquafin CRC: 2002-2005) identified several system changes consistent with anticipated responses to increased inputs of organic matter and nutrients. The report concluded that fish farm inputs associated with the industry expansion are likely to be partly responsible for the increase in ammonium concentrations and the decrease in bottom water oxygen concentrations in the Huon Estuary. Unfortunately a lack of comparable ammonium and oxygen data pre-BEMP in the Channel obfuscates meaningful assessment there.
- Despite the changes in ammonium and oxygen concentrations in the Huon Estuary, there is no clear evidence of a concomitant change in water column productivity (i.e. phytoplankton biomass). There is some indication that phytoplankton composition may have changed in the Huon Estuary and D'Entrecasteaux Channel; however, more data and further analyses (i.e. inclusion of count data) are required before concluding an unambiguous change in composition through time and/or direct links to any single source.
- Compared against recommended performance measures of the ecosystem, instances when level 1 (low risk) trigger values were reached several times, but in only a few instances the system reached level 2 (moderate risk) trigger values for the key water quality parameters. The level 1 low risk triggers were predominately observed for bottom water ammonium and DO conditions, and phytoplankton biomass and bloom frequency. Overall these occurrences were more common in the Huon Estuary compared to the D'Entrecasteaux Channel MFDP area.
- There was no evidence in the infaunal community composition of any significant organic enrichment or change in the community or sediment function.

More recently attention has focused on the potential for adverse effects on reef health as a result of increased salmonid aquaculture. Several past and current IMAS studies have investigated the influence of fish farming activities on rocky reef communities (Oh, 2009; Crawford et al, 2006). Crawford et al. (2006) undertook an analysis of changes in abundance of the seven most abundant macroalgal species for annual surveys (1992-2002) at the Ninepin Point and Tinderbox MPAs to assess whether broadscale impacts of effluent from marine farming activities could be detected. The report found no apparent patterns of changes in macroalgal community composition over the 10 year time period. Oh (2009) examined macroalgal community data at varying distances from 12 active salmonid lease areas and found that the macroalgal community composition at sites 100m distant100 m was significantly different from that at sites 5 km away in both exposed and sheltered locations. Sites at 400 m varied in their response to farms, with some sites showing characteristics similar to 100 m sites. The change in community composition observed by Oh (2009) was due to an increase in the cover of epiphytic algae and the presence of opportunistic algae, with no apparent change in the dominant canopy forming perennial algae. Crawford (unpublished data) conducted an assessment of intertidal macroalgae on rocky reefs proximal to and distal from salmon farms in the Huon Estuary/ D'Entrecasteaux Channel region and found no clear trends in abundance with distance from salmon farming. A reassessment of these sites 11 years after the initial assessment has recently been funded (FRDC CC035 Reassessment of intertidal macroalgal communities near to and distant from salmon farms and an evaluation of using drones to survey macroalgal distribution).

Several projects are currently underway to further investigate the impacts of salmon farming on reef health. IMAS FRDC project 2011/042 (Clarifying the relationship between salmon farm nutrient loads and changes in macroalgal community structure/ distribution) includes two key elements:

- Nutrient sources were added to three reef systems to assess the effects of increased nutrient availability on macroalgal community composition. No effects on canopy forming algae were detected, whereas opportunistic species (e.g. filamentous algae) proliferated where nutrients were elevated at one site but not the others. Although there was little evidence of change in macroalgal abundance, there was evidence of physiological differences in several species
- Modelling was used to assess the feasibility of growing algae in and around salmon farms in the D'Entrecasteaux Channel/Huon Estuary for integrated multi-trophic aquaculture (IMTA). The results indicate significant potential for algal growth in conjunction with salmon farming for the purposes of IMTA. However, the study also found that the location of algae culture within the system would differ if IMTA is for profit or for nutrient mitigation purposes.

Understanding the effects of farming activities on rocky reef health will also be the focus of two recently funded FRDC projects. IMAS FRDC project 2015-024 (Managing ecosystem interactions across differing environments: building flexibility and risk assurance into environmental management strategies) will investigate the broadscale interactions of salmon farming with reef systems through sediment deposition and nutrient dispersion, including the development of risk appropriate approaches for assessment and monitoring of reef health. Importantly this project involves strong stakeholder participation across the multiple users of the region (e.g. Tasmanian Rock Lobster Fishermen's Association, Tasmanian Abalone Council, Tasmanian Association for Recreational Fishing, Tasmanian Salmonid Growers Association, Tasmanian Seafood Industry Council). IMAS is also playing a key role on FRDC project (Understanding broadscale impacts of salmonid farming on rocky reef communities). This is a precursor to the aforementioned project that will analyse long term (2003-2014) MPA data sets from Tinderbox and Ninepin Points to determine whether there have been any broadscale changes associated with the development of the salmon industry over the corresponding period. The project will also resurvey reef communities at 11 locations throughout south east Tasmania.

The aforementioned work is largely directed at investigating the impacts of organic matter and nutrient emissions from fish farming on environmental health; however, several other issues have arisen in recent years, namely concerns regarding environmental effects associated with the use of both antibiotics and antifoulants. Antibiotics and antifoulants are used in aquaculture operations to ensure the health and well-being of farmed stock. Antibiotics are used as a direct response to infectious diseases, whilst antifoulants have been needed to counteract bio-fouling, a condition which is a significant problem to the local marine farming industry and reduces water flow and oxygen supply in the cages, increasing stress levels, and hence disease susceptibility in the fish. MacLeod and Eriksen (2009) conducted a review of the ecological impacts of the antibiotics and antifoulants currently used in the Tasmanian salmonid industry. Current data indicate that water column concentrations of antibiotics are extremely low and consequently impacts on phytoplankton communities are likely to be limited. The testing of wild fish with respect to human health toxicity showed no risk to human health. The review suggested that although major environmental changes are unlikely to have occurred, identification of suitable indicator species would be valuable to ensure ongoing sustainability. It also suggested that where antibiotics are used, a measure of bioavailability rather than simply a measure of total residue level would be preferable, and that the effect of local environmental conditions (i.e. oxic status, temperature, pH, and salinity) on ecotoxicity be assessed. For antifoulants there didn't appear to be major acute effects of antifoulant release in the water-column, but this was based on the limited data available at the time. The review suggested the greatest risk is likely to be the potential for build-up of copper and zinc in the sediments around the farms. FRDC project 2011-041 subsequently conducted a detailed assessment of the environmental impacts and remediation potential associated with copper contamination from antifouling paints (MacLeod et al., 2014). The study found that the proportion of the total copper concentration that is potentially bioavailable was likely to be relatively small. Toxicity testing showed no evidence of acute toxicity effects due to farm derived copper inputs nor was there any evidence of any significant changes in benthic community composition or ecosystem function. However, there was potential for chronic toxicity and adjustments to the current monitoring requirements were proposed to ensure the trigger values are not exceeded. The report also reported no evidence of recovery in sediment copper concentrations from an evaluation of farm data (>5 years), but the results of long cores suggest potential for recovery over the long term. It should be noted that the industry has implemented many actions due to the findings of this study, including making the decision to replace all nests coated with copper based antifoulants; this process is now complete.

IMAS research has been integral in identifying impacts to date and has responded directly to the needs and expectations of the industry, government, and the broader community. This continues to be the case with future planned research focusing on those areas of current concern. Development of Macquarie Harbour has been a key component of the industry's strategic growth plans. A draft amendment to the Macquarie Harbour MFDP and accompanying Environmental Impact Statement was submitted to the Tasmanian Government in late 2011, and State approval was granted in mid-2012. This Plan provides for a 64% increase in lease area from a current total of 564 ha to 926 ha. IMAS conducted the zone assessments for these new development areas. During and subsequent to the approval process multiple concerns have been raised regarding the potential for adverse interactions between salmon farming and the environment. Consequently, IMAS has been involved in several research projects to better understand the environmental interactions of salmonid aquaculture in Macquarie Harbour, and to help inform monitoring and management strategies.

A key knowledge gap identified during the approval process was a lack of data on the capacity of Macquarie Harbour sediments to process organic matter and nutrients, particularly given the expectation of increased localised organic loads associated with expanded farming. As a consequence, there was concern that these processes be adequately captured in the environmental model that is being used to assist decision making in the Harbour. A recently completed IMAS study has quantified sediment - water column nutrient fluxes at both the farm (local) and harbour (regional) scales. These data were used to provide re-calibration data for sediment - water column interactions in the Macquarie Harbour environmental model and to identify ecologically relevant and practical indicators of key ecosystem processes (FRDC 2012-047; Ross et al., 2014). This study demonstrated the importance of anaerobic processes and the production of reduced compounds to the benthic biogeochemistry of the harbour, particularly at farm enriched sites. The impact of farm derived enrichment on benthic processes is consistent with expectations based on similar assessments (e.g. increases in oxygen consumption, carbon dioxide, and ammonia production, and a decrease in denitrification efficiency) in other farming regions in Tasmania and overseas. However, some, but not all sites showed response patterns consistent with expectations during fallowing and stocking. The anomalous results suggests that drivers other than stocking (e.g. changes in diet, conversion ratios, feeding regimes, bottom water conditions) may play a role in determining sediment condition and therefore further investigation of these underlying mechanisms is needed. Interestingly, a significant decline in bottom water oxygen was observed during the later stages of the study and the cause of this and the implications for broader ecosystem dynamics warrant further investigation. Ross and Macleod (IMAS) are members of a working group established by the Tasmanian Salmonid Growers Association to investigate the oxygen decline and likely causes.

