Food Security

Abstract

Fisheries and aquaculture provide an important contribution to food security and nutrition. They are the primary source of protein for 17 percent of the world's population and nearly a quarter in low-income food-deficit countries. Demand and price for aquatic products are projected to continue rise.

Australia's fisheries and aquaculture industry is relatively small by global standards (~$2.4 billion 2012-13) – but this need not be. Australia's location presents opportunities for seafood production and export, as well as the provision of services covering the whole fishery management system. It is significant that globally, of the major food sources, aquatic products are predicted to have the largest real price increase.

Funding for fisheries and aquaculture research has been stable or declining in recent years (2009-2013) while the breadth of that research has increased considerably. Key priorities include the need for new smart ways of monitoring and data acquisition including NextGen technologies; expansion of performance evaluation metrics; methods for data- poor fisheries assessment including recreational and Indigenous sectors. For aquaculture investment in R&D addressing the technological bottlenecks to production - including new species - husbandry and reducing the sector's environmental footprint and simultaneously improving its economic viability is needed. With the expansion of the aquaculture sector in Australia since the 1990s, there has been an increasing need to develop capability, capacity and expertise in aquatic animal health and biosecurity.

In addition, the safe and nutritious components of fisheries and aquaculture are often unseen, but remain the foundation of seafood trade and market access domestically and globally. Maintaining core capability in this field is essential to maintaining and building the wild harvest and aquaculture seafood sectors.

Finally there are a number of cross cutting research needs that include understanding social license and efficient community engagement; 'whole of system' approaches including explicit consideration of social and economic dimensions; and interactions with other non-fishery sectors; and national standards for monitoring, assessment and management.

Background

Fisheries and aquaculture research is conducted by State agencies and the NT, CSIRO, many universities and museums. In addition research is directly carried out by private providers consultants and the seafood industry. ABARES and AAD also undertake fisheries research. Research on aquatic animal health and biosecurity is currently undertaken by Commonwealth and State Government departments, some universities including veterinary medicine faculties. Seafood safety research in Australia is a relatively small field, primarily conducted through SARDI, CSIRO, UTAS, QDAFF and Curtin University. Seafood innovation and quality are researched in these institutes, as well as a range of other universities.

There have been recent structural changes in distribution of capability. There has been a reduction in fisheries research undertaken by some State agencies particularly on the eastern seaboard. Overall, however, the total numbers engaged in fisheries and aquaculture research have remained relatively stable over the last five years (2009-2013) as there has been a shift to universities and private consultancies in some cases. A positive trend is the increasing collaboration between institutions. In 2013, total FTEs directly engaged in fisheries and aquaculture research was in excess of 550 (wild commercial fisheries 60%; aquaculture 33%; recreational fishing 6%; and Indigenous/customary 1%) (Murphy and Lewis 2014). Total investment in fisheries research was around $65m in 2012/13 and has been stable, but slightly declining in real terms. Annual investment in aquaculture RD&E increased between 2009-2013 from around $29m to $35m per annum (Murphy and Lewis 2014).

The main structure or process that drives fishing and aquaculture research priorities in Australia is the National Fishing and Aquaculture RD&E Strategy which is in turn driven by the needs of fishing and aquaculture stakeholders.

Fisheries research has been undertaken in Australia for over a century. The more traditional aspects of fisheries research, such as that supporting target species management, is considered a mature science (The Status of Key Australian Fish Stocks can be found at www.fish.gov.au.). However, even in this context there are on-going improvements and developments in quantitative methods especially with respect to data-poor, recreational and indigenous fisheries. However, social and economic science is much less developed. Since the early 2000s, international requirements and market forces have placed much greater emphasis on the broader ecosystem impacts of fishing, termed ecosystem-based fisheries management (EBFM), which is not a mature science. Recent research has concentrated on the development of tools that are cost-effective and applicable to a range of situations. A number of tools developed in Australia, including the various Risk Assessment methods (e.g. Fletcher, 2005; Hobday et al 2011) have been included within the Food and Agricultural Organisation's Toolbox for Implementing the Ecosystem Approach to Fisheries (Fletcher and Bianchi, 2014, http://www.fao.org/fishery/eaf-net/ en). Some are also available from the USA NOAA toolbox (e.g. http://nft.nefsc.noaa.gov/PSA.html). A significant development has been the increasing use of end-to-end ecosystem models in fisheries drawing from the field of complex systems science. The complexity of these models means that, in most cases, data and process understanding are now the limiting factors. There has also been increasing interest in integration of economic and social objectives into 'whole of system' approaches (Fulton et al 2011).

Australia's state government aquatic science institutes have a long history of supporting aquaculture expansion, from the development of the Sydney Rock Oyster sector to the last 40 years of R&D to develop the Tasmanian Atlantic Salmon farming sector. Twenty seven universities in Australia have capacity and capability in aquaculture with many playing leading roles both domestically and internationally. Universities play a role in both basic and applied science; fish health being an example of the latter. Specifically; new technology and species production (State Governments, Universities), Environmental assessment and mitigation (State Governments, Universities), Applied breeding and quantitative genetics (CSIRO, Universities, State Governments), molecular genetics (CSIRO, Universities, State Governments), bioinformatics and genomics (CSIRO, Universities), virology and immunology (CSIRO, Universities, State Governments), physiology and general biology (CSIRO, Universities), nutrition and feed technologies (CSIRO, Universities, State Governments), microbiology (CSIRO, Universities, State Governments), bioactive (CSIRO, Universities), sensor based technology and decision support systems (CSIRO, Universities), integrated ecosystem and multiple-use management across sectors including aquaculture (CSIRO, Universities, State Governments)

Aquatic animal health and biosecurity is a field of research activity that had little attention in Australia until 1981 with the establishment of a national fish health reference laboratory which was subsequently moved to CSIRO's Australian Animal Health Laboratory, Geelong in 1989. Coincidentally, Australian aquaculture was at the start of a rapid growth period which continues to the present day. Seafood safety has long been studied in Australia but a national approach to this area is relatively recent.

Australian fisheries research is highly regarded and well cited. For example, CSIRO is rated in the top 0.1% of global research institutes in four research fields of which Marine Biology and Fisheries is one. Six Australian universities had ERA rankings of three or four in the latest ERA report, in the fisheries/marine biology category. However, there is no specific ranking within ERA for aquaculture. Australia's qualitative reputation is high in specialist areas. For example, in aquatic fish health and nutrition; many research providers have developed a national and international reputation in aquatic animal health including leading international OIE Reference Laboratories for globally significant diseases/pathogens of aquatic animals (OIE, 2014). Further, most states and the northern territory have excellent modern aquaculture research facilities.

Major sources of funding are the Commonwealth government (Department of Agriculture, the

Australian Fisheries Management Authority), FRDC, State governments, CSIRO, RIRDC, ACIAR, AusAid, World Bank, Australian Seafood CRC, Department of Industry, ARC and the seafood industry.

This white paper summarises four working papers:

1. Food Security – Wild Catch
2. Food Security – Aquaculture
3. Food Security - Aquatic Animal Health And Biosecurity
4. Food Security – Food Safety and Innovation

Relevance

Fisheries and aquaculture are an important element of global food and economic security. In 2011, wild fisheries and aquaculture produced 155 million tonnes globally, of which commercial wild fisheries contributed 94 million tonnes (83 million tonnes marine) although this has been stable while production from aquaculture continues to rise (FAO 2014). Global fisheries as a food source provide 2.9 billion people with 20% of their protein. They provide employment for 46 million people directly and 180 million including secondary activities. Demand for seafood is likely to increase with increasing populations both domestically and in our region, placing additional pressure on sustainable production of seafood.

The Department of Agriculture estimates that Australia produces enough food to support 60 million people and overall, Australia is fortunate when it comes to food and hence food security is not an acute issue for the nation. However, the world is changing and Australia will face challenges related to climate change, competition for resources, changing economic conditions, regional stability etc. For example, >50% of current Australian agricultural land is threatened by soil acidity and 17% by salinity (Stirzaker 2012), the future median year is projected to match a dry year today with a potential drop in production (e.g. in wheat, sugar, cattle and sheep) of 5-20% or more, which reduces Australia's export capacity (Gunasekera et al 2007). This means fisheries and aquaculture may have a growing role in Australia's food security. In addition, as major producing developing nations utilise their own seafood for domestic use, this will put growing pressure on developed nations, including Australia, to address production requirements.

Australia's fisheries are relatively small by world standards, accounting for 0.2% of global marine fisheries landed by tonnage and 2% of landed value (FRDC 2010). The domestic demand is such that imports exceed exports both in tonnage and value (Skirtun et al 2013). Australia's relatively small production is also highlighted by its juxtaposition against its Asian neighbours, with Indonesia one of the world's largest fishing nations - ranked 2nd for fisheries production (FAO 2014). Fish is also a mainstay for food security for Pacific island countries and territories providing 50-90% of animal protein in rural areas and 40-80% animal protein in many urban areas of the Pacific (Bell et al 2009). These fisheries share species and ecosystems with Australia and Australia is bounded by the world's two largest tuna fisheries, in which it has shared interests – politically as well as through access to migrating seafood resources. There is also increasing Australian interest in the Indian Ocean and rim nations in which fisheries are significant industries.

Aquaculture in Australia has developed rapidly and now contributes over 45% in value and 35% in tonnage of Australia's total production. It is one of the most efficient systems for converting feed into high quality food (e.g. four times more efficient than beef). It has a smaller environmental footprint than other livestock systems (e.g. lower carbon, nitrogen and phosphorus emissions per kg production; low freshwater requirement).

Aquaculture in Australia is focused in regions which are both local enough to be managed and large enough to have a critical mass of stakeholders and investment (e.g. Tasmania and SA). They provide opportunity to lead world's best practice for whole of system approaches. Australia has unique opportunities around R&D: Tasmania is a global climate change hot spot and is leading science including selective breeding; disease free status of several industries and potential to stock global hatcheries; world leading research depth across institutions in key fields.

With the growth in Australian aquaculture since the late 1980s there are many research issues to be addressed, including research of aquatic animal diseases and health. In comparison with the terrestrial animal industries, the state of knowledge of aquatic animal health management is limited. Research has a critical role in expanding this knowledge and enhancing management practices to prevent disease or limit its impact on the expanding fisheries/aquaculture sector, including recreational fishing and natural resources.

Food safety across the supply chain and other post-harvest activities such as new product development are directly relevant to ensuring food security in Australia. These activities ensure protection and expansion of the market, enabling high demand and market access for seafood products, which translates to profitable activities for seafood businesses.

Another element of Australia's fisheries is the catch by the recreational sector. Unlike many other nations in the world, recreational fishing is a major social and economic activity in Australia, with up to four million people participating per annum, and catches of many species exceeding commercial catches (Henry and Lyle 2003). Indigenous fishing is also an important use of our marine resources with growing recognition of the importance of this sector (Calogeras et al 2011).

Across all forms of fishing, Australia's fisheries jurisdictions have adopted ecosystem-based fishery management (EBFM) as a policy goal, since the mid-2000s. This is consistent with the growing international demand for environmentally sustainable food production. Australia has well established participatory processes for fishery assessment and management. In general these include direct engagement between resource managers, scientists, the fishery sectors and eNGOs. Our fisheries are considered well managed by global standards. For example, it has been estimated that only 15% of our commercial fisheries are classified as overfished, with an improving trend, compared to 30% globally (FAO 2010, Smith and Webb 2011, Woodhams et al 2011). However, during the debate around large factory trawlers fishing for small pelagics (the *Margiris*), it is also clear that there is limited community understanding regarding Australia's fishery management systems and their successes over the last 10-20 years.

Despite the relatively small size of Australia's fisheries and aquaculture (representing <0.2% of Australia's GDP in 2010) they have important ecological, social, and political footprints. They sectors are but one user of the aquatic environment and increasing marine uses can lead to tensions between sectors and generate competing priorities for the same areas. No arrangements currently exist to provide a forum for identifying integrated strategic marine management or for setting spatial management priorities across multiple sectors.

Australia's location also presents opportunities for seafood production and export, as well as the provision of services covering the whole fishery management system. It is significant that, of the major food sources, aquatic products are predicted to have the largest real price increase.

The beneficiaries of this research are the fisheries and aquaculture sectors including the ornamental and recreational fisheries and the managers of the aquatic natural resources, i.e. State government departments of fisheries/environment/natural resources and/or primary industries and/or agriculture. In addition, Commonwealth Government departments (Agriculture and Biosecurity) have research needs to address national issues relating to aquatic animal health and biosecurity such as quarantine-related issues and issues related to Australia's disease status.

Science needs

There remain crucial research needs and challenges. These are in response to community concerns regarding sustainability of fisheries and aquaculture and their broader ecosystem impacts and interactions between and within other uses and the environment. There are also significant challenges in understanding multiple-use interactions and cumulative impacts.

Many of the easy advances in aquaculture production have been made. The next 20 years will require investment in multi-disciplinary science to solve technologically difficult and scientifically challenging problems that offer significant jump changes in aquaculture and advances in integrated management.

Australia is fortunate to have an aquatic animal sector free from many diseases that cause significant economic impact elsewhere in the world (e.g. McColl *et al*., 2004). It is vital for Australia to maintain this high-health status, not only to enhance our competitiveness but also to protect Australia's natural resources. However, Australia also has a unique range of poorly understood host species and endemic pathogens which are becoming increasingly important and of significance to our export trade.

There are clear synergies and opportunities with the other themes, in particular 'Biodiversity conservation and ecosystem health', 'Urban coastal environments', 'Dealing with climate change' and 'Optimal resource allocation'. New technologies have opened opportunities to provide major research impact.

Wild Catch:

Understanding aquatic ecosystems:

- Clearer understanding of the dynamic linkages between catchment, coasts and oceans and their role in fishery production
- Understanding the cumulative impacts of multiple use on coastal habitats for fish production
- The implications of climate change and variability in particular, range shifts, non-stationarity, and ocean acidification.

Observations and data acquisition:

- Improved and cost-effective monitoring (e.g. e-monitoring) for data collection and improved assessment strategies for data poor situations. Implementation of new observational technologies, remote sensing, genetic and biochemical methods and linkages with other observing infrastructure such as IMOS
- Improved recreational fisheries monitoring
- Ongoing social and economic data.

Assessment approaches:

- Development of methods to assess Australia's total sustainable fishery production
- Development of harvest strategies that incorporate all sectors (including social and economic indicators where appropriate), as well as influences from beyond fisheries (such as other marine industries operating in the same area)
- Assessment methods including monitoring and performance evaluation of the objectives of spatial management, including stocks that straddle jurisdictional boundaries
- Common reporting standards for data and assessment methods
- Ecological risk assessment and predictive models
- IUU, provenance and traceability.

Social and economic considerations:

- Determining overall benefits health/wellbeing of fishing/seafood
- Assessing the economic potential for utilising discards and under-utilised species
- Understanding social license and efficient community engagement – determining preferred uses, measuring performance accordingly and defining acceptable impacts and environmental standards
- Exploring means to ensure Indigenous fishing cultural rights are addressed and process to develop an Indigenous catch and allocation model
- Understanding and communicating health and nutrition benefits from fish and fishing
- Understanding market dynamics, trade and market access and how these may need to change moving forward if environmental change or ecosystem based approaches to sustainable management suggest that species targeting needs to shift away from the species that have

traditionally defined the Australian palate

- Processing and supply chains for eco-produced and certified seafood products
- Economic evaluation of enhancement strategies.

'Whole of system' and multiple-use approaches:

- Operationalising end-to end- quantitative ecosystem models
- Assessing the role of spatial management in meeting EBFM and EBM objectives
- Understanding multiple use interactions and cumulative impacts
- Understanding coupled socio-ecological systems, including developing methods to explicitly model human behavior and institutional dynamics
- Mechanisms for tradable rights within and between sectors.

Aquaculture

Farming systems:

- Environmental engineering and production system science for low footprint (enclosed), offshore and overcoming constraints on the expansion of sustainable intensive aquaculture
- Automation of farming systems and application of digital science to production and environmental monitoring – sensors etc
- Feasibility of semi-intensive aquaculture: e.g. low trophic level species; polyculture; integrated multi-trophic aquaculture (IMTA)
- Evaluation of enhancement strategies: restocking; translocation; management of environment.

Societal values:

- Quantitative indicators for assessing farming impact and multiple use interactions and cumulative impacts
- Biosecurity: e.g. monitoring; escapees; control of invasive pests and infectious disease management;
- Managing Climate Change impacts
- Animal Welfare in relation to domestic and international markets
- Production technologies:
- Optimising the use of all potential feed ingredients based on sustainability and societal values:
- Advanced technologies in controlled breeding
- Integration of innovative advances in production technology with biology and commercialisation: e.g. off-shore farming; biotechnological solutions to vaccines, reproduction and genetic breeding.
- Need for small scale, low maintenance production systems for Indigenous communities utilising key traditional target species
- Shift research paradigm to large scale whole of chain research and integration across R&D disciplines such as technology, biology, and food science and marketing.

Aquatic Animal Health and Biosecurity

- Improving the state of knowledge of aquatic animal health management including the epidemiology of disease threats, physiology of the hosts and technology for managing disease
- Better understanding of the factors that trigger disease emergence
- More effective methods to manage diseases in farmed aquatic animals
- Information on geographical and host ranges; pathogen/host/environment interaction and the mechanisms of disease transmission within populations
- Developing systems for rapid detection and management of exotic incursions
- Assessing the implications of climate change as a key factor influencing the emergence of diseases.

Food Safety and Innovation

- Increased capability for screening techniques for rapid, sensitive, cheap, reliable detection of pathogens and contaminants in the food industry
- More effective risk management methods for the seafood industry
- Approaches to the minimization and utlisation of waste
- Capability and capacity in the marine biotoxin field, including improved understanding of the ecology of harmful algal blooms and development of rapid screening tests.
- Cost-effective mechanisms to enable traceability and provenance
- Trade and market access research

Perspective

Food security is an important issue for Australia and our regional neighbours. With a growing population, increasing demand by other users for access to aquatic resources, compounded by long term changes in the environment due to climate change and the increasingly crowded marine and coastal space there are significant challenges to be met. Food security is not only about the volume of product, of which seafood is a major source, but also to maintain human health.

Significant challenges for Australia's fisheries and aquaculture include increasing community requirement for government and industry accountability, poor social license to operate for the industry, and maintenance of resource access including the recreational and indigenous sectors whilst still maintaining a viable industry. Regionally challenges include capacity, resources and suitable institutional frameworks.

Aquaculture is playing an increasingly important role in global food production and food security. It is the fastest growing food production sector in the world, with an annual growth rate of 7%, and now supplies 50% of total fish and shellfish for human consumption. Globally, the industry will need to produce and additional 40 million tonnes of aquatic food per year by 2030 just to maintain the current per capita consumption. The demand will be higher still if the current flat trajectory of wild capture fish production is persistent into the long term. The Australian aquaculture sector has an annual growth rate of 6% (albeit from a small base).

Australia currently imports 60% of its seafood. This provides the opportunity for a step-change in the sustainable growth of Australian aquaculture, supported by more efficient use of fishery resources. This would increase Australia's self-sufficiency in seafood and enable the industry to respond to the increasing demand for high quality seafood from Asia. Our location adjacent to world's largest market for seafood, and the southeast Asian region's predicted growth, provides significant opportunities for seafood production and export, as well as the provision of services covering the whole fishery and aquaculture management system. It is significant that, of the major food sources, aquatic products are predicted to have the largest real price increase. This will require enhancing our Business Development expertise so that we can respond to increasing international private and public sector/aid agency demands for Australian knowledge and technology.

However, the increased, and growing, movement of people and commodities on a global scale is a major risk factor contributing to the spread of disease (Hine *et al*., 2012). Increased trade causes a concomitant increased in risk. The risk of introduction of exotic disease, via various pathways, is a major concern and a constant threat to the aquatic environment and natural resources, and to wild and farmed fisheries.

The Australian Fisheries Management Forum's recent 'National Statement of Intent' identifies four goals for fisheries and aquaculture:

1. Australia's fisheries and aquaculture industries are managed, and acknowledged, to be ecologically sustainable

2. Secure access to fisheries and aquaculture resources
3. Profitable and viable fisheries and aquaculture industries
4. Supporting the health of habitats upon which fisheries and aquaculture rely

These have informed the following priorities at least those in the short term. Into the long term it is hard to anticipate what will be the highest priorities. However, if an adaptive approach is maintained then these issues can be addressed as they become apparent rather than being missed by focusing on topics which may decline in importance with time.

Wild Catch

Science Priorities: 5-year horizon

- Fishery assessment methods and harvest strategies, particularly for data-poor species and fisheries, standardised and reported across all jurisdictions
- Improved recreational fishing data sets and incorporation in assessments
- Agreed national science and management standards to support increased efficiency across jurisdictions and improved community confidence
- Methods and approaches to estimate total national sustainable fisheries production
- Improved methods to mitigate the impacts of fishing on TEPs, discards and habitats including performance metrics
- Addressing barriers to full and effective indigenous involvement in mainstream fisheries decision making processes and develop models to determine Indigenous catch and allocation
- Fill critical information gaps regarding ecosystem process, such as the way in which relationships between predators and prey may change through space and time; the implications of climate change and variability in particular, range shifts, non-stationarity, and ocean acidification on stocks, ecosystems and management arrangements; and a clearer understanding of the dynamic linkages between catchment, coasts and oceans and their role in fishery production
- Assess the implications of marine noise on fishery resources and the ecosystems that support them

Science Priorities: 10-year horizon

- Integrate citizen science where appropriate in data sets that inform management of fishery systems
- Given the likely changes in climatic conditions and other environmental drivers, determine whether there are key habitats within each bioregion that drive fisheries production and, where relevant, develop cost effective methods to monitor changes to these habitats through collection of empirical data
- Investigate increasing productivity through habitat repair, enhancing habitat and stock manipulations and determine the ecosystem and policy implications of such activities
- Explore the remaining potential in wild fisheries production through emergent fisheries and better utilisation of under-utilised species and bycatch etc

Science Priorities: 20-year horizon

- Gaps and challenges with respect to impacts of changing climate on fisheries and coastal communities; several neighboring nations predicted to be affected even more intensively than Australia which will put pressure on Australia to assist in seeking solutions and contributing to global food production
- Integration of real time monitoring (potentially of large volumes of data) into assessments and research as sensorisation continues and the number of data streams grows. In combination with

this will be understanding the reporting needs/desires of a public that is dealing with a general increase in information–what will they desire in terms of access verses filtering?

Aquaculture

Science Priorities: 5-year horizon

- Commercialisation of at least one new aquaculture species production (eg Yellowtail Kingfish, Cobia)
- Strengthen biosecurity, and foster new links with energy technology, product development, packaging and cold-chain opportunities.
- Development of information technology that incorporates bio-sensors and farm management decision tools.
- Expand activities in applied breeding programs, including the move into the 'omics' domain (managing and applying metadata) and integration with other domains (physiology and health).
- Expand activities in nutrition and feed technologies; in particular, fishmeal and fish oil alternatives; and closer linking of health and nutrition.
- Development of a small scale, low maintenance production systems for Indigenous communities utilising key traditional target species

Science Priorities: 10-year horizon

- Increased activities in the application of sensor technologies for animal welfare and monitoring and controlling production environments
- Further establishment of new aquaculture systems being developed overseas, including offshore aquaculture, multi-trophic integrated aquaculture (MTIA), and on-land recirculating aquaculture systems (RAS).
- Increased automation of farming and harvesting systems
- Establishment of novel preventive health management technologies –including vaccines and integrated breeding.
- Improved biosecurity technologies for detection and control of new diseases.
- Research to ensure Australia dominates world supply of disease free stocks of several key species e.g. salmonids; prawns and lobsters.
- Integrated sector leadership underpins integrated approach to R&D and adoption, research mainly done by large multi-discipline teams located across world leading organisations.
- Climate change impacts being managed effectively through the development of new species; selective breeding of current species and changes in technology used to growth them.

Science Priorities: 20-year horizon

- Close lifecycle of high value difficult to produce endemic species
- Increased aquaculture production to meet more of domestic market and increased export in niche areas where Australia has a competitive advantage. Aquaculture based on a 'whole of system' approach using shared values.
- Develop a 'whole of system' approach by integrating current capabilities with enhanced capabilities in aquaculture systems (open ocean, closed containment, recirculation), production environment monitoring and management.

Aquatic Animal Health and Biosecurity

Science Priorities: 5-year horizon

- Knowledge of known exotic diseases remains current
- Systems are in place to enable rapid detection and management of exotic incursions
- Collaborations with international experts are strengthened
- Develop validated diagnostic tests for significant new and emerging diseases of aquatic animals in Australia.

Science Priorities: 10-year horizon

- Establishment of novel preventive health management technologies –including vaccines and integrated breeding.
- Development and application of next-gen sequencing for disease diagnosis.
- Increase the sensitivity of Australia's passive surveillance systems for aquatic animal diseases.

Science Priorities: 20-year horizon

- Invest and adopt new technologies that provide novel solutions for improved detection and prevention of biosecurity threats to aquatic animals.
- Develop national aquatic animal health curricula for veterinary and vocational education.
- Systems are in place for improved epidemiology/intelligence gathering/social scanning for the early detection of new emerging viral pathogens.

Food Safety and Innovation

Science Priorities: 5-year horizon

- Building processes to develop new technological approaches to pathogen and contaminant detection
- Development of rapid detection diagnostics based on biosensors
- Development of lean manufacturing technology including automation systems to deal with multiple species
- Develop waste minimization technologies
- Development and validation of rapid screening techniques for marine biotoxins
- Assessment of which toxins are a hazard in Australia and which species are at risk
- Development of options for improved traceability and provenance

Science Priorities: 10-year horizon

- Commercialising diagnostic sensors and adapting for use in the field and on-site.
- Implement waste reduction and/or use technologies
- Improved risk management options to reduce monitoring and management costs
- Implementation of methods for improving traceability and provenance.
- Defining and enhancing nutritional benefits of seafood including investment in functional foods and foods targeting specific populations

Science Priorities: 20-year horizon

- Prediction of algal blooms and improved monitoring including in situ sensors.

Cross-cutting Issues

There are specific science needs for each of the four areas (as elaborated in the working papers). However, there are a number of clear cross-cutting issues that have broad relevance.

Science Priorities: 5-year horizon

- Research on social license to operate and define activities necessary to support debate around acceptable impacts and environmental standards
- Methods to better integrate coupled socio-economic and biophysical approaches to resource assessment
- Development of new observational technologies, remote sensing, genetic and biochemical methods, and methods for recreational fisheries monitoring. Develop a framework for sustained ecological observing including linkages with other observing infrastructure such as IMOS
- Assessing the role of spatial management (including those for other purposes, such as conservation) and develop performance measures
- Develop methods to assess cumulative impacts on marine and coastal resources including dredging, marine harvest, coastal development
- Investigate the science basis for determining acceptable impacts and develop environmental standards

Science Priorities: 10-year horizon

- Implement a national ecological observing framework that supports research in fisheries and aquaculture, biodiversity conservation and other marine uses
- Operationalise end-to end ecosystem models. Development of a tool kit of socio-ecological frameworks that span scales and levels of data availability (as has happened for biophysical assessments) and extend the tool kit to enable trade-offs within and between users of marine resources.
- Have an open discussion on marine interventions. As ecosystems shift under global change it needs to be clear whether enhancement, translocation, human-assisted closure of life histories etc are considered acceptable or desired management actions by society.
- Cumulative impacts and competition for space will grow with expanding marine industries, in addition upstream pressure could have significant effect on marine production, so integrated management is required. The transition to such an approach is likely to be on a generational scale (unless accelerated by changing public opinion or a significant event). Consequently, there will be further work required on how to operationalise and effectively implement integrated management.
- Strong societal support for industry achieved through whole of system approaches to sensitive issues including animal welfare and multiple use of environment. Research underpins decision making and informs debate on values.

Realisation

The funding for fisheries and aquaculture research has been stable, or declining in real terms, over recent years. This is despite fisheries and aquaculture being an increasingly complex research environment (Murphy and Lewis 2014). The National Fishering and Aquaculture RD&E Strategy has provided a mechanism to support better collaboration, coordination and reduction in duplication. The National Research Providers Network (Research Directors, representatives from universities and stakeholder groups) has supported this Strategy, but more needs to be done. An overall decrease in availability of funding requires consolidation of groups but could compromise the capacity to address the demands for evidence-based management advice and maintaining the standard of our industry advice. Given the current funding limitations, research capacity could be improved through increased collaboration between fisheries agencies, universities and industry by using the existing infrastructure, expertise and availability of research students at universities to address fisheries and aquaculture research (e.g. funded through ARC Linkage and FRDC projects).

Assessment and management of marine resources requires a commitment to ongoing monitoring and performance evaluation. However, this should be separated from specific research priorities. This will be crucial as funding becomes tighter.

Key capability requirements include:

- The ongoing need for highly quantitative scientists
- Establish a collaborative network for aquaculture under the National Fishing and Aquaculture RD&E Strategy
- Inclusion of Indigenous participants in the establishment of collaborative networks for fisheries and aquaculture.
- Economists and social scientists with experience in the domain leading to monitoring and research in support of the economic, social and cultural dimensions of fisheries and food security (perception, social licence, engagement, institutional dynamics, governance, changing desires)
- Better communication between and integration of disciplines across the bio-physical and social sciences
- Developing a 'whole of system' approach by integrating current capabilities with enhanced capabilities in aquaculture systems (open ocean, closed containment, recirculation), production environment monitoring and management (nutrient dynamics and ecosystem health and integrated adaptive multiple use and ecosystem based management).
- Role of professional societies, e.g. AMSA and ASFB
- Rollout of NextGen technology in an accessible and efficient form, including molecular approaches such as DNA 'sniffers', and increased activities in the application of sensor technologies for animal welfare and monitoring and controlling production environments.
- Strengthen links in biosecurity, and fostering new links with energy technology, product development, packaging and cold-chain opportunities.
- Expand activities in applied breeding programs, including the 'omics' domain (managing and applying metadata), integration with other domains (physiology and health) and activities in nutrition and feed technologies; in particular fishmeal and fish oil alternatives; and closer linking of health and nutrition.

Infrastructure:

- Explicitly building on existing research infrastructure such as IMOS
- Access to vessels such as the Investigator to address national challenges
- CSIRO, in partnership with the Queensland Department of Agriculture, Food and Fisheries (QDAFF), has a developed a world class, controlled environment aquaculture facility on Bribie Island. The opportunity exists to transform this facility into a Centre of Excellence for Aquaculture research in Australasia.
- National network of research laboratories, including universities, that could, for example, conduct experimental research on climate change and cumulative impacts on fisheries and aquaculture species
- All state government fisheries and aquaculture research institutes have extensive aquaculture facilities. For example NSW DPI at Port Stephens, SARDI at West Beach, NT Fisheries in Darwin.
- Many universities also have extensive capabilities – the key universities are: Southern Cross

University, JCU, UTas, Flinders Uni, Deakin Uni, Curtin Uni, Charles Darwin Uni, Uni of Sunshine Coast, Wollongong Uni

- Improved fish health facilities –including large fish systems for developing feeds and vaccines

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Australian Antarctic Division
Australian Prawn Farmers Association
Bureau of Meteorology
Commonwealth Scientific and Industrial Research Organisation (CSIRO)
Curtin University
Deakin University
Department of Agriculture, Fisheries and Forestry (QLD)
Department of Fisheries, Government of Western Australia
Department of Primary Industries, Government of New South Wales
Fisheries Research and Development Corporation (FRDC)
Geoscience Australia
IC Independent Consulting
Institute for Marine and Antarctic Studies (IMAS), University of Tasmania
James Cook University
Macquarie University
Petuna Aquaculture Pty Ltd
RDS Partners Pty Ltd (Consultants)
Seafood CRC
Seafood Industry Victoria
South Australian Research and Development Institute (SARDI)
Southern Cross University
The Department of Agriculture
University of Melbourne
University of Queensland
University of Tasmania
University of Technology, Sydney
University of Technology, Sydney
University of Western Australia Oceans Institute
University of Wollongong
University of New South Wales
Western Australian Marine Science Institution (WAMSI)

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