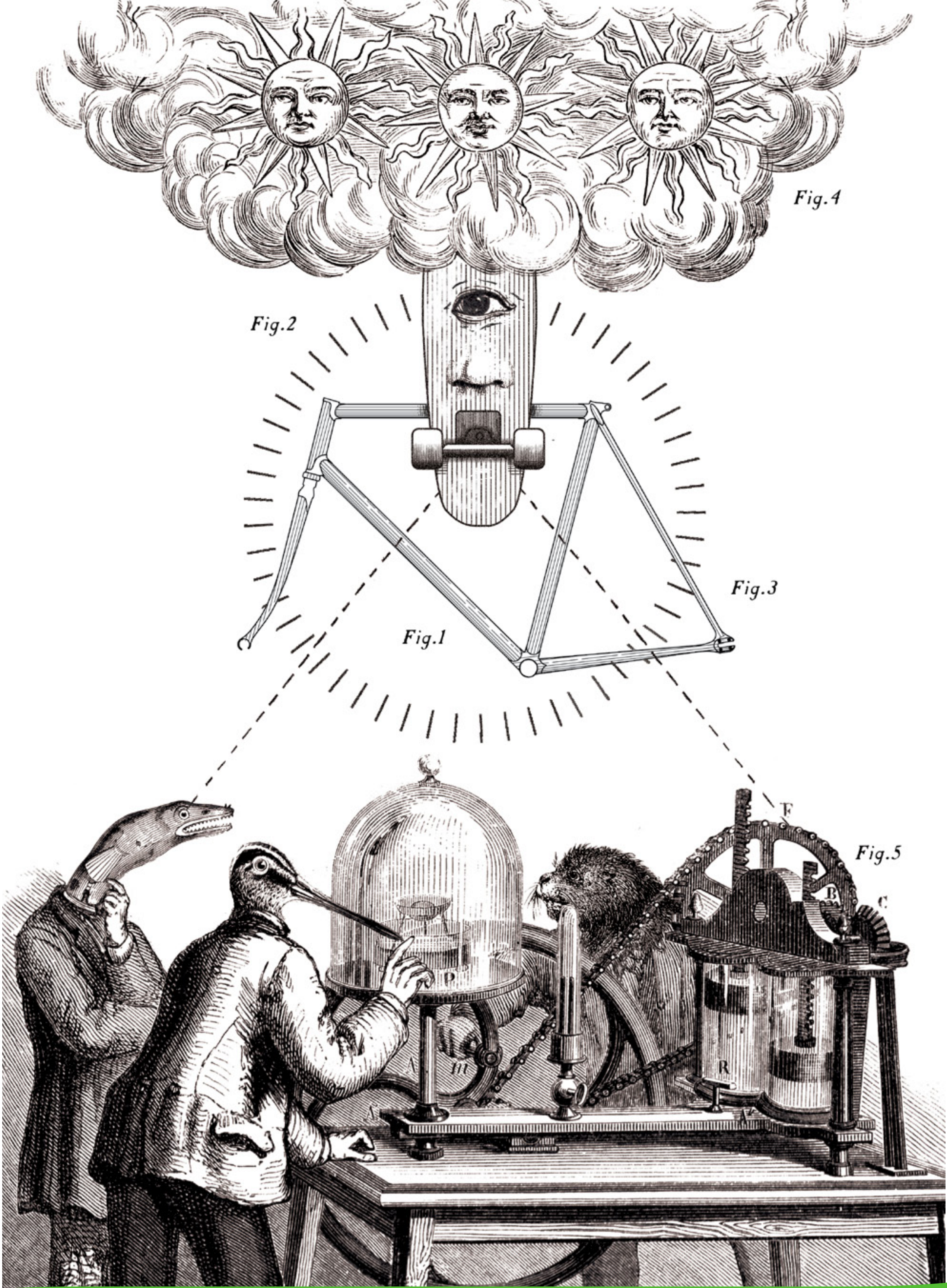

Public Agricultural Research in an Era of Transformation: The Challenge of Agri-Food System Innovation

Resource Document I: Case studies

CGIAR Independent Science and Partnership Council

CSIRO

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Public Agricultural Research in an Era of Transformation: The Challenge of Agri-Food System Innovation

Resource Document I: Case studies

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AUSTRALIAN COTTON INDUSTRY

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SUMMARY

This case study examines the development of the Australian cotton industry from the rapid adoption and subsequent further innovation from a high-input, industrialised cotton production system in the early 1960s, to becoming the third largest exporter of cotton in the world. Today, Australian-bred cotton varieties produce the highest yields globally and are among the most sustainably farmed. This history of innovation critically depended for its genesis on high levels of public investment in water infrastructure, subsidies to incentivise farmers to grow cotton and research and development of new cotton varieties, coupled with the private investment, technologies and knowledge brought to Australia by immigrant cotton farmers.

More recently, it was the deployment of sustainable management practices through a form of co-regulation between industry and government, and a unique architecture of alliances between public research, industry bodies and government that have allowed the Australian cotton industry to maintain its competitive edge.

This case illustrates that concerted, collective public- and private-sector investments were necessary to build a modern cotton production system in Australia and makes a case for the value of ongoing public investments in foundational science and technology to maintain the innovation dynamic and sustainability of the industry into the future.

Table. Patterns of Innovation and Impact processes Summary table

Initiator	Creation of the Australian Cotton Growers Research Organisation and the Australian Cotton Foundation in 1974 (and subsequent organisational developments) to coordinate research for national benefit and enable a series of subsequent institutional developments to support innovation across the sector.
Critical features	A unique architecture of alliances. The development of deep public science capability, particular in CSIRO. A mode of innovation that is both responsive and forward-looking.
Role of research	Critical in developing varieties and practice suited to Australia, but also responding to environmental concerns through step change varieties and management practices.
Operational alliances	Strong industry-research alliances.
Strategic alignment of stakeholders at sector or national level	Coordination mechanism to address industry needs, national benefits, and environmental concerns.
Solution, product, or system innovation	Novel products and management strategies that have enabled the sector to transform and continuously adapt to changing conditions.
Scope of impact (and metrics)	CSIRO's cotton breeding programme shows an estimated 80:1 return on investment and more than $5 billion net present value from increased yield and regional adaptation in Australia.