In recent months a significant change in the abundance of Dorvilleid polychaetes has been observed, particularly on central harbour sediments. In Macquarie Harbour, Dorvilleids were considered to fit the same functional role as the taxa previously defined as a relevant environmental trigger of organic enrichment in the south (i.e. Capitellids); however, the relationship between Dorvilleids and the level of enrichment was not explicitly tested in this region. IMAS has commenced a project (FRDC 2014-038) to review the current understanding of Dorvilleid ecology, and in particular, their response to organic enrichment as well as their current use as indicator of the impacts of finfish aquaculture. Preliminary results suggest that Dorvilleids can be effective indicators of organic enrichment and sediment condition in Macquarie Harbour, although their sensitivity to enrichment may differ to that observed for Capitellids in the southern farming regions. This information will be used to inform benthic monitoring requirements in Macquarie Harbour. The research outputs from this project will also feed directly into FRDC project 2015-024 (Managing ecosystem interactions across differing environments) that will provide a comprehensive assessment of whether the current on-farm monitoring approach and local scale impact benthic indicators are “fit for purpose” in Macquarie Harbour.

As documented in the Environmental Impact Statement prepared for the assessment of the expansion in Macquarie Harbour, the increase in production will result in an increase in nutrients – nitrogen and phosphorous – from salmon farming waste products into the environment. These nutrients have the potential to increase primary production of micro and macro-algae in the Harbour; however, the extent of increased production and the potential for eutrophication of the system is not fully understood. Macroalgae are largely restricted to the intertidal zone in Macquarie Harbour because light can only penetrate a short distance into the darkly coloured tannin waters. To establish a baseline against which the effects of proposed increases in salmon production on macroalgal composition and abundance can be assessed, Crawford et al., (2013; FRDC 2011-086) surveyed the distribution and percentage cover of common macroalgal species at 40 sites throughout the Harbour in autumn and spring 2012.

IMAS is currently investigating (FRDC 2013/008) the movement, habitat utilisation, and population status of the endangered Maugean Skate in Macquarie Harbour and the potential impacts of current and proposed marine farming operations. The spatial and temporal dispersal patterns of salmonid escapees in Macquarie Harbour and strategies to reduce the probability of encountering Maugean skates whilst fishing (gillnetting) for farm escapees are also being evaluated. To address these objectives an acoustic array was deployed in Macquarie Harbour from October 2013 - February 2015 to track the movements (location and depth) of 59 Maugean skates, and of 30 released Atlantic salmon and 30 rainbow trout, all fitted with acoustic tags. Seasonal sampling was conducted to determine size at maturity and reproductive cycle (blood biochemistry and ultrasound), diet, and population genetics. Tag recapture rates are being used to estimate population size and physiological experiments were conducted to assess impacts of low DO on metabolism. Preliminary findings indicate that some Maugean skate move widely throughout Macquarie Harbour, while others appear to be more site attached and the vast majority of their time is spent in the 6-15 m depth range, although some individuals moved into deep (>40 m) or very shallow water (<1 m). Data suggest a diurnal pattern of movement, with individuals tending to move into shallower water and exhibiting increased activity during the night. Environmental data collected as part of the project are being analysed to examine how factors such as salinity and DO influence patterns of behaviour. The diet of the skate appears to comprise mainly of invertebrates (crabs and shrimps), with no evidence of feeding on salmon feed pellets. Although population size estimates are not yet available (to be informed by our tagging plus genetics data) it is clear from the catch rates that the population is substantially larger than the ~1000 individuals suggested in the past. Information on farmed stock escapees demonstrate rapid dispersal from their release sites and movement throughout the harbour. With few exceptions, escapees tended to be detected for less than 3 months, implying that most do not survive for long, although six Atlantic salmon and one rainbow trout were last detected at the entrance to the harbour implying movement out of the harbour while three rainbow trout were last detected at the mouth of the Gordon River. Examination of the stomach contents of escapees caught in gillnets, provided very little evidence of feeding on natural fauna. This is consistent with a previous IMAS study that examined the stomach content and body condition of escapes in Macquarie Harbour (Abrantes et al., 2011).

(d) the interaction of state and federal laws and regulation;

IMAS has been involved in several projects addressing marine governance and this remains a research focus for IMAS. An IMAS-led project, the FRDC-funded 'Meeting sustainability expectations: translating and aligning objectives, reporting and evaluation of the performance of Australian fisheries' project (FRDC 2013/204), is examining the consistency of management systems (across policy, management objectives and strategies, operational frameworks including regulation, and performance assessment and reporting frameworks) for Australia's key marine resources, and the extent to which goals and objectives of management align with the Australian community's expectations of sustainability. The scope of this research includes wild capture fisheries but not finfish aquaculture directly.

Preliminary observations from this and other research (Colquhuon and Archbold, 2009) propose that the legislative objectives of the Living Marine Resources Management Act 1995 (LMRMA) are broad in their design and encompass potentially conflicting objectives - protection of marine areas and habitats and use and extraction of marine resources for commercial and recreational purposes. However, the LMRMA does not directly address the balance (trade offs) between these dual purposes and multiple sectors in allocating and managing resource access and use. This is the function of policy.

The LMRMA incorporates the objectives of Tasmania's Resource Management and Planning System (RMPS) (Schedule 1) and includes the objective of sustainable development of resources. Ensuring the RMPS objectives are operationalized in the context of finfish aquaculture, the whole of system cumulative impacts, and interactions between all marine sectors is not currently a function of the LMRMA or State legislation, but relies on policy. The specific interaction between the LMRMA and finfish aquaculture consists of: authorisation of marine farming licenses, licensing and permitting of other marine resource uses (fishing) and declaration of marine resources protected areas.

The legislative objectives of the Marine Farming Planning Act 1995 (MFPA) encompass both the sustainable development and the regulation of the industry. The objectives of the Act include integration of aquaculture with other marine uses (objective a). Objective (c), which is to “set aside areas for activities other than for marine farming activities” is an operational objective which enables (a) to be addressed. The Act established the Marine Farming Planning Review Panel which serves an important role in considering draft plans, amendments to plans and environmental impact statements, and in making recommendations to the Minister.

A further IMAS-led project, the Your Marine Values study (stage 1 of the FRDC-funded project ‘INFORMD2 Stage 2: Risk-based tools supporting consultation, planning and adaptive management for aquaculture and other multiple-uses of the coastal waters of southern Tasmania’ 2012/204), used public values mapping techniques to identify the values held by local communities, user groups, community organisations (including environmental groups), commercial fishing and marine tourism sectors, and the marine farming sector (finfish and shellfish) for the marine environment and ecosystem services of the D’Entrecasteaux Channel and lower Huon estuary in south-eastern Tasmania. The seventeen key values identified were then mapped to current legislation and policy which addressed those values.

This study highlighted for stakeholders that there are 19 current Acts, policies and strategies at Local Government, State and Federal levels which address the identified public values. A number of Federal Acts have jurisdiction over ecological values affected by marine farming, and these interactions are identified and triggered through the environmental impact statements developed for Marine Farming Development Plans (as required by the MFPA). These include:

- Water Quality and Sediment Quality (specifically, impacts associated with use of antibiotics) – Agricultural and Veterinary Chemicals (Administration) Act 1992 and the Agricultural and Veterinary Chemicals Code Act 1994.
- Marine Communities and Marine Species (specifically, communities or species which are listed or deemed of national significance) – the Environmental Protection and Biodiversity Conservation Act 1999

A key aspiration identified by all sectors (communities, industry and government) relating to the management of identified public values was the need for streamlining of governance arrangements through identification of equivalence in meeting regulatory conditions, and through the development of regional-level integrated management arrangements with statutory authority over resource management.

(e) the economic impacts and employment profile of the industry;

IMAS has conducted research on the ways that communities in Australia and elsewhere receive economic benefit from the use of community resources such as wild fish stocks, or in the case of finfish aquaculture, areas of seabed (e.g. McGarvey et al., 2011, Hartmann et al., 2012, Gardner and Emery, 2014). In some cases, a regulated mechanism ensured that the community benefited from these operations, such as by royalty payments, lease fees, community quota, and systems to maximise employment. However, in most cases no regulated system exists to ensure community benefit; instead, the only benefits accrued are regional economic impact (at the state level) and company tax (at the Commonwealth level). Where these benefits are not regulated, they can be reduced.

A PhD study is currently underway examining the economic implications of options for expansion of salmonid aquaculture in Tasmania (Seafood CRC Project 2011/735). This study is developing an options analysis and decision support framework to support the industry in assessing alternative production technology options. The project will develop a conceptual framework for objectively evaluating possible expansion options and considering the specific constraints relevant to the Tasmanian salmonid industry. The first stage of this research provided a critical review of possible strategies and an economic analysis of those options using “stylised” but conceptually relevant industry data, producing a comparison of financial performance and risk. The final stage of the project will deliver a framework of complementary decision support approaches to enable decision-makers to better understand the factors influencing aquaculture development, and examine alternative production (grow-out) technologies that more effectively address the challenges associated with intensification and expansion. This project is due for completion in mid-2015.

The potential impacts of climate change on the salmonid farming industry (including economic implications) were detailed by Battaglene et al. (2008); this is commented on further in section (f).

(f) any other relevant matters.

There will inevitably be gaps in our understanding, and the ability to address these will depend on the level of risk and concern associated with each particular issue, and availability of resources. Resources for research are allocated according to a range of prioritisation metrics: but these generally include factors such as environmental, community and industry significance, as well as economic and political imperatives. There are a variety of mechanisms for identifying and prioritising concerns (both in a regulatory compliance context and in more general matters) and perhaps this process needs to be clarified.

<u>Climate change and finfish aquaculture</u>

The potential impacts of climate change on fisheries and aquaculture (Hobday et al., 2008) and specifically on marine farming of salmonids (Battaglene et al., 2008) have been assessed in previous reports. Battaglene et al. (2008) documented potential effects on salmonid health and on growth and nutrition before discussing alternative species and solutions. Without any change in practices, increased seawater temperature is likely to decrease production through increases in thermal stress and disease events and decreases in feed intake and growth. The industry is currently addressing these issues in various ways including changing farm management practices, site location, and selective breeding. A lack of knowledge about the performance of large salmon in cages was highlighted as an area to address. This emphasised the need for a local research facility to work on large salmon; the Experimental Aquaculture Facility at IMAS is slated to become operational by late 2015.

Tasmania is a climate change hot-spot; IMAS identified the issue of nutrition under sub-optimum conditions and has done world leading research on the interaction between nutrition and climate change effects, particularly temperature (summarised in Carter et al. 2002, 2005, 2008, 2010). Research has informed international models on salmon growth, redefined nutrient requirements, identified nutrition-health-environment interactions, and investigated how temperature impacts on flesh quality and therefore affects the value of aquaculture product to human nutrition. IMAS has shown that protein requirements, and therefore amino acid requirements, of salmon increase with increasing temperature and with decreasing dissolved oxygen (DO). IMAS has shown that increased temperature will decrease the content of essential omega-3 fatty acids in salmon (Miller et al. 2006). IMAS-led research (Carter et al. 2008; Katersky et al. 2011) has also shown that critical climate change responses by salmon may differ according to size, sex, and ploidy (number of sets of chromosomes in a cell).

IMAS has had an enduring program on the development of species for Tasmanian aquaculture; species have included trout and salmon as well as several marine species, most notably spiny rock lobster, striped trumpeter, and greenback flounder. IMAS has several major advantages in this field: facilities, history, current expertise, and a large diverse pool of research staff with broad expertise to apply to any problem area. The approach taken is to combine concurrent development of technology with understanding the biology of the species under culture conditions.

In relation to finfish aquaculture, as a climate change hot spot Tasmania experiences climate change effects before and more intensely than other regions. It therefore has the opportunity to act as a global “research facility” and thereby advantage local industry and the state through first user status. The Experimental Aquaculture Facility will support this vision.

Future-proofing finfish aquaculture in Tasmania

The expansion of finfish aquaculture in Tasmania needs to consider a long-term strategic approach to economic and environmental sustainability. Key components include: salmonid stock improvements through selective breeding program, alternate species to salmonids, new technology, sustainable feed production maximising local ingredient use, and optimising whole ecosystem use. Globally aquaculture is recognised by institutions such as the World Bank as having the potential to be a major component in addressing food security. Access to land and water are major restrictions and new technology around offshore structures and onshore recirculation technology are advanced as vital. Expansion of finfish aquaculture in Tasmania needs to incorporate a strategic view about development and adoption of new technology (see section TOR (d)). The local economy can benefit from this with local companies working on developing the technology including software.

IMAS has been engaged in the development of species new to aquaculture for several decades, including examination of the potential for salmonid and oyster aquaculture in the 1980s, and additional and alternate species since then. Planning for the finfish aquaculture industry should consider how to incorporate continued investigation of alternative species. The State Government strategically invests in this, currently in collaboration with the University via the SMRCA (Sustainable Marine Research Collaboration Agreement).

Expansion of finfish aquaculture, regardless of species, requires expansion of feed production. This is a significant challenge because of the increasing cost and uncertainly of importing key ingredients, principally fishmeal and fish oil, from South America. This also presents a significant opportunity to increase the use of local ingredients in feeds and reduce the use of imports, Australia has access to a range of key ingredients and specifically to grains, legumes, fisheries by-catch, and rendered and milk-based proteins from terrestrial animal production. There are many advantages of this approach: greater control over supply (in a world where competition for commodities is increasing), lower cost, and local economic stimulation. Australia needs a research program on the use of ingredients in feeds, because much has changed since previous programs. Australia has potential large new ingredient sources from marine algae, insects, and fishery by-catch as well as local cereals that can be bred with more suitable characteristics for aquafeed. Australia also needs to determine whether to use genetically modified organisms as ingredients in feeds.

Australian finfish aquaculture products are highly advantageous for human nutrition and thereby contribute to national food security, particularly for older and younger people. Important nutrients provided by finfish are essential fatty acids, protein, and essential vitamins and minerals. Feed composition can impact on product quality and several areas of research are required to maximise the nutritional value of finfish aquaculture product. Reduction and replacement of South American fish oil is a long term industry goal, and IMAS provides the facilities, researchers and students that can progress this (e.g. Miller et al.2008a, b; Codabaccuss et al. 2012a, b). IMAS and the University, through the Food Innovation Centre, have capacity to support the expansion through understanding how to manage product quality.

To improve finfish growth and decrease the waste of valuable feeds, topical research is required. This research should be applied, involve teams, and be done on appropriate sized fish. Australia is a world leader in this field due to a combination of many research leaders, innovative feed producers, and a research literate aquaculture industry. IMAS has the capacity to link nutrition research with environmental researchers, feed producers, and the aquaculture industry to improve model inputs and outcomes and direct feed formulation and practice. Furthermore the Experimental Aquaculture Facility will provide a unique site in Australia to conduct the research.

Integrated multi-trophic aquaculture (IMTA) combines aquaculture species to maximise production through additional production. A simple example would be to locate a farm for filter feeding bivalves, e.g., mussel or oysters, near a salmon farm on the basis of increased primary production to provide extra food for the filter feeders. This is a complex area that is relatively new and requires considerable research, ranging from establishing overriding principles to optimising the species mix according to local conditions. However, some preliminary research has already been conducted by IMAS in this area and several research ideas are currently being developed – see details of IMAS IMTA study in section (a).

<u>Education to support -fish aquaculture</u>

Expansion of the finfish aquaculture industry will require a coordinated approach to workforce development. Tasmanian education and training providers are well known to each other and can integrate to provide different pathways in relation to industry and societal needs. IMAS has relevant pre-degree, undergraduate, and post-graduate courses, and works with other providers such as high schools and Seafood Training

Tasmania. As the only university in Tasmania and one that is involved in Tasmanian education, UTAS is ideally placed to work with industry and other stakeholders to ensure the required workforce.

Research to support finfish aquaculture

Infrastructure - IMAS and the University of Tasmania have considerable research infrastructure. IMAS has laboratories at all three of its campuses and aquaculture research facilities for experiments on live animals at IMAS-Taroona and IMAS-Launceston.

Boats and Diving – IMAS-Taroona. IMAS maintains a fleet of inshore vessels and equipment for survey work and manages the University's scientific diving program.

Aquaculture Centre – IMAS-Launceston. The main foci of research are aquatic animal health, biosecurity, and welfare. These strengths consider staff expertise and location near the DPIPWE Fish Health Unit at the state's Mount Pleasant laboratories. The Aquaculture Centre meets needs for student research projects and teaching, and consequently focuses broadly across freshwater-marine, temperate-tropical, numerous species, and short experiments with smaller animals. Proposed investment in the University in Launceston mean there is opportunity for development and to further integrate capability across IMAS.

Aquarium – IMAS-Taroona. This comprises a state-of-the-art marine hatchery and a hatchery water treatment facility. It is currently dedicated to research on rock lobster hatchery and nursery production, with a focus on pre-commercial scale-up, health, and nutrition. It also used seasonally for the production of different genetic lines of oyster spat for Australian Seafood Industries and an oyster selective breeding program.

Experimental Aquaculture Facility (EAF) - IMAS-Taroona. Phase 1 of the EAF is under construction; it is designed to house large production sized salmon and provides a unique facility in Australia. It will focus on salmon nutrition and health research through an industry partnership. Recirculation aquaculture system (RAS) technology will be used and provide a research tool in this important field. Phase 2 will include a new seawater pump station and a controlled environment room for aquaculture-environment research. Phase 2 is not funded and requires investment. It; it will support a major research requirement that underpins the expansion of finfish aquaculture.

People - Research informs marine farming planning, management, regulation and the understanding of their impacts. Research is required across multiple disciplines to understand key components of industry including improving production, use of technology, managing environmental change, animal welfare, and values that society places on regulation. Furthermore, it incorporates expertise in social science, economics and the law. Integrated organisational structures facilitate a team approach to addressing important issues including the expansion of finfish aquaculture in Tasmania. IMAS has considerable research expertise and capacity to address the needs of finfish aquaculture.

Appendix – Project Summaries and References

To assist the committee, summaries of the main IMAS reports are provided below and all of the documents associated with, and referred to, in this submission have been collated and can be found on the IMAS website (http://www.imas.utas.edu.au/research/senate-enquiry).(www.imas.utas.edu.au).

Summary of IMAS Research Projects Related to Salmon Farming/ Environmental Impacts Assessment / Waterway Health in SE Tasmania

TAFI Technical Report (Completed 2002): Evaluation of Techniques for Environmental Monitoring of Salmon Farms in Tasmania (2002) Crawford, Macleod & Mitchell

This study was commissioned by the Tasmanian government (DPIW) to assess several environmental variables/techniques for their suitability (i.e. are practicable, inexpensive, and scientifically credible) as indicators of organic enrichment from salmon farms and for inclusion in an industry wide monitoring program.

The general conclusion was that no one variable was sufficiently reliable as an indicator of environmental condition, and that several variables should be routinely monitored. Also, the monitoring program should be regularly assessed and improved as more data become available. Of the physical/chemical variables investigated, only redox was considered to be suitable. Organic matter, as measured by Loss on Ignition, was found to be highly correlated with sediment particle size but not with the level of organic input, and %C and %N were suitable indicators of organic matter only at very high concentrations. Similarly, stable isotopes of nitrogen and carbon in fish food were effective indicators only at high levels of organic enrichment. The community structure of the macrobenthic invertebrate fauna was found to be a sensitive and reliable measure of sediment condition. Multivariate analysis of the data was able to separate the fauna into major, moderate, and minimal impact levels. In degraded conditions, the ubiquitous polychaete, *Capitella capitata* sp. complex, occurred at very high densities and may be suitable as an indicator species.

Identification of organisms to family level was found to be sufficient to show levels of organic enrichment; however identification to species level provided more subtle information on the condition of the sediment. The number of benthic infaunal samples required to reliably assess an impact was suggested to include monitoring at fixed sites, at sites that have been determined to have had relatively high levels of impact and at several reference sites.

Video recordings were found to be suitable for a monitoring program because they provide a relatively inexpensive, instant, permanent record of sediment conditions that is readily interpreted by stakeholders. Degraded conditions were clearly evident in the video footage, in particular from the presence of Beggiatoa bacterial mats, black sediments, waste food and faeces, and from the decline in macroalgal cover at specific locations. Video recordings identified severe impacts similar to the macrofauna, but moderate levels of impact were not so obvious.

The findings of this report were integral to the development of the current Marine Farm Monitoring program.

TAFI Technical Report (Completed 2002) Evaluation of Sediment Recovery After Removal of Finfish Cages from Marine Farm Lease No.76 (Gunpowder Jetty), North West Bay. (Macleod et al., 2002)

This study was a joint initiative of the aquaculture industry (Aquatas Tasmania Australia Pty Ltd) and the Department of Primary Industries, Water and Environment (DPIWE) with the aim of assessing the rate of sediment recovery and identifying biological/ biogeochemical indicators of improvement over time after a farm was vacated.

The results indicate that although the cage sediment was highly impacted at the time of cage removal the extent of impact diminished rapidly with both time and distance from the cages. The influence of the cages was not generally detectable beyond 35m and after 2 months conditions could be classed as transitional. At the end of the study (24 months), although the sediment biogeochemistry appeared to have recovered, the benthic community structure within the lease still differed significantly from that of reference stations.

There findings of this research have been published in:
- Macleod et al., 2004a; Macleod et al, 2008

Visiting Scientist Project (Completed 2003) - Detection of organic enrichment near finfish net-pens by sediment profile imaging (SPI)

In 2002 Dr David Wildish, an internationally renowned environmental researcher from Canada with particular expertise in the impacts of mariculture visited Tasmania. He collaborated on a project to assess the viability of using sediment profile imagery as a means to monitor salmon farm impacts. The findings indicated that, although SPI was very effective at detecting organic enrichment, the application was limited to soft sediments and there were technical difficulties that would need to be resolved before it could be generally applied in the Tasmanian context - See Wildish et al. (2003) for more details.

Aquafin CRC Project 4.1 (Completed 2004) Development of novel methods for the assessment of sediment condition and determination of management protocols for sustainable finfish cage aquaculture operations. (Macleod et al., 2004b)

Organic enrichment of the sediments is one of the most significant impacts from caged fish farming. However, the effect that differing farming practices, such as rotational farming/fallowing, have on the level of impact, or the effect that different background environmental conditions may have on overall impact was less clearly understood. This project was initiated to assess the rate of recovery associated with fallowing practices, to determine if current farming practices were sustainable and to identify indicators of sediment degradation and recovery that could be used by farmers to gauge the environmental status of the sediments within their lease and make appropriate management decisions.

This research showed that although finfish aquaculture significantly affected the sediments under the cages, it was possible to manage sediment conditions to ensure that ongoing farming can be sustained. The research found a clear relationship between farm management practices and level of impact, and identified 9 distinct stages of sediment condition that could be used to enable farmers to easily classify sediment condition.

Several established environmental monitoring approaches were found to be poor indicators of sediment recovery, although useful measures of sediment degradation. Semi-quantitative video assessment was determined to be the most effective approach for simple farm-based assessment of sediment condition. When linked with farm data, the condition of a lease can be reviewed in a management context and informed management actions undertaken. Furthermore, when video footage is assessed with farm data it is possible to categorise the sediment condition to a particular stage and also predict the likely future classification on the basis of the proposed farming schedule. If there is any uncertainty as to the classification resulting from the visual assessment, the findings could be validated with infaunal grabs and subsequent evaluation of key species. Other approaches (e.g. redox/sulphide, signature lipid analysis, microbial status) can be undertaken if a greater sensitivity or understanding of the system processes is required. It is important to note that the proposed protocols were developed specifically in relation to on-farm monitoring, and were not intended for regulatory or compliance purposes although the findings have informed ongoing monitoring.

There were several research publications associated with this project
- Macleod et al., 2007; Macleod et al, 2006; Bissett et al., 2009

Aquafin CRC Project 4.1 (Extension) (Completed 2004): Development of a field guide and associated training to facilitate rapid transfer of the outcomes of CRC Project 4.1 to marine finfish farms in Tasmania. (Macleod & Forbes (eds), 2004)

The application of the recommended techniques is fully described in an interactive farm field guide that was developed as an extension of this project. The field guide & associated training fully explains the sampling procedures and analytical techniques underpinning the visual assessments (Macleod et al., 2004).

The research undertaken as part of the Aquafin CRC has significantly informed the understanding of environmental interactions with salmon farming.

TAFI Internal Project (Completed 2005) Broad-scale effects of marine salmonid aquaculture on macrobenthos and the sediment environment in southeastern Tasmania (Edgar et al. 2005).

This study investigated several key biotic and abiotic metrics recommended in previous studies for assessing environmental impacts of fish farm waste to determine those most effective for discriminating fish farm impacts at different distances from cages, with emphasis on those able to distinguish more distant effects. The study compared sediments and associated macrobenthos at sites sampled within 20 fish farm leases distributed across southeastern Tasmania and identified major natural changes along a regional cline. Introduced taxa were strongly represented in the fauna, comprising 45% of total macrofaunal biomass. Large differences were evident between sites affected by different levels of organic farm waste. Sites located adjacent (<10 m) to farm cages had significantly depressed sediment redox levels, a dominance of opportunistic (capitellid and dorvilleid) polychaetes, and low macrofaunal species richness. Subtle impacts extended across farm lease areas in the form of depressed redox potential at 40 mm depth and consistent changes to the macrobenthic community. Minor farm effects were also evident at sites sampled 35 m outside farm lease boundaries, most notably as elevated population numbers of the polychaete *Terrebellides* sp., bivalve *Mysella donaciformis* and heart urchin *Echinocardium cordatum*. Amongst the univariate metrics examined, redox potential at 40 mm depth and the ratio of bivalves to total molluscs provided the most sensitive indicators of farm impacts, with the latter metric relatively insensitive to spatial variation between locations within the region studied.

NHT/NAP Project No. 2003/050 (Completed 2005) - Ecological Status Of The Derwent And Huon Estuaries (Macleod and Helidoniotis, 2005)

This study was undertaken to provide baseline information on the ecology of the two main estuaries in southern Tasmania with the intention of assisting in the ongoing management of these systems. The Derwent and Huon estuaries are similar in their biogeographical, climatic and physical characteristics but differ markedly in their levels of industrialisation and impacts. The Derwent Estuary is highly impacted with several major industrial and urban contamination sources throughout its catchment. Heavy metals in particular, represent a considerable threat to the system. In contrast the Huon Estuary is largely unimpacted, finfish aquaculture being the only major industry affecting the system. Both the Derwent and the Huon estuaries are strongly depositional with the majority of the estuaries composed of soft sediments. Information on the benthic ecology is an essential pre-requisite to any effective management strategy. Accordingly, baseline information on the current biological condition of these systems was collected.

This study found similarities in the pattern of community distribution along the estuaries. In neither system were there any areas where fauna was completely absent, in fact diversity was high throughout most of the sample sites. The faunal community in both estuaries was most strongly related to the natural geomorphology and salinity gradient of the estuaries, and in turn to the depositional character of the system and the organic content. Changes throughout the estuaries were gradual but several discrete communities were identified within each estuary and the species which most strongly characterised these communities are described. The community distribution in the Derwent was slightly more complex than the Huon, as in addition to the natural gradient there were also multiple anthropogenic gradients. Prior to this study it was anticipated that the extremely high concentrations of metals throughout the Derwent would be the most significant structuring influence on the ecology of the system. However, the results show that metal contamination was not the overriding determinant of benthic infaunal community composition, although both organic enrichment and metal contamination had a significant influence on the community structure in localised areas.

The biological information provides an important resource for researchers and managers. It represents a baseline ecological reference for any future assessment of sediment condition and ecological status. The study defines species indicative of communities characterising particular regions within the system. These biological zonation patterns will enable environmental managers to locate biologically relevant monitoring sites and to evaluate improvements and deterioration in the estuarine condition both spatially and temporally. This study mapped the current status of invasive species in both estuaries providing a point of reference to monitor and manage their spread and distribution. Examination of the environmental preferences of these species suggests that in general their environmental tolerances are broad and that range extension is more likely to result from opportunity and reduction in competitive pressure rather than any particular environmental preference. This has significant implications for the management of these ecologically and potentially economically important species. Although this study was specifically focussed on the Derwent and Huon estuaries, the findings can be applied in a much broader spatial context. Comparison of the faunal information for the lower estuary regions with other local studies suggests that the community characterisation would be applicable to other estuaries in south-eastern

Tasmania. The general response of the main species and infaunal community groups to metal contamination could potentially be applicable throughout southern temperate Australia, whilst the functional community response and invasive species information has even wider application.

Aquafin CRC Project 4.2 - FRDC Project No. 2001/097 (Completed 2009): A whole-of-ecosystem assessment of environmental issues for salmonid aquaculture. (Volkman et al., 2009)

This project has established a detailed set of data and provides a good picture of the environmental conditions in the Huon Estuary and D'Entrecasteaux Channel. The findings suggest that environmental conditions are generally good with occasional periods of high phytoplankton abundance and low DO. These data have been used to calibrate and validate a suite of sophisticated 3-dimensional hydrodynamic and biogeochemical models of the region that capture the main physical and biological processes. Specific process studies were carried out to illuminate particular aspects of the nutrient-phytoplankton-zooplankton relationships and sediment biogeochemistry. Technical reports providing the details of these studies are provided separately and are listed below.

A major goal of this research was to design a monitoring program with the capacity to detect the effects of those processes judged to be most threatening to the Huon and D'Entrecasteaux ecosystem at the whole-of-ecosystem level. The monitoring program proposed is designed to provide knowledge of how well the ecosystem is functioning with an increased nutrient load and to allow any significant temporal trend(s) in ecological indicators to be detected. A major challenge was converting indicators of ecological condition into recommended quantitative performance measures that can be used in a regulatory manner to adaptively manage the ecosystem. These recommendations have been extensively discussed with industry and DPIW representatives and refined through an iterative process.

The measurements and modelling results obtained indicated that the salmonid industry is a significant contributor of nutrients to this region and that these have led to measureable increases in phytoplankton abundance. As a result, the industry is reaching a size where significant further expansion in the same region could lead to deleterious environmental effects.

The information generated as part of this project has been used by the marine farming planning review board to impose a limit on the salmonid industry in the Huon and D'Entrecasteaux based on the industry's projections for salmon production in 2009. This decision was informed in part by the scenario of likely effects on phytoplankton populations produced by our project using the environmental modelling suite. If the industry is to expand further it will either have to demonstrate that it is not having serious environmental impacts (which can only be achieved by a comprehensive monitoring program of the type suggested by the project), or place new production outside of the Huon Estuary and D'Entrecasteaux Channel or find ways to reduce or ameliorate nutrient inputs (e.g. by polyculture, although this study has suggested that this would not assimilate all the nutrients produced by the salmonid industry).

In summary, this project has generated considerable knowledge of the possible environmental effects of salmonid aquaculture at an ecosystem level and led to the development of the monitoring and modelling tools that can be applied to other fish species or to other regions. The research has been materially assisted by the industry's support for this project and their demonstrated commitment to ensuring the environmental sustainability of their operations. Also, the involvement of staff from the Tasmanian Department and Primary Industries and Environment (DPIWE, now DPIW) Marine Farming Branch was essential to ensure that our research was relevant to the effective regulation of salmonid farming in Tasmania

The detailed technical reports that were produced in conjunction with this project are listed below:

- Herzfeld, M. Parslow,J., Sakov, P. & Andrewartha, J. Numerical Hydrodynamic Modelling of the D'Entrecasteaux Channel and Huon Estuary - July 2005
- Thompson, P. & Bonham, P. Effects of grazing by microzooplankton on phytoplankton in the Huon Estuary. CSIRO Marine and Atmospheric Research - July 2005
- Thompson, P., Bonham , P., Willcox, S., Crawford, C. Baseline monitoring in D'Entrecasteaux Channel. CSIRO Marine and Atmospheric Research & Tasmanian Aquaculture and Fisheries Institute, University of Tasmania - July 2005
- Thomson, D., Volkman, J., Burke, C., & Purser, J. Sediment Biogeochemistry of the Huon Estuary – July 2005.
- Wild-Allen, K., Parslow, J., Herzfeld, M., Sakov, P., Andrewartha, J. & Rosebrock, U. Biogeochemical Modelling of the D'Entrecasteaux Channel and Huon Estuary - July 2005
- Volkman, J., Parslow, J., Thompson, P., Herzfeld, M., Wild-Allen, K., Blackburn, S., Crawford, C., Bonham, P., Holdsworth, D., Sakov, P., Andrewartha, J. & Revill, A. System-wide environmental issues for sustainable salmonid aquaculture - January 2006
- Bonham, P., Rousseaux, C. & Thompson, P. Effects of grazing by microzooplankton on phytoplankton in the Huon Estuary and D'Entrecasteaux Channel - June 2008
- Clementson, L., Blackburn, S., Berry, K. & Bonham, P. Temporal and spatial variability in phytoplankton community composition in the mouth of the Huon River Estuary - June 2008
- Clementson, L., Blackburn, S., Thompson, P., Berry, K. & Bonham, P. Phytoplankton comm unity composition during spring blooms in North West Bay and Port Esperance, Tasmania - June 2008
- Herzfeld, M. Numerical Hydrodynamic Modelling of the D'Entrecasteaux Channel and Huon Estuary: Phase II - April 2008
- Holdsworth, D., Revill, A., Volkman, J. & Swadling, K. Lipid biomarkers in sediment traps and sediments from North West Bay, Tasmania - June 2008
- Macleod,C., Revill, A., Volkman, J. & Holdsworth, D. Characterisation of the benthic environment of the D'Entrecasteaux Channel and Huon Estuary - July 2008
- Macleod,C. & Foster, S. Evaluation of selected alternative approaches for monitoring nutrient enrichment associated with caged marine salmonid aquaculture in Tasmania - July 2008

- Revill, A., Holdsworth, D., & Volkman, J. Fluxes of organic matter and lipids to sediments in the Huon estuary - June 2008
- Swadling, K. , Macleod,C., Foster, S. & Slotwinski , A. Zooplankton in the Huon Estuary and D'Entrecasteaux Channel: community structure, trophic relationships and role in biogeochemical cycling - July 2008
- Thompson, P., Wild-Allen, K., Macleod, C., Swadling, K., Blackburn, S., Skerratt, J. & Volkman, J. Monitoring the Huon Estuary and D'Entrecasteaux Channel for the Environmental Effects of Finfish Aquaculture - June 2008
- Wild-Allen, K. Huon Estuary and D'Entrecasteaux Channel Biogeochemical Model Scenario Simulations for 2002 and 2009: Farm Impacts on Seasonal Pelagic Biogeochemistry - July 2008

TAFI Internal Report (Completed 2009) Broadscale effects of marine salmonid aquaculture and introduced pests on macrobenthos and the sediment environment in Tasmania between 1998 and 2003 (Edgar et al., 2009)

This study was undertaken in conjunction with the salmon industry and DPIPWE and expands the scope of the earlier investigation of broad-scale effects of salmonid aquaculture in southeastern Tasmania outlined above (Edgar et al. 2005) to include analysis of temporal change over the six year period from 1998-2003. The study also investigated potential interactions between salmon farming and marine pest species using the marine farm monitoring data set to assess impacts of introduced species on the benthic environment.

There were clear regional differences in the benthic macrofauna around Tasmania, with Macquarie Harbour fauna being particularly differentiated as depauperate in species and animal numbers. Between 1998-2003 the inshore Tasmanian marine environment appeared to change, with evidence of generalised organic enrichment in several sediment condition measures

Significant effects on the sediment biogeochemistry could be identified on/ near leases in all farming regions other than Macquarie Harbour, where no effect of fish farm activity was detected. Minor effects were detected beyond the lease boundaries in some areas; however, there was no indication of negative impacts on the biota. The study identified several positive and negative indicators of farm impacts, which were consistent with previous studies however, it was noted that those species which were negatively-associated with fish farm impact tended to be localised in distribution and were not significant in the statewide analyses.

Whilst it was not possible to specifically assess the effects of fish farming at the regional scale (the monitoring program did not include reference regions without fish farms), many of the factors measured suggested low levels of organic enrichment within farming regions and that macrofaunal density was also increasing at these scales. However, it is important to note that the scale of fish farm impacts was substantially less than the scale of natural regional variation.

Introduced species were consistently present in the study (although there were fewer in Macquarie Harbour), and increased in proportional abundance by 2-3% per annum. However, there was no evidence of them displacing native populations. The most abundant and widespread species were: bivalves *Theora lubrica* and *Corbula gibba,* and the screwshell *Maoricolpus roseus;* the bivalve *Raeta pulchella* and fanworm *Euchone* *limnicola* were also locally abundant. Populations of *M. roseus* were stable through time and largely unaffected by fish farm activity. *C. gibba* flourished between 1998 and 2001 and whilst positively associated with high organic loading and fine sediments it was not related to fish farms and numbers declined markedly in the latter part of the study. *T. lubrica* did respond to fish farm activity, being present at farm and compliance sites but not at reference sites.

The findings note that the Tasmanian salmonid farm monitoring program provides an invaluable statewide baseline for assessing environmental impacts not only of salmon farming but also more broadly, and with that in mind recommends that it be expanded to include monitoring of reference sites in regions without fish farms.

FRDC Project 2007/246 (Completed 2009) A Review Of The Ecological Impacts Of Selected Antibiotics And Antifoulants Currently Used In The Tasmanian Salmonid Farming Industry (Marine Farming Phase) (Macleod & Eriksen, 2009)

This study provides a review of the international literature and current research to identify the existing state of knowledge regarding the environmental effects of antibiotics and antifoulants currently used or likely to be used in the Tasmanian salmonid farming industry (marine production phase). It also provides an analysis of local datasets on currently used antibiotics and antifoulants, collected in compliance with current licensing requirements, and makes some recommendations regarding what is needed to appropriately evaluate the environmental impact of current management practices.

The ongoing sustainability of the aquaculture industry requires some use of antibiotics and antifoulants to ensure the health of farmed stocks. However, it is important to ensure that any associated environmental impacts are known and minimised. There is a considerable body of international literature in relation to the environmental effects of both antifoulants and antibiotics. Understanding the main environmental concerns regarding the current usage of selected antibiotics and antifoulants allows for the evaluation of the key ecological risk areas and this can then be used to determine where research or monitoring is most needed. The aim of this review being to assist aquaculture and resource managers appropriately focus future research and monitoring efforts. This study found that although a proportion of this information can be related directly to the local Tasmanian conditions, there are instances where it may be necessary to verify assumptions locally. There are also many synergies between the areas of environmental concern associated with the use of both antibiotics and copper based antifoulants. In both instances the key issues are environmental fate/ persistence and effects on non-target organisms and ecosystem processes (i.e. ecotoxicity and bioaccumulation). Given that neither antibiotics nor antifoulants are used in isolation, there may be synergistic/ antagonistic effects, and consequently the report recommends combining research efforts wherever possible. Fate of residues was one area where a clear need for further understanding was identified; this included further determination of the effects of antibiotics and antifoulants on sediment processes and vice versa and the development of modelling tools to evaluate environmental pathways/ consequences and help to develop appropriate monitoring/ management strategies.

The analysis of the industry based monitoring were encouraging, suggesting limited bioavailability of metals under current conditions. However, there were several areas of concern not covered in the current monitoring, and some of the results were inconclusive, consequently the report indicated a need for additional research to better understand the local situation, to develop targeted and appropriate monitoring and management strategies and to ensure environmental sustainability, and suggested some specific areas for further investigation. This study was followed up with a workshop at which government and industry stakeholders and relevant experts discussed the project outcomes and proposed future research.

The project led directly to an FRDC research project looking specifically at the fate of copper-based antifoulants in sediments and how that might impact sediment recovery processes.

The findings of this research have been published in:

- Macleod, C and Eriksen, R, (2011). Antibiotics in Salmonid Aquaculture: Environmental Considerations for Marine Cage Farming
- Eriksen, R and Macleod, C (2011). Antifoulants in Salmonid Aquaculture: Environmental Considerations for Marine Cage Farming
  In "Fish Farms: Management, Disease Control and the Environment". Andrews, G.L. and Vexton, L.A. (Eds), Nova Publishing Ltd. ISBN: 978-1-61209-538-7

FRDC Project 2010/063 (Completed 2012) Evaluation of Approaches to Improve Sediment Remediation (Rate & Function) Under Salmonid Fish Cages. (Eriksen et al., 2012)

Salmonid cage farming in sheltered coastal areas can result in localised, spatially predictable and temporal accumulation of organic material around cages, and an associated decline in sediment quality. In Tasmania, fallowing the seabed under cages for a period of time is a regulatory requirement to allow sediments to recover from the effects of organic enrichment. The fallowing period required varies depending on the prevailing environmental conditions and the intensity and history of operations. Currently fallowing relies on passive remediation, however, if the natural processes can be fine-tuned it may be possible to increase the rate or extent of sediment recovery Enhancing the recovery process could have significant benefits for both farm production and the environment; enabling farmers to manage the timing of their production at each given site more precisely and to have a means by which to remediate the sediments should conditions become sub-optimal.

This project comprised two parts, firstly a review of options for sediment remediation and ranking of potential options with respect to Tasmanian conditions, and secondly an experimental study to test the viability of selected options. The review identified three main approaches (physical, biological and chemical) to accelerating the natural recovery processes. An assessment matrix for the various options was developed and two methods were identified as having potential under Tasmanian conditions: harrowing and direct introduction of oxygen to the sediments. The viability of harrowing as a remediation tool was tested using a combination of field and laboratory studies. Performance was assessed using two key measures of sediment condition: nutrient fluxes and oxygen penetration depth. Highly degraded farm sediments were collected for the study as these were the most appropriate conditions for testing the efficacy of approaches to improve sediment remediation. The sediments selected had been subject to significant build-up of organic matter and consequently were extremely anoxic and exhibited high rates of ammonia and phosphate efflux. Ammonia fluxes reduced considerably over the period of the trial (14 weeks), consistent with a reduction in the organic content of the sediments and recovery of the nitrification process (conversion of ammonia to nitrate) in the sediments. Oxygen penetration depth of organically enriched sediments increased from 0 to 2mm in both the harrowed and controls sites over 14 weeks. Although the results did not show a significant difference overall between harrowing and passive recovery over the trial duration, there were clear indications of a reduction in variability in sediment quality when undertaken on the most degraded sediments, and some evidence of a trend suggesting that harrowing may improve the process over a longer timeframe.

These evaluations were conducted under controlled laboratory conditions, and it is possible that the greater potential for oxygen exchange under field conditions might improve the outcome and enhance the observed trend.

FRDC Project 2011-041(Completed 2014) Assessment of the environmental impacts and sediment remediation potential associated with copper contamination from antifouling paint (and associated recommendations for management) (Macleod et al, 2014)

This study was undertaken as a collaboration between researchers at the Institute for Marine and Antarctic Studies (University of Tasmania) and CSIRO, and with the cooperation of the Tasmanian Salmon farming industry to determine whether copper concentrations in sediments under salmon farms in the Huon and D'Entrecasteaux Channel have any major or long-term impacts on the local ecology or sediment function and to identify the remediation potential of these sediments and what, if any, management strategies could be used to enhance recovery. Noting that in this instance recovery was assessed as either i) a marked decline in copper over time (recovery in progress) or ii) return to background/ baseline copper concentrations (total recovery).

Conditions were assessed over the short-term (12 months, this study) at sites selected for high copper loads, as well as over the longer-term (> 5 years, incorporating the results of previous farm-based assessments) at sites where the copper concentration history was well-known. Changes in background concentrations were assessed by reviewing copper data from both the farm assessments and a range of previous studies in the region, and integrating broader environmental data on prevailing conditions and exposure. Finally, targeted sedimentation studies provided data on deposition and accumulation rates that could be used to provide longer-term projections for recovery.

A specific concern at the start of this study was that ongoing farming, even without the use of antifoulant nets, could increase the risk of toxicity in sediments where copper concentrations were elevated; the results of this study clearly identify that this is not the case. The results indicate that the risk of serious adverse impacts on sediment processes from current copper contamination levels is relatively low; largely because most of the copper occurs as paint flakes and can't be easily taken up by benthic organisms.

Copper can exist in a variety of forms in the sediments, with some being more toxic than others. The concentrations of relevant forms of copper were assessed, and the associated sediment conditions determined. Whilst antifoulant usage was shown to be the primary source of elevated copper concentrations within farms, local environmental conditions and certain farming practices can have a significant influence on copper accumulation and impact levels throughout the system. Consequently, it was possible to make operational management recommendations that will reduce the potential for impacts into the future. The study also recommends refined regulatory guidelines that should provide better protection with respect to chronic ecotoxicological impacts.

The report makes some key recommendations for both farm management and monitoring. With respect to farm management it is suggested that the use of copper based antifoulants should be minimised, and farms should look to replace nets where there is evidence of metal accumulation in sediments; where antifoulants are used net manipulations and other activities with the potential for abrasion should be minimised, but where this cannot be avoided (i.e. fish crowding/ transfer) then farms should look to replace with non-antifouled nets; and finally that farms should look to increase the use of monofilament/ plastic nets wherever possible, but especially at depositional sites - it is suggested that copper based antifoulants should be restricted to sites where sediment organic content is <15%. Recommendations for monitoring suggest that where total recoverable copper concentrations in the sediments exceed the ISQG-High (270 mg/kg) then dilute acid extractable copper concentration should also be assessed to ensure that concentrations are below the TV (65 mg/kg) and that regular monitoring should continue to measure total recoverable copper (as this is necessary for consistency with historical datasets and protocols, and therefore essential for assessment of recovery).

Industry has already adopted the management recommendations of this study and copper based antifoulant nets have now largely been replaced.

IMAS Technical Report (Completed 2014) Long-term Recovery – Review of sediment condition at Marine Farm lease No.76 (Gunpowder Jetty), North West Bay (Macleod et al, 2014)

This study was undertaken to assess the Gunpowder Jetty site (Marine Farm lease No.76) 10 years after it was finally vacated to determine whether the benthic, visual and physical-chemical conditions were consistent with background conditions and to what extent the system has recovered. The results suggest that, based on the selected environmental condition variables assessed, the sediments around the Gunpowder lease have largely recovered. Whilst some parameters still showed small differences between locations these do not appear to be having a major effect on the ecology or nutrient mineralisation processes, and consequently there is no evidence that the farming activity has had any permanent impact on the ecology in this area.

IMAS Technical Report (Completed 2013) Evaluation of Broadscale Environmental Monitoring Program (BEMP) data from 2009-2012. (Ross and Macleod, 2013).

There has also been a significant body of research undertaken through IMAS (and as TAFI) which has been targeted at characterising environmental conditions in our coastal waterways more broadly, and this information provides the baseline by waterway health can be more broadly assessed.

The BEMP provides a comprehensive assessment of ecological condition in the D'Entrecasteaux Channel and Huon Estuary. The program commenced in March 2009, and is currently undertaken by all marine finfish farm licence holders in the D'Entrecasteaux Channel and Huon River/Port Esperance MFDP areas. Fifteen sites within the MFDP areas are monitored throughout the year to assess spatial and temporal patterns of water and sediment quality; this includes a broad suite of parameters capturing the physical, chemical and biological characteristics of the system. This dataset provides a significant body of information that can be used by regulators, industry and other stakeholders to assess ecological condition and to support adaptive management strategies.
This report represents a comprehensive summary of both the water and sediment quality data collected as part of the BEMP from 2009-2012. It also provides an evaluation of the data in the context of the major system drivers, previous environmental

data sets and broader ecosystem performance measures. Collectively the information in this report has improved our understanding of the key processes and interactions, forms a comprehensive reference point for future assessment of the Huon and Channel system and provides an assessment of ecological functioning at the whole of ecosystem level (i.e. a “state of the system”).

FRDC Project 2012/047 (Completed 2014) Characterising benthic pelagic interactions in Macquarie Harbour - organic matter processing in sediments and the importance for nutrient dynamics

This study assessed the impacts of organic enrichment from salmon farming on nitrogen cycling processes in the sediments in Macquarie Harbour and assessed the sediment’s capacity to recover during fallowing.

This research has improved our understanding of sediment processes in Macquarie Harbour and has enabled sediment function to be more appropriately represented in the environmental model. It is clear that the Macquarie Harbour ecosystem and the associated biogeochemical processes are different from that previously described for other systems in Tasmania. Consequently, any changes in environmental conditions and our understanding of system dynamics would require the model to be revised. From a sediment monitoring perspective, bulk identifiers of organic matter source (C:N ratio and $\delta^{13}C$ and $\delta^{15}N$ signature) together with measured rates of respiration appeared to be good environmental indicators of the footprint of farm derived organic matter and sediment function respectively. Anaerobic processes and the production of reduced compounds were important in the overall benthic biogeochemistry of the harbour. Measurement of sediment function at some, but not all, sites showed patterns consistent with expectations during fallowing and stocking. This suggests that drivers other than stocking (e.g. changes in diet, conversion ratios, feeding regimes, bottom water conditions) are playing a significant role in determining sediment condition. A greater understanding of the drivers of sediment function in response to different stages of farming activity is likely to improve the effectiveness of farm based management of stocking and fallowing regimes.

Interestingly, in the second half of the study a significant decline in bottom water oxygen conditions was evident. The causes of this decline and the implications for broader ecosystem dynamics warrants further investigation, and as such, may require the model to be revised for future use.

<u>ONGOING IMAS Research Projects:</u>

SeaMap Tasmania Project

The SeaMap Tasmania project commenced in 2000 and remains actively engaged in surveying marine habitats in Tasmanian coastal waters to support the management of Tasmanian marine resources by:

- mapping the distribution of seabed habitat types in estuarine, coastal and marine waters of Tasmania through photographic, acoustic, biological and sediment sampling
- consolidating all existing Tasmanian seabed habitat mapping data into a single Geographic Information System and relational database
- providing a series of seabed habitat maps for Tasmanian State waters and making these available on the Internet and in other digital forms

- promoting and coordinating postgraduate projects in the area of seabed habitat mapping.

Seabed habitat mapping provides specific information on ecosystem structure within a spatial framework and can inform a wide range of coastal planning issues, providing an important underpinning information for both marine farm planning and subsequent environmental impact modelling and assessment. The research outputs also provide baseline data for monitoring changes in habitat extent and structure over time. Habitat maps
(http://seamap.imas.utas.edu.au/about-seamap/)

FRDC 2011/042 (Ongoing) Clarifying the relationship between salmon farm nutrient loads and changes in macroalgal community structure/distribution (Existing student support)

This project commenced late in 2011 and is due for completion this year. The project directly supports one PhD student who's main research focus is to investigate the effects of increased nutrient availability on macroalgal communities in the Channel/ Lower Huon however, there is also some support funding for a second PhD student investigating the potential to offset the nutrient inputs from fish farming via co-culture of algae. The research seeks to clarify the effect of nutrient changes on key reef species under a variety of different environmental conditions, identify potential nutrient "hotspots" and key response species and make recommendations as to the viability of macroalgae as an approach for nutrient mitigation. So far the empirical (field) studies have shown that there is little evidence of any major effect of nutrients on local reef systems; although there is evidence of changes at the physiological level. Opportunistic algae have been found to respond to an increase in transient nutrients but this response does not seem to have any major influence on the dominant or keystone algal species and can be markedly influenced by the prevailing environmental conditions. Location within the Estuary and particularly in relation to exposure/ salinity regime would appear to be a significant driver of algal community changes and the relative sensitivity/ resilience of the reef systems. The modelling studies show that there is significant potential for algal growth in conjunction with salmon farming for the purposes of integrated multi-trophic aquaculture (IMTA). Results show that where the algae culture is located within the system is important, and that this may differ if intention of IMTA is for profit or for nutrient mitigation purposes.

SCRC 2011/735 (Ongoing) Innovative Technologies: An Evaluation of the options for expansion of Atlantic salmon aquaculture in Tasmania
Phase 1. Options Analysis (Commercial in Confidence)
Phase 2. Keeping ahead of the game: A framework for effective aquaculture decision-making.
Phase 3. Information assessment/decision support framework (Pilot Study – Storm Bay)

Phase 1 & 2: Options analysis and development of decision support modelling
This PhD project looked at an economic analysis of alternative production technology options for the Tasmanian salmon industry, with a view to developing a conceptual framework for objectively evaluating possible expansion options and considering the specific constraints relevant to the Tasmanian Atlantic salmon industry. The study provides a critical review of possible strategies, outlines the conceptual framework and provides an economic analysis model to undertake preliminary analysis of "stylised" but

conceptually relevant industry data and scenarios and through that process a formal option analysis.

This component of the study presents a framework of complementary decision support approaches to enable decision-makers to better understand the factors influencing aquaculture development, and examine alternative production (growout) technologies that more effectively address the challenges associated with intensification and expansion. This was achieved through a combination of fieldwork (international data-gathering), key stakeholder discussions, and the application of targeted qualitative and quantitative analytical approaches; using the Tasmanian industry as a Case Study. The initial research focused on shorter-term (tactical) decision support. A situational analysis defined the business environment, and appraised viable expansion options (offshore, closed-containment and extractive bio-remediation). An economic analysis of selected options provided a comparison of financial performance and risk. The outcomes of this initial component were then used to inform strategic decision-making approaches; employing scenario analysis to explore plausible strategies for the adoption of land-based recirculating aquaculture systems; and qualitative modelling to understand the causal dynamics driving and regulating the industry, and their impact on technology selection.

Phase 3: Information Assessment/ Data Support Framework (Pilot Study-Storm Bay):
The primary aim of this project is to outline a decision support framework that combines established information requirements (i.e. spatial, social, environmental and production) with spatial planning and risk evaluation tools. This will then lead to the development of a standardised and all-inclusive package by which the aquaculture industry can assess and compare the risks and information needs for aquaculture development/ expansion proposals. The project will use Storm Bay as a test site in which to assess a hypothetical aquaculture development, and will construct and evaluate a theoretical decision support model on this basis.

The component of the study (Phase 3) comprised 4 main components:

i) identification of the various information needs, taking into account any specific constraints likely to be encountered by a new development proposal (e.g. depth appropriate areas for farming, shipping/ tourism usage overlap, proximity to MPAs or threatened species, wave height restrictions on infrastructure) and including an assessment of any issues that might be affected by the scale/ form of the development (e.g. infrastructure depth requirements, restrictions on distance to shorebase).

ii) gap analysis - identification of any missing data/knowledge relevant to the development of the decision support tool.

iii) assessment of information systems that can be used to collect, filter, overlay and review the various datasets – this may include integration of various geographical information systems (GIS) (e.g. LIST), as well as risk assessment and data visualisation tools.

iv) identification of specific trigger points – i.e. limiting criteria and key decision points, and any notable information gaps.

This project will provide a comprehensive inventory of the various information needs (types and sensitivity) and any defined constraints/ limitations (in relation to spatial planning, environmental and production criteria) commonly associated with aquaculture development proposals. It will also identify how defined “trigger points” might change with the scale or nature of operations. Finally, this information will be integrated where possible with GIS and risk profiles to provide an all-inclusive but easy to review decision support package.

Whilst this project is being developed as a tool for the aquaculture industry specifically it is hoped that it will prove useful for communication with other stakeholders, and that it will underpin informed decisions by characterising for all resource stakeholders the reality of the potential risks and benefits of aquaculture development in any selected region.

FRDC 2012-024 INFORMD Stage 2 (Ongoing): Risk-based tools supporting consultation, planning and adaptive management for aquaculture and other multiple-uses of the coastal waters of southern Tasmania.

This project is looking to bring the methods developed in the original INFORMD studies into practical use for risk assessment and management of the aquaculture industry in the INFORMD region, as an example of application in an individual industry. A range of human activities influence water quality and other marine environmental values in southern Tasmania. For example, cage based salmon farming is currently restricted to the Huon Estuary, D'Entrecasteaux Channel and Tasman Peninsula, with other activities in these waters having the potential to be affected by, or have an effect on, aquaculture (e.g. industrial processes, urban development, municipal services, fisheries, recreation, tourism). Given the multi-user nature of the marine environment, it is important to recognise the diverse needs and expectations of the broader community when identifying values and evaluating trade-offs in the system as a whole. For example, water quality issues such as eutrophication and nuisance algae are important to both the aquaculture industry and the wider community, while issues such as public access, views and maintenance of recreational assets may be of particular concern to local communities. There is an urgent need to develop and apply innovative tools based on the best available scientific knowledge (e.g. INFORMD) to support consultation, planning and management of aquaculture and other uses of southern Tasmanian coastal waters.

Objectives:

- For the marine environment of southern Tasmania, characterise key environmental, social and economic values and aspirations from industry, government and community perspectives.
- Relate these values to measurable indicators based on understanding of key biophysical and socio-economic processes.
- Develop a framework to support spatial risk assessment for planning of future development within the system, with an initial focus on aquaculture leases.
- Develop a framework for developing and evaluating spatial risk management strategies, with an initial focus on managing aquaculture leases.
- Integrate the planning framework (objective 3) and risk management framework (objective 4) into an online tool accessible to stakeholders.

Your Marine Values – Public Report 2013
*(*http://www.imas.utas.edu.au/__data/assets/pdf_file/0003/535908/Your-Marine-Values-Document_WEB-FULL.pdf*)*

FRDC 2012-047 (Ongoing) Characterising benthic pelagic interactions in Macquarie Harbour - organic matter processing in sediments and the importance for nutrient dynamics

A key knowledge gap in Macquarie Harbour was a lack of ecological data on the capacity of sediments to process organic matter and nutrients and the influence on bottom waters, particularly in response to increased loads associated with expanded farming. This study assessed the impacts of organic enrichment from salmon farming on nitrogen cycling processes in the sediments including the capacity to recover during fallowing. This was achieved via sediment water column incubations conducted at farm and harbour scales repeated across seasons and farm production cycles. This study has shown that bottom water oxygen is a major driver of organic matter recycling in benthic sediments and that the process of sediment recovery during fallowing appears to be slower than recorded in the south. The results of this study have fed directly into re-calibration and validation of sediment water column interactions in the environmental model and the findings of this study have been instrumental in framing the current FRDC EOI proposal, suggesting that it might be valuable to review the benthic monitoring program in Macquarie Harbour.

FRDC Project 2013-008 (Ongoing) Movement, habitat utilisation and population status of the endangered Maugean skate and implications for fishing and aquaculture operations in Macquarie Harbour

The objectives of this project are to:

- Determine the distribution, habitat utilisation and movement of the Maugean skate in Macquarie Harbour.
- Determine the key biological characteristics of Maugean skate, including population size, reproductive dynamics and feeding habits.
- Describe the spatial and temporal dispersal patterns of salmonid escapees in Macquarie Harbour.
- Assess the potential impacts of current and proposed marine farming operations on the Maugean skate population.
- Evaluate strategies to reduce the probability of encountering Maugean skate whilst fishing (gillnetting) for escapees.

FRDC 2013-204 (Ongoing): Meeting sustainability expectations: translating and aligning objectives, reporting and evaluation of the performance of Australian fisheries

This project proposes to:

1. Conduct a desk-top examination of all primary Australian fisheries management legislation and management plans for each of the key Australian fisheries as reported against for the SAFS reports.

1. This review will examine the level of alignment and consistency of:
    a) Legislative objectives for fisheries resources with the Australian community's expectations for the management of those resources, as indicated by the FRDC 2012/301 Let's Talk Fish project, as well as other related research;

b) Legislative objectives for fisheries resources between the jurisdictions; and

c) Management objectives for each of the key fisheries included in the SAFS reports by type.

2. The review will also examine a representative sub-set of the key fisheries included in the SAFS reports for the translation of legislative objectives for fisheries resources in that jurisdiction into management/operational objectives specific to each fishery, as well into indicators, benchmarks and classifications (where used) for reporting and evaluating the performance and status of each fishery to the wider Australian public.
3. On the basis of consultation with AFMF members, the SAFS Advisory Group, and ABARES, make recommendations for common reporting frameworks and formal classification systems for social, economic, ecological, and management performance of key fisheries, based on the identification of areas of greatest alignment between the existing reporting frameworks used by the jurisdictions
4. Develop guidelines for the optimal setting of legislative objectives for fisheries resources and of management objectives for specific fisheries for use during formal legislative and management review processes, and for use in the development of management arrangements for new/developing fisheries. The intent of the guidelines will be to enable objectives to be operationalised and translated into indicators, benchmarks and classifications. This, in turn, will facilitate reporting to meet the wider Australian community's concerns regarding the performance and status of fisheries.

FRDC 2014/ 031 (Ongoing) Predicting marine currents, nutrients and plankton in the coastal waters of south eastern Tasmania in response to changing weather patterns.

This project aims to provide scientific information important to the ecologically sustainable development of salmon aquaculture in SE Tasmania, in particular potential expansion into Storm Bay. The complex oceanography off this region is characterized by large fluctuations in temperature, salinity and nutrients on variable temporal and spatial scales. This is due to the southerly extension of warm nutrient-depleted sub-tropical waters transported via the East Australian Current (EAC), whilst the south and south-west coasts are influenced by the cooler nutrient-rich sub-Antarctic water mass from the south and the Leeuwin Current from the north-west. These water masses all impact on coastal waters of south-eastern Tasmania, including Storm Bay, which is also modified by freshwater flows from the Derwent Estuary. This project expands on a previous broad-scale study of the Storm Bay ecosystem that began in November 2009. Extreme weather events have been recorded in the plankton, e.g. the La Nina conditions that resulted in extreme rainfall along Australia's eastern seaboard in 2011. It also supports an assessment of change in water quality in Storm Bay over a quarter century period as it repeats the sampling conducted at a site in central Storm Bay by CSIRO in 1985-89.

This project will provide essential baseline data for development of salmon aquaculture in Storm Bay, and will extending the dataset to explore issues of significance to various stakeholders such as:

- interactions between temperature and wind and rainfall patterns, and how these might influence nutrient concentrations and plankton dynamics (e.g. HABs)

- how do gelatinous species around farms and Neoparamoeba perurans (the causative agent of AGD) relate to broader environmental conditions .

This information will enhance the various risk and decision support systems being developed for management of salmon farming in the Storm Bay region and will link to, and provide essential support information for, the FRDC EOI research if successful.

FRDC 2014-038 (Ongoing) Understanding Dorvilleid ecology in Macquarie Harbour

Previous research has shown a clear impact gradient associated with cage salmon farming operations, and that presence of bacterial mats (Beggiatoa) and proliferation of opportunistic species are features commonly associated with high levels of organic enrichment (e.g. Pearson & Rosenberg, 1978) that can be used in SE Tasmania to define "unacceptable impact" (Macleod et al., 2004). This premise underpins regulatory monitoring requirements statewide (DPIPWE, 2004). Although the understanding that proliferation of opportunists represents deteriorating conditions was translated to monitoring protocols in Macquarie Harbour, but the relationship between opportunists and the level of enrichment was not explicitly tested in this region. Video surveys suggest that in Macquarie Harbour it is Dorvilleid worms rather than Capitellids that are indicative of organic enrichment (DPIPWE, 2004).

However, Macquarie Harbour is ecologically very different to other farming areas in SE Tasmania; the sediments are inherently depauperate, largely epibiotic and spatially patchy. A recent study in Canada has highlighted the need to better understand the relationships and compliance thresholds for established enrichment indicators (i.e. Beggiatoa sp and opportunistic polychaete complexes) in systems where ecological patchiness may occur (Hamoutene et al 2014); suggesting that, where there is significant potential for small scale spatial variability, normal successional responses may not be as reliable. Consequently, the responses may not be consistent with expectations developed from southern Tasmanian regions. In this context it is important to identify the relationship between Dorvilleids and sediment condition; determining the reliability of this species as an indicator of sediment condition, and characterising the environmental conditions associated with changes in Dorvilleid abundance.

This project is nearing completion with a draft final report in review. The report provides a review of current understanding regarding Dorvilleid ecology, and in particular, their response to organic enrichment as well as their current use as indicator of the impacts of finfish aquaculture. It also provides details of targeted field surveys at selected leases clarifying the relationship between Dorvilleids and sediment condition, and defining the environmental conditions associated with changes in Dorvilleid abundance. The results show that Dorvilleids can be effective indicators of sediment condition in Macquarie Harbour, although there are some considerations for monitoring.

FRDC Project 2014-241 (Ongoing) A reassessment of intertidal macroalgal composition and abundance near to and distant from salmon farms in the Huon and D'Entrecasteaux Channel region.

In 2003 an assessment was conducted of the cover of intertidal macroalgae on rocky reefs near to, and distant from, salmon farms in the D'Entrecasteaux Channel and Huon region. These sites were located in Port Esperance, Southport, mouth of the Huon Estuary and Great Taylors Bay. Key outcomes from this assessment were:

- “intertidal algal communities, in particular the dominant species Ulva and Hormosira, show natural variation and no clear trends in abundance with distance from salmon farms”, and
- “These results suggest that a simple ecological measure for the effects of increased nutrients on the environment would be to measure the abundance of Ulva and Hormosira in the mid intertidal zone at sites near to and distant from salmon farms in spring and autumn each year”.

Since the original assessment in 2003, major expansion of salmon aquaculture has occurred in the region. Concomitantly, there has been increased concern from the community about the effects of salmon farms on the environment, including reports of increased intertidal algal abundance. With the proposed expansion of salmon farming in this (and other) regions, there is a need to assess the potential of macroalgae as an indicator of salmon farming nutrient impacts. Now is an ideal time to repeat this study, eleven years later, to survey for changes in intertidal macroalgal abundance and species composition near to and distant from salmon farms.

FRDC 2015-024 (Commencing) Managing ecosystem interactions across differing environments: building flexibility and risk assurance into environmental management strategies

In order to double production by 2030 the Salmon industry in Tasmania must consider alternate production approaches and expansion into new areas. However, maintaining high environmental performance (a priority for both the industry and its regulators) requires an understanding of how farming in new areas might change environmental interactions. In order to ensure that management remains best practice, and farms continue to be efficient and sustainable, assessment of the local scale impact/ recovery dynamics and potential interactions with other resource users is required in newly developed farming environments and under different farming technologies. In addition identifying how understanding farm impact and associated nutrient dynamics might be used to inform local, medium and broad-scale interactions will provide an important basis for establishing an effective strategy for system-wide management and interactions with other users of the water-bodies.

It is clear from discussions with various resource users (i.e. fish farmers and commercial and recreational fishers) that the perception of potential risks differs between Macquarie Harbour and the southern farming regions. In Macquarie Harbour a critical issue is whether the current on-farm monitoring (and local scale impact indicators are “fit for purpose” i.e. do they support sustainable management by providing an accurate understanding of sediment conditions. Whilst in the new farming areas in the southern regions (Lower Channel/ Storm Bay), although establishing the effectiveness of the local scale monitoring is important, the key concern is whether there may be adverse effects on reef health (i.e. off-site interactions) as a result of increased aquaculture activities. Therefore a key element of this study will be to provide a better assessment of the potential risk to reef systems from sediment deposition and nutrient dispersion from fish farms directly.

This study has been designed to target the different research priorities and concerns in each new farming region (Lower Huon/ Channel, Storm Bay, Mac Harbour). In Macquarie Harbour the emphasis will be on validating local scale monitoring approaches (on-site focus), and whilst this will also be an important element in the Southern regions a key element of the research in the south will be defining cost-effective and risk appropriate approaches for assessment of reef health (off-site interactions). An important component of this study will be to use the empirical monitoring data to calibrate and validate sediment deposition and nutrient dispersion models. Dispersion modelling will be used to link the reef assessment information to the local scale studies, specifically looking to identify the exposure of reef systems to nutrients and sediments from fish farms. Nutrient DGT and sediment trap measurements will be critical for model calibration and validation. Ultimately, the deposition and dispersion models will provide an important predictive tool for determining risk to the ecology of soft sediment and reef habitats in new farming regions. Overall, the project research and outputs will be specifically developed to align with the broad-scale monitoring and management measures currently in place and to connect with, and build on, broader ecosystem based management and research currently underway (i.e. existing DPIPWE and industry spatial planning processes, INFORMD2 project, Storm Bay project, intertidal algal monitoring, current abalone spatial mapping initiatives and any local/ regional hydrodynamic modelling) and particularly any other research aligned to the broader stakeholders key concerns. Importantly, the proposed study builds on existing research and management understanding, seeking to inform and improve practices rather than replace current approaches.

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