CHALLENGE/OPPORTUNITY

Australia is a relatively small producer of cotton with 4.2 million bales produced in 2016/17 (less than 3% of global production) compared to 27 million bales for India, 22.8 for China and 17.2 for the United States. However, Australia exports 87% of its cotton, making it the third largest exporter in the world (Cotton Inc., 2017). The industry faces numerous challenges, including the need to develop varieties suited to Australian conditions, the management of insecticide and herbicide resistance, and the environmental concerns related to their use and the management of water.

The critical factor determining cotton production in Australia is the availability of irrigation water. Cotton production in Australia has consistently fallen in dry years. Since cotton is generally a higher value and more profitable crop than alternatives such as wheat and oilseeds, growers tend to decide on cotton plantings based on the volume of water they have available and are less responsive to changes in cotton prices. Changes in spot prices are also less of a factor, because farmers commonly use futures markets and hedging to manage their risks. The profitability of cotton relative to other crops becomes important to crop selection in years when prices fall sharply (ABARES, 2017). In recent years competition from synthetic fibres has also increased, driven by depressed oil prices and technological innovation.

Therefore, to remain competitive and thrive, the Australian cotton industry has needed to continue to innovate to produce higher yields and quality of lint and decrease production costs, as well as exploring post-farm value-added options.

INNOVATION

The establishment and development of the Australian cotton industry into a mature and globally competitive industry represents multidimensional innovation. A favourable policy and economic environment coupled with private farmers' investments in advanced production methods gave the industry its start. The gradual evolution of an architecture of alliances and institutional arrangements between public research, industry and government allowed the industry to survive and grow.

Technological innovation. Australia achieves the highest irrigated cotton lint yields in the world, while keeping the costs of production on par with the world average. Australian cotton growers produced on average 12.95 bales/ha in 2016 (CRDC, 2016), more than three times the world average of 0.76 t/ha (3.3 bales/ha) (OECD/FAO, 2016).

In the past decade there has been a 126% increase in cotton production, although the area sown has only increased by 50% and it has been achieved with ever more efficient water use. Australian producers almost doubled their irrigation water use efficiency from 1.1 bales/mega litre in 2000–01 to 1.9 bales/mega litre in 2009–10 (CRDC, 2012). These achievements are attributed to the development of new cotton varieties and improved management practices (Liu *et al.*, 2013; CRDC, 2012). A core activity of Australia's cotton varieties research undertaken by the CSIRO is to source or create diversity of genetic features that influence yield, fibre quality, disease resistance and plant growth patterns to match diverse climates and crop management systems. Novel germplasm is sourced from overseas, managed through quarantine, and evaluated for use in cross-breeding.

Deployment of transgenic varieties. GM cotton was the first transgenic field crop introduced into Australia. Transgenic traits were initially introduced to reduce use of pesticides and address resistance, the first variety being Ingard® in 1997, followed by Roundup Ready® and Bollgard II®. In the past 35 years, CSIRO has released more than 100 conventional and transgenic cotton varieties, containing multiple improvements to disease resistance, fibre quality and adaptability. Today, 99% of cotton planted in Australia is transgenic.

No trade restrictions have yet been applied to cotton fibre, yarn, or other textile products made with GM cotton in the world, although GM adoption has been slow in many countries. Cottonseed oil does not require GM food labelling, as the oil is separated from Bt and other transgenic proteins during processing and contains no GM material (Cotton Australia, 2016).

Yield increases and regional adaptation. Cotton varieties have been adapted to Australia's diverse soil and climatic conditions, including the effects of heat stress, which has increased commercial viability in areas where cotton could otherwise not have been grown and has improved yields due to reduction in crop losses due to disease and pests.

Disease and pest resistance. The first generation Bt insect resistant trait (Ingard®) reduced insecticide application by 45%, but was used on less than a third of the total area of farms to reduce the risk of resistance developing. The second-generation two Bt gene trait (Bollgard II®) was used over 90% of plantings and has reduced insecticide use by up to 80% across the industry. The latest product, Roundup Ready Flex® allows for a more environmentally friendly weed control system compared to earlier methods (Constable *et al.*, 2011).

High fibre quality. Cotton breeding has improved the quality of Australian cotton staple length and fineness and maturity (micronaire), building Australia's international reputation among spinners as a producer of high-quality cotton and allowing Australia to compete in premium export markets.

Water efficiency. Improved farm water and crop management and the use of new cotton varieties mean that Australian cotton crops use on average 40 per cent less water in producing a bale of cotton than they did 10 years ago (CRDC, 2012).

Institutional innovations. Today, Australia's cotton industry is a network of domestic and international professional disciplines, public organisations, not-for-profit organisations and private companies bounded by legislation and commercial relationships (CIN, 2014).

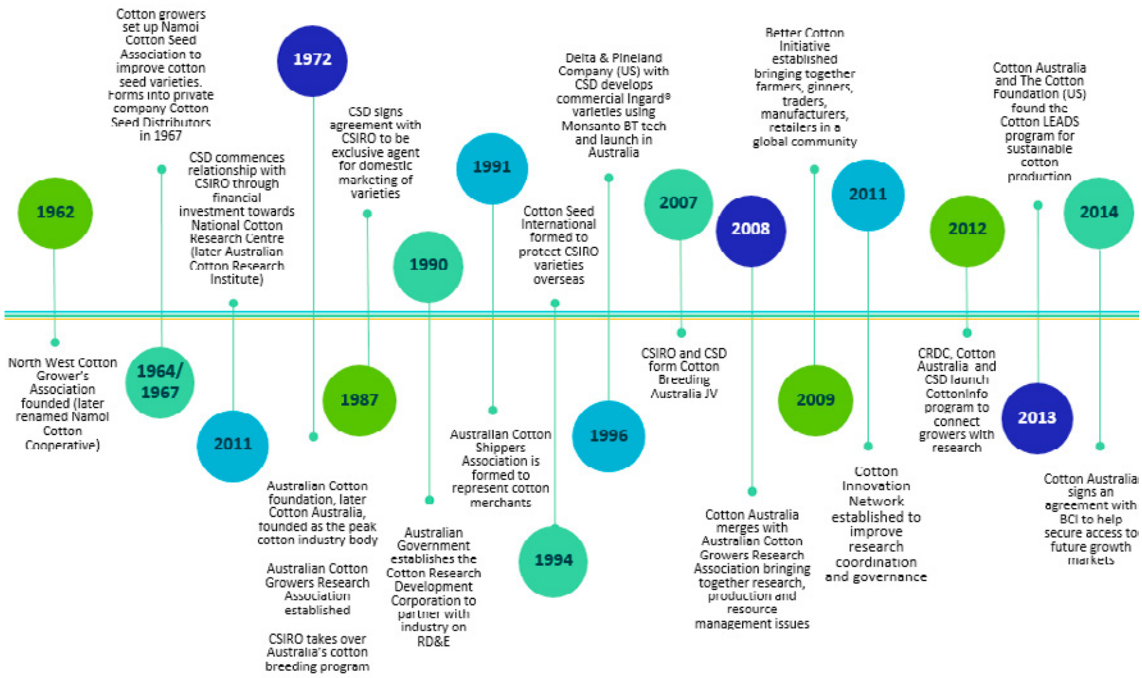
At the centre of the industry are the 1300 cotton farms, primarily family owned and operated, each growing, on average, no more than 500 hectares of cotton (Cotton Australia, 2016). Farmers are generally organised into cooperatives that arrange machinery purchases, provide seed, advise on pest control and undertake processing and marketing. Examples include the Namoi Cotton Cooperative, the first cotton cooperative established in Australia, and now one of Australia's largest cotton ginners. Cotton farmers frequently diversify into other cropping or livestock activities. From 2006 to 2016, 78% of farms had between three and six enterprises each year, and 22% had seven or more (ABARES, 2017). Land management often involves the rotation of crops. In other circumstances, farmers will reduce cotton acreage in response to better returns from grains or in response to water scarcity. There are several major corporate cotton producers, but their combined market share does not exceed 20% (IBISWorld, 2017).

The development of R&D architecture began in the 1970s and continued through the 1980s with CSIRO facilitating a process of uniting the disparate breeding programmes and establishing a cohesive approach to cotton research and breeding in Australia. The Australian cotton industry has benefited from this highly integrated system of research into cotton breeding and management. Up to today, no other organisation in the world has been able to replicate CSIRO's level of cotton research coordination (CIE, 2002). In the USA, for example, numerous universities and private companies employ unique breeding programmes for their local environments. However, these breeding programmes are not connected to a larger strategic programme and are not effective for a broader range of environments across the USA.

Australian cotton research is funded through a complex set of public and private arrangements. Questions continue to be raised over whether public funding should be directed to research that directly benefits private businesses (CIN, 2014). Joint Commonwealth and industry funding of the CRDC and public providers such as NSW DPI, QDAFF, CSIRO, and universities delivering programmes with public benefit address this issue to some degree. For example, the Cotton Research and Development Corporation and the Cotton Seed Distributors have funded CSIRO's research efforts from the early 1970s to the present (CSD, 2017). In 2007, CSD and CSIRO established a joint venture, Cotton Breeding Australia, to invest in research and breeding of future cotton varieties for Australia. To date the joint venture has invested $101.7 million and has a projected shared investment of over $175 million by 2024 (CSIRO, 2017). In addition to these co-financing arrangements, CSIRO is also engaged in commercial arrangements with global agricultural biotech companies such as Monsanto and Bayer, which have provided Australian farmers with access to valuable new traits delivered through CSIRO cotton varieties.

A number of non-financial partnerships exist to facilitate innovation in the cotton industry. Under the National Primary Industries RD&E Framework (NPIRDEF) policy initiative introduced in 2009 each major sector (e.g. cotton, grains) and cross sector (e.g. water use and soils) is tasked with developing and implementing a national RD&E strategy. In the cotton industry, key R&D actors (CRDC, Cotton Australia, CSIRO, NSW DPI, QDAFF and ACDA) came together to form a working group to develop a strategy. By 2011, the Cotton Innovation Network (CIN) was established to provide improved governance to the industry's research model, including coordination between actors to identify priorities and pathways to achieve these priorities. Over time the network has become a channel for members and other research organisations to raise challenges and promote opportunities for improved coordination. For example, CSIRO collaborates with the Australian Cotton Shippers Association (ACSA) and the International Textile Manufacturers Federation on initiatives to improve post-harvest transportation and handling with the aim of ensuring that damage to, or contamination of, high-quality cotton fibre is minimised (ACIL Allen, 2014).

Figure 1. Key milestones in the institutional history of the cotton industry



Market innovation. To meet international market standards, Australia's cotton industry has led and supported a range of branding strategies, quality systems and environmental assurance frameworks to differentiate Australian cotton and meet consumer and market expectations.

Cotton Australia is the representative organisation for the Australian cotton growing industry. Established in 1972 as the Australian Cotton Foundation, Cotton Australia merged with the Australian Cotton Growers Research Association in 2008 to bring together research, stewardship, natural resource management and cotton production issues. Cotton Australia established a number of programmes to promote Australian cotton in the world market and create value for Australian cotton growers.

In 2013, Cotton LEADS™ was established, a partnership between Cotton Australia and US cotton industries (The Cotton Foundation) demonstrating a commitment to the supply and use of responsibly produced cotton and offering manufacturers and retailers a reliable supply chain and confidence that cotton is responsibly produced and traceable.

In 2014, Cotton Australia signed an agreement with the Better Cotton Initiative (BCI) on behalf of Australia's cotton industry to help secure access to future growth markets as Australian cotton growers contend with competition from synthetic fibres. The agreement transfers a BCI license to Australian cotton produced under BMP certification. In 2014–15, 11% of Australia's cotton crop was grown under BCI licence, with some growers able to negotiate a premium price per bale of $3–$8 (Cotton Australia, 2017).

In the Australia marketing system growers forward sell their crops directly to independent merchants, who on-sell the cotton into overseas markets and pay the grower. The Australian Cotton Shippers Association was formed in 1991 to represent the interests of these companies and the industry generally in overseas markets and promote the export of Australian cotton.

INNOVATION PATHWAY

Cotton seed was first imported to Australia with the British Fleet in 1788. However, not until the American Civil War, which disrupted supply to Britain and increased cotton prices, was a significant quantity grown in Queensland. After the Civil War, prices declined and production in Australia effectively ceased, though attempts were made to keep it alive. In 1890 the first Australia cotton mill was built in Ipswich, following a reward offered by the Queensland government, but it was unable to compete with imports and closed down after a few years (Basinski, 1963). Cotton growing was still a labour-intensive enterprise and the lack of a large and cheap labour force is cited as another contributing factor. Colonial sensibilities did not consider white labour suitable to work the cotton fields (Keys, 2012).

Following Federation, Queensland remained the focus of cotton growing efforts, supported by government incentives. The first Commonwealth bounty was introduced under the *Bounties Act 1907*, granting farmers a 10% bonus on the value of cotton and cottonseed supplied. The First World War suppressed cotton growing, but it revived in the 1920s and 1930s, supported by state and federal guaranteed minimum prices and bounties and the establishment of a compulsory centralised marketing system through the Queensland Cotton Marketing Board in 1926, although no special provisions were made for cotton research. In the late 1920s the Queensland Department of Agriculture and Stock took on the responsibility for research. Amendments to the Cotton Bounty Act in 1935 allowed for a bounty on cotton lint, and the government re-established a minimum price on cotton before the outbreak of the Second World War, but cotton production declined again during the war and ensuing years due to labour shortages (Basinski, 1963). The *Cotton Bounty Act 1951* reintroduced a guaranteed minimum price in response to increasing demand at the outbreak of the Korean War. The guaranteed minimum price was maintained until 1963.

Although the existence of such economic incentives was meant to stimulate production of cotton, it was still a matter of debate whether cotton should be grown in Australia at all, given its possible effect on the balance of trade with key partners such as the US and Japan (Bureau of Agricultural Economics, 1962). Cotton growing was still a minor undertaking, confined primarily to Queensland and with the average acreage per cotton grower not exceeding 20 acres. Farmers growing cotton did so as a "side-line enterprise or as a chance crop" (Keys, 2012).

Australian cotton production did not occur at the scale required to make it economical and the industry suffered from low and variable yield and poor quality of cotton, a large percentage of which was unsuitable for textiles (Basinski, 1963; McHugh, 1996).

The industry changed completely in the early 1960s when high-input irrigated cotton production started in NSW, Queensland and Western Australia. Insecticide-resistant pests closed down the WA industry situated on the Ord river in 1974, but production in NSW and QLD increased from around 100,000 bales in 1975 to over 1 million bales by 1985 (Cotton Australia, 2016).

The emergence of the modern, intensive, irrigated and industrialised form of cotton production would not have been possible had it not been for the convergence of political, geographic and economic factors and the resulting public- and private-sector investments and institutional arrangements:

1. Public and private spending on research and development of cotton varieties and traits.
2. Public spending on infrastructure in the form of construction of dams, making large-scale irrigation possible.
3. Government subsidies in the form of cotton bounties until 1973.
4. Importation of technologies and knowledge by immigrant cotton farmers in the early 1960s.

The New South Wales Department of Agriculture founded the Narrabri Agricultural Research Station in 1958, which was tasked with investigating the suitability of crops that would be grown with irrigation from the Keepit Dam (completed in 1960), such as grain crops, pasture crops and cotton. A crucial appointment was made of a Hungarian immigrant cotton specialist in 1959. 136 varieties of cotton were trialled in 1959 alone (McHugh, 1996). Positive results prompted the NSW Department of Agriculture to invest some GBP200,000 in the research station.

The widely published results from these trials attracted the interest of Californian cotton farmers. Two farmers undertook an exploratory mission, touring sites in Queensland and NSW and meeting with departments and local members of government.

Attracted by a combination of good climate and soil, cheap land prices (a third of those in California), the Commonwealth cotton bounty, and with easy access to irrigation water, the first group of Californian farmers set up farms around Wee Waa in 1961, introducing the intensive industrialised cotton growing they had known in California. (Irwin, 1972; McHugh, 1996). This introduced new methods of working and irrigating the land. Heavy machinery was required to clear vegetation and level the land, then grade it and 'hill it up' so it could be used for flood irrigation. Storage dams were built and tailings dams were added. Some of the necessary equipment could not be purchased in Australia and had to be imported (Keys, 2012).

The first harvest in 1962 was successful on multiple levels. The farmers had achieved a good yield and proved that the region could do cotton well, and the associated Field Day attracted curious crowds from Queensland and NSW who wanted to see what the foreigners were up to. By the next season, there were eight cotton growers in the Namoi and the number rose exponentially from then. An indication of the growing importance of cotton growing in the region was the establishment of the North West Cotton Growers Association in 1962 (later renamed the Namoi Cotton Cooperative), which secured a loan for the first cotton gin with 50% backing from the NSW Government. The gin was purchased from the US, shipped to Australia in 100 crates and assembled at Wee Waa. The gin opened in 1963.

In 1964 the growers set up the Namoi Cotton Seed Association to work with government bodies to promote and improve the varieties of cotton seed; this was formed into a private company limited by guarantee in 1967 known as Cotton Seed Distributors (CSD), whose founders included the first Californian farmers. CSD would go on to test more than 200 cotton varieties over the next 20 years.

Cotton was established in the late 1960s in the Macquarie Valley and at Bourke (NSW) and in the 1970s in the Gwydir Valley (northeastern NSW) and the Macintyre Valley (southern Queensland) following the construction of dams in those regions.

Manufacturing systems, including cotton ginning, oil milling and seed distribution, developed rapidly alongside the new agricultural system of cotton production and so did urban systems in the cotton growing regions. For example, small rural towns such as Wee Waa rapidly increased their populations after 1961 by about 70% in a single decade with commensurate expansion in services to the town community (schools, hospitals, banking facilities, etc.) and farmers. A number of oil companies established depots from which petroleum products could be distributed. Earth moving contractors, chemical supply firms, engineering firms and aerial spraying contractors also established businesses in town to cater to the cotton growers (Irwin, 1972). Due to the extensive mechanisation of the industry, much of the employment generated was not on-farm, but in auxiliary industries.

A drought in 1966 highlighted an issue that would remain a source of conflict until the present – the control over and allocation of water. In the Wee Waa area alone, water licences covering 4000 ha of land had been granted when the Keepit Dam was completed in 1960. By the end of the decade, that figure had increased tenfold. When the drought began in the mid-1960s, water taken from the river by irrigators left little for landowners downstream, creating resentment (McHugh, 2012).

In 1965, cotton irrigation used about 80% of the water from the dam, which had originally been built to assist in hard times without having to report to artesian sources. In 1966, water users associations banded together to form an umbrella committee called the Coordinating Committee of the Namoi Valley Water Users Associations, who coordinated water allocation with the Water Commission. As the drought continued, a rostering system was introduced where farmers could pump water only on certain days, and in 1968 a new volumetric allocation system was legislated.

The new system changed farming practices. Once farmers had been given their projected allocations for the year, they had to adjust plantings according to allocation, and conservation of water became more important. Farmers built off-river storage to help manage drops in allocation. The disadvantages to the environment of this system of managing water within a single valley became clear in the 1990s, when excessive extraction of water from the upper reaches had damaged the ecological health of the Murray-Darling system (McHugh, 2012).

The over-allocation of water licences was not just a feature of the ambitious early days of the industry in the Namoi, but was repeated a decade later in the Gwydir Valley. It is estimated that the river was over-allocated by about 50% by the time the Gwydir was closed to irrigation (McHugh, 2012). Another drought in the early to mid-1990s created further bitter battles over water, which are ongoing. More recently, the cotton industry has been challenged to impose moratoria on its growth to reduce its effects on the Murray-Darling Basin (AAP, 2006). In 2017, the NSW Deputy Director-General of water resigned amid a scandal that involved allegations of some cotton growers harvesting water that had been set aside for the environment, tampering with water meters and sharing government knowledge that would help lobby against the Murray-Darling Basin Plan (ABC, 2017a). Cotton production is inextricably linked with the political economy of water management in the Murray-Darling Basin and the implementation of the Basin Plan that some scientists and farmers now argue is broken and has not delivered promised water savings since its implementation five years ago (ABC, 2017 b,c).

It is dependence on water and other unique Australian conditions that have led breeding efforts by the CSIRO to maximise cotton productivity, water use efficiency and quality. Since 1972, over 100 new cotton varieties have been bred. In the 1960s and 1970s, the only cotton varieties grown were US cultivars, and Australia's strict quarantine laws meant significant delays in getting seeds approved for planting. Anecdotal evidence suggests that some farmers may have taken matters into their own hands by smuggling seed into the country. During this period, state agriculture departments and the CSIRO funded separate breeding programmes in Griffith and Narrabri (NSW), Biloela (QLD) and Kununurra on the Ord River (WA). These programmes pursued different research goals and were geographically so dispersed that research capability was left uncoordinated. This led to the closure of the multiple programmes and CSIRO taking over the research unit at Narrabri in 1972.

Thereafter, CSIRO commenced a breeding programme that sought to develop full-season varieties for Australia's primary cotton growing regions (Constable *et al.*, 2011). The start of CSIRO's cotton breeding programme coincided with the establishment of the Australian Cotton Growers Research Association (ACGRA) in 1972, funded by a voluntary levy of 25 cents per bale. Members were Namoi Cotton Cooperative, Auscott Limited, Queensland Cotton Marketing Board, Cotton Seed Distributors and the Ord River Cooperative. ACGRA was established to raise and invest grower dollars in research projects. The association merged with Cotton Australia in 2008, setting a new path for the industry by bringing together research, governance, resource management, and production concerns.

The industry reached a milestone in 1985, when cotton production exceeded 1 million bales for the first time. Just over a decade later the first transgenic cotton variety Ingard® was introduced, followed by Roundup Ready® in 2002 and Bollgard II® in 2003. The introduction of these transgenic traits provide the cotton plant with in-built tolerance to the Helicoverpa caterpillar and the use of herbicides. The use of transgenic cotton is a key tool in farmers' integrated pest management (IPM) strategies that combine natural controls with pest-specific chemistry to reduce pesticide use.

The heavy use of pesticides and weed killers in the cotton industry had started to raise community concerns as early as the 1970s when DDT contamination of the environment was found to be widespread, and erupted in the late 1980s when export cattle were found to be contaminated with high levels of pesticides. In the early 1990s, a number of Agricultural Health Unit studies, the biggest scientific monitoring of cotton industry workers to date, warned of the risks of chemical exposure of cotton workers and recommended a change in work practices to better protect workers. Between 1980 and 1985 childhood deaths from leukaemia in Emerald were believed to have been linked to heavy pesticide use in cotton production in the region. In 1995 and 1996 in Gunnedah and Narromine further community health concerns were raised and a suspected cancer cluster investigated (Fragar and Temperley, 2008). The industry's social licence to operate was being challenged.

The cotton industry responded by commissioning its own independent environmental 'audit' in 1991, which led to the development of an industry-wide programme of environmental best management practices (BMP) in 1997 aimed at increasing grower understanding of practices, impacts, choices and interactions in their environment. The programme also fit under the internationally recognised ISO14001 standards with growers being audited by industry auditors (Richards *et al.*, 2006).

The BMP manual was designed to give growers tools for multiple aspects of cotton production including pesticide application and management and integrated pest management. A second environmental audit commissioned in 2003 confirmed the BMP as supporting systematic environmental assessments and continuous improvement (GHD, 2003). The BMP manual was supported by implementation and auditing programmes. Cotton Australia and the CRDC respectively provided specialist advice and training.

Going a step further, in 2005, the Queensland government signed an MoU with the Queensland Farmers' Federation to develop an accreditation framework for farm management systems programmes. This co-regulatory framework was considered an alternative compliance mechanism to the traditional either/or of self-regulation and external regulation and involved agreement between the cotton industry and regulators that would be able to meet both legal requirements and the needs of cotton growers. It required an amendment to the *Water Act 2000* to allow an approved industry programme, such as the BMP, to satisfy regulatory requirements in circumstances where a land and water management plan is required (Williams, 2005). In 2007, the Cotton BMP programme became accredited by the Queensland state government (Cotton Australia, 2008).

The BMP system helped transform the farming practices of the cotton industry, and in 2010 an updated and expanded programme was relaunched online as myBMP. To incentivise farmers to achieve myBMP certification, Cotton Australia, the CRDC and Monsanto set up a grants programme 'Better Farming Brighter Future' (Cotton Australia, 2017).

In 2011–12, the Australian cotton industry produced a record crop of 5.3 million bales despite almost a decade of drought. In 2014, Australia and Japan signed an Economic Partnership agreement (AJEPA), which binds tariffs at zero in the Japanese market.

The future of Australian cotton seems assured as world cotton use is expected to grow at 1.5% p.a. in the next decade as a result of population and economic growth (OECD/FAO, 2017) and consumer preference for sustainably produced goods is driving up demand for Australia's crop. Traceability, water use efficiency and reduced pesticide coupled with high-quality yarn is attracting growing interest from overseas and local buyers, who are now introducing clothing ranges made from 100% Australian cotton (ABC, 2017d).

However, the Australian cotton industry may face significant challenges in coming decades due to the effects of climate change. Modelling undertaken for CSIRO future climate projections using the biophysical simulation model APSIM show cotton yields decreasing by about 20% by 2050 (without the effects of CO_2 fertilisation) and 8% including CO_2 effects. Importantly it was shown that irrigation amounts would have to increase by almost 50% to maintain adequate soil moisture. Given current policy and community concern over the Murray-Darling Basin health it is unlikely that this water would be available. It will require farmers and the industry as whole to consider adaptation options to reduce the impact of climate change and water policy (Williams *et al.*, 2015).

IMPACT EVIDENCE

Today, all Australian cotton, half the dryland cotton in the United States and about one-third of the cotton in Brazil, Turkey and Greece, benefits from Australian-bred varieties. An impact assessment undertaken by ACIL Allen Consulting in 2014 identified a number of positive economic, environmental and social impacts for Australia's cotton industry.

Environmental impact	
Reduced chemical contamination from insecticidal sprays	Cotton varieties utilising Bollgard® II have led to a roughly 80 per cent decrease in pesticide use across Australia. Varieties utilising Roundup Ready Flex® have led to a 52 per cent decrease in residual herbicide use (CSIRO, 2014). This has resulted in improved water, soil and air quality in cotton growing regions and lower levels of environmental pollution (Knox *et al.*, 2006).
Increased water use efficiency	CSIRO varieties have significantly increased the water use efficiency of cotton growing in Australia. Over the past decade, water use efficiency in cotton farming has improved by 40 per cent due to a combination of changed water management and new, water-efficient cotton varieties (Roth *et al.*, 2013).

Social impact	
Improved quality of life and health	A reduced dependency on aerial spraying of pesticides has led to reduced interaction with harmful chemicals for farmers, labourers and local communities (Knox *et al.*, 2006).
Social licence to operate and community confidence	Farmers who grow CSIRO cotton varieties can lessen public concerns over environmental damage or health impacts from aerial pesticide spraying near towns by generally avoiding this practice.
Increased sustainability of rural communities	Cotton underpins the economy of rural areas in which it is grown, providing income for farmers, labourers, cotton transportation workers and cotton ginning workers. The cotton industry also supports local economic activity by supporting secondary industries and services.
Economic impact	
Increased productivity of cotton growing	• Reduced crop losses as a result of disease and pest attacks means higher yields of usable cotton and lower expenditure on pesticides and herbicides. • Reduced crop damage due to pest and disease attacks yields higher-quality cotton, which commands a price premium on the market. • Expanded area over which cotton farming is viable: from 2005 to 2013, an average 24 per cent of the area of cotton grown in Australia annually was due to CSIRO's new cotton varieties, according to data supplied by CSIRO. • Average 15 per cent increase in productivity (measured as cotton produced/hectare) from 2006/7 to 20013/14, after adjustments for year-to-year production volatility.
Increased international trade	• Increased competitiveness of cotton exports due to increased productivity of Australian cotton farming and production of higher-quality lint. Total export value of $2.7 billion in 2012–13. • Increased export of CSIRO-developed cotton cultivars due to suitability for use in countries such as Brazil, the US, Greece and Turkey and the competitiveness of Australian cotton varieties against major international seed suppliers.
Employment, contribution to GDP	Increased economic activity and employment as a result of expansion of cotton growing areas and greater productivity. In the 2011 national census, 1,740 people self-identified as being employed in the cotton growing industry, a figure that would not include additional employment in downstream cotton transportation and processing industries as a result of increased productivity further upstream.

CONSEQUENCES

Cotton systems continue to evolve as they need to respond to economic and environmental challenges. The Australian cotton industry has sustained yield improvements over many decades, providing a source of competitive advantage to alternative crops. Its story is one of identifying opportunities and adapting to challenges to create step changes and open the next frontier for development and application of science and technology. The Australian cotton industry created a system that deeply embedded and connected multiple actors, including researchers, policy makers, processors and growers.

This highly developed architecture of industry players allows for a constantly evolving capacity, which puts it in a favourable position to adapt and deal with future challenges and uncertainty.

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ENVIRONMENTAL MANAGEMENT, COTTON INDUSTRY, AUSTRALIA

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SUMMARY

This case study is complementary to the Australian Cotton Industry case study, and dives deeper into two related innovations in the Australian cotton industry over the past two decades. These innovations have helped the industry respond to significant environmental risks resulting from production, including pesticide contamination and land and water degradation. The former of these seriously threatened the industry's social licence to operate, and the latter threatened its capacity to develop through potentially restricting access to new water entitlements and water trading.

The first innovation was the development, codification and grower uptake of industry environmental best management practices (BMP) under an industry-led BMP programme (1997–ongoing). This programme supported growers to undertake self-assessment of their practices (e.g. for pesticide application), identify risks, and implement continuous improvement actions within an auditable and certifiable process.

The second innovation leveraged the first. In 2008, the cotton BMP framework became the first industry-developed framework to be accredited by the Queensland State Government as providing an alternative compliance pathway for new regulatory requirements for preparation of a Land and Water Management Plan, under the *Water Act 2000*. This institutional innovation, namely the development of a novel type of co-regulation, was made possible through a close working partnership between rural industry groups, Research, Development and extension (RD&E) entities and government. It has reduced costs of compliance for cotton producers and improved security of access to water resources while reducing risks to the condition of natural resources.

Table. Patterns of Innovation and Impact processes Summary table

Initiator	Industry and policy responses to environmental risks of cotton production.
Critical features	The development of a co-regulation approach based on industry-defined best management practices.
Role of research	Adaptive research responses to need for sustainable cotton production practices and support for skills transfer.
Operational alliances	Strong 'within' industry collaboration between CRCs, RDCs, industry and growing districts. Also negotiated framework between industry and government.
Strategic alignment of stakeholders at sector or national level	Convergence of community and market demands, productivity improvements and regulatory response.

Solution, product, or system innovation	System innovation enabling the deployment of technical and institutional innovations across the sector.
Scope of impact (and metrics)	Sector-wide impact with significant economic and sustainability returns.

CHALLENGE/OPPORTUNITY

By the late 1990s and early 2000s the Australian cotton industry had, in just over three decades, become an AUD1.5 billion dollar industry, and globally the third largest cotton exporter (Gunningham, 2004). However, this had come with significant environmental risks and increasing community concern about the health of farm workers, from neighbouring communities, fish kills, and chemical contamination of (export) beef in adjacent grazing enterprises. While several pieces of legislation already existed to regulate risks related to chemical use in farming, these concerns seriously threatened the industry's social licence to operate (Gunningham, 2004). Likely outcomes may have included outright bans on the use of specific pesticides, significantly affecting productivity, and land use controls to prohibit the growing of cotton in certain locations.

Concerns were also increasing among the two state governments over impacts of intensive agriculture on land and water resources and the legislative agenda was expanding to regulate land and water management on farms more broadly (Darbas *et al.*, 2008). The Queensland Government in particular had tied the requirement to prepare a prescriptive property-level Land and Water Management Plan, under the *Water Act 2000*, to any cotton business that secured a new water entitlement for irrigation purposes or was making significant transfers on the water market, i.e. accessing water for the purposes of increasing intensification of production. Eminent scientists at the national level were also commenting that the presence of multiple, fragmented regulations was affecting water management on farms and the prescriptive nature of the requirements (instead of outcome-based requirements) was 'militating against innovation' (Cullen, 2002, cited in Darbas *et al.*, 2008). A perception in the farming sector was that governments 'failed to acknowledge industry sustainability initiatives; did not provide integrated, clear advice on how their farming systems should be reconfigured, and thus interfered with their ability to manage their properties so as to maintain enterprise profitability' (Darbas, 2008, p. 88). While legislation is often effective in improving environmental performance of industry, in agriculture, multiple small farms over large areas and diverse production contexts make traditional enforcement of environmental regulation highly problematic (Gunningham, 2004).

The cotton industry's challenge was therefore to formulate a response that would maintain (or regain) its social licence to farm (i.e. meet community expectations of human and environmental safety) and maintain industry control over that response in a context of increasing and fragmented legal requirements to meet environmental standards.

INNOVATION

There were two sets of interrelated innovation processes. The first of these was the development of a BMP programme within and by the cotton industry, and the second, broader state-level negotiations and policy development to establish the enabling policy and regulatory environment to support the application of that BMP programme. The innovation, described by Darbas *et al.* (2008) as an eco-agricultural innovation, is in essence an institutional one. The industry responded with an industry-wide response that internally reorganised the cotton farming systems through the codification of best management practices and, later, in partnership with state government regulators, embedded that code within a novel co-regulatory framework. There were effectively three foci of this activity: (i) an agreement on course of action that achieves multiple parties' goals and avoids sanctions (political); (ii) design of the BMP framework (technical-regulatory); and (iii) a dedicated programme of implementation and adoption (engagement, supported adoption and auditing). This led to the adoption of new techniques and, notably, increased the efficiency of existing practices and area-wide coordinated use.

INNOVATION PATHWAY

The BMP programme. Between 1997 and 2006 development and preparation of the BMP Manual, including scientific and technical contributions from officers in the respective regulatory agencies, identified 'best' practices and expected performance outcomes in the production system resulting from the use of those best practices. The manual was designed as a risk assessment and management process for growers. It was developed as a suite of 11 modules covering pesticide application, storage and handling; integrated pest management (IPM), farm design and management; soil and water management; storage and handling of petrochemicals; and farm hygiene and others. The second industry-wide environmental audit[1] commissioned by the sector stated "the BMP manual provided a systematic and detailed evaluation of environmental issues and implementation of continuous improvement action plans" (GHD, 2003).

The second element of this BMP programme was the implementation process, which involved the employment of eight grower services managers by the peak industry organisation, Cotton Australia, to work with growers through the self-assessment process in the Manual and identify appropriate management responses.

The final element was a voluntary auditing programme to assess grower and industry compliance with the BMP manual. The intent of the auditing programme, which in part adopted an internationally recognised Environmental Management Systems (ISO1400) logic of 'plan-do-check-act', was intended to support continuous improvement for growers and facilitate industry-level reporting. The Cotton Research and Development Corporation supported this part of the programme by providing specialist environmental audit training to 20 individuals with existing expertise in the cotton industry. The development (codification) of this auditable 'best' management practice framework needed to meet expectations of government and external stakeholders (e.g. environmental NGOs, consumers, markets) and be implementable in farming systems and cotton enterprises in multiple geographic locations.

Development of the co-regulatory framework. The environmental risk and social licence that led to codification of the BMPs, while arguably an innovation in its own right, also provided the preconditions for the application of that framework to a co-regulatory agreement under the Farm Management Systems (FMS) framework with the Queensland Government.

The Queensland Farmers' Federation (QFF) (of which Cotton Australia is a member organisation) signed a Memorandum of Understanding (MoU) with the Queensland State Government in March 2005. The MoU explored the application of Farm Management Systems framework (i.e. industry BMP) programmes as an alternative compliance mechanism (QFFandQG, 2005). By September 2005, a joint working group with QFF and three agencies of the Queensland State Government (environmental protection agency; natural resources and water; and primary industries) had prepared an agreed process for *Development of the Accreditation Framework for Farm Management Systems Programs* that formed the basis of the broader co-regulatory arrangement. In December 2007, the Cotton BMP programme became the first intensive irrigation industry programme to be accredited for a period of 10 years under the Water Regulation 2002. This was equivalent to the development of a Land and Water Management Plan (LWMP) under that regulation.

[1] Three environmental audits or assessments have been commissioned by the industry and carried out via second parties in 1991, 2003 and 2012.

The high level agreements between the industry (Cotton Australia) and state government regulators (Queensland State Government) required amendment of the *Water Act 2000*, to allow for an 'approved industry programme' to satisfy the regulatory requirements for a statutory, farm scale, *land and water management plan* (essentially, farmers certified under the industry programme were considered as having achieved an alternative means of complying with the regulation). The BMP framework and FMS agreement provided a way of translating an abstract general environmental duty (within law) into practical requirements suited to the needs of managing a cotton growing enterprise (Williams, 2006).

The industry had a strong desire to respond to those concerns, and had the capacity to make an appropriate technical response to co-regulation because of its ability to mobilise significant levels of industry research. The industry displayed a capacity to organise and devise an industry-tailored, system-level response and, as described above, had the capacity to partner and enter into new types of relationships that met different parties' needs. There was also a strong technological development pathway where the sector was able to value add to other co-evolving technological innovations such as the development of GM cotton and efficient irrigation technologies.[2]

IMPACT EVIDENCE

The first formulations of modules for the BMP programme in 1997, for the storage and handling of pesticides and the application of pesticides, were reported as having very high uptake. A study by Macarthur Agribusiness (2004, cited in Gunningham, 2004) reports that by 2003 some 300 industry workshops had been held; 97% of cotton producers had prepared a pesticide application management plan; and, some 90% uptake of recommendations in the 'Farm design and management' module for matters relating to spray drift, water, buffer zones and tail water recirculation had been achieved. Cotton Australia reported that 46 per cent of cotton growers (representing 60% of farming area) were certified BMP compliant in 2006, but this dropped to 12 per cent in 2008 (Inovact Consulting, 2012).[3] In addition to improved spraying practices, the BMP programme also provided the vehicle for a broader push towards Integrated Pest Management approaches, and this complemented progress made on other fronts, such as the development of genetically modified cotton. The Cotton CRC reported that these factors in combination led to a 65% drop in total pesticide use between 1999 and 2002 (Cotton CRC, annual report (2002–3), cited in Gunningham, 2004).

The subsequent accreditation of the cotton BMP framework as having equivalence to a statutory Land and Water Management Plan under the State's Water Act was a significant, but in the end unfruitful, achievement. The accreditation created the possibility of reducing costs of regulatory compliance to the industry; enhancing productivity benefits to the industry from more secure water access under the Act; and avoiding compliance costs to government through administration of its own regulatory instruments. However, in practice, a key industry representative later indicated that following the Queensland State election in 2009, the part of the water regulations that recognised the BMP framework as meeting regulatory requirements was removed as one of several changes to natural resource management legislation to reduce 'green tape' for agriculture.

2 For more information refer to the Case Study on the Cotton Industry in Australia read the case study.

3 The Third Environmental Assessment (Inovact Consulting, 2012) attributes the reduction in numbers to the 'drought and the need at that time to update the program with more contemporary issues given much of the early focus was on pesticides.' Further, in 2008/9 the industry revised its BMP program into an internet-based registration and certification process 'myBMP'. Data provided by Cotton Australia to the Third Environmental Assessment shows 198 growers having completed Level 1 of the program (met basic legal requirements relevant to each module) between 2009 and 2012 and 21 growers having completed level 2 (met industry identified best practice beyond legal requirements) between 2010 and 2012 (Inovact, 2012).

CONSEQUENCES

The industry has enjoyed significant success with grower participation in BMP, improved environmental management and recognition of regulatory equivalence in state legislation. Despite these successes, which peaked around 2007–8, recent assessments of the industry's progress (Inovact Consulting, 2012) have identified declining participation at household or enterprise level with growers questioning the rationale and/or benefits of the BMP programme to their business. This highlights that even when significant cultural and practice change is achieved within a sector at a given time, this does not guarantee the persistence of the benefits over time. It also highlights the need for industry leadership and other institutional stakeholders to review the change processes and their ongoing value to growers. That is, innovation must be linked with processes that support ongoing individual and collective learning in order to anticipate and respond to the changing implementation environment.

However, in addition to gaining agreement to apply the BMP framework as a co-regulatory instrument in water, these developments have positioned the industry to deal with other emerging challenges around environmental management, market access or consumer demands for cotton produced in a less environmentally damaging way (Williams, 2006). For example, BMP accreditation provides entry for growers to opt into the Better Cotton Initiative, a global sustainable supply chain partnership between the cotton industry and environmental NGOs (WWF) to create a market access mechanism and price premium for growers producing more environmentally friendly cotton. In the 2014–15 season Australia produced 59,334 tonnes of licensed Better Cotton (11% of the 2014–15 crop). Under these arrangements some Australian cotton growers negotiated a \$3–\$8 per bale premium for their cotton sold as BCI cotton.[4]

It is worth noting that the industry, through its levy-funded industry organisation Cotton Australia, was able to drive the coordination of both the policy and implementation agendas, and was able to work successfully as part of a broader network of agricultural industry bodies. This engaged the Queensland Government under a wider issue and strategic remit to make it about 'more than cotton'. Other factors working in the industry's favour included the presence of the Cotton Research and Development Corporation, and the industry-focused collaborative research centre (a collaborative RD&E facility), albeit in three incarnations, between 1994 and 2012. The industry's access to, and ability to leverage, significant RD&E capability has been key to its success

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BARLEYMAX™

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SUMMARY

This case study examines the development of a new nutritional food and its launch and spread in the market. Growing consciousness among consumers about their health and proper diet, coupled with a need to address malnutrition and metabolic diseases globally, are providing food producers and manufacturers with viable options in the functional foods market.

The Commonwealth Scientific Industrial Research Organisation (CSIRO) is using advanced genetic technologies to create differentiated grain, food and feed products, which are either more productive or address growing consumer demands for healthy foods and ingredients. One of the outputs of the research into cereal carbohydrates and nutrition has been the development of BARLEYmax™, a non-GM wholegrain with enhanced nutritional benefits, including a low glycaemic index, twice the dietary fibre of regular grains and four times the resistant starch, which are indicated in supporting human health, such as reducing the risk of Type II diabetes and colorectal cancers.

Having developed a successful product, CSIRO worked with a range of collaborators to bring the first consumer product to market. The additional research capability developed, and the architecture of partnerships involved, has subsequently allowed the development and marketing of more complex nutritionally enhanced grains, opening up opportunities for growers and manufacturers beyond Australia and providing consumers with increased health food choices.

Table. Patterns of Innovation and Impact processes Summary table

Initiator	Public investment in research to create grain varieties with special traits.
Critical features	Series of technical and institutional innovations involved in the introduction and market uptake of new food product, BARLEYmax™.
Role of research	Advanced genetic technologies to create differentiated grain, human trails to test nutritional attributes , and modification of infrastructure and storage management.
Operational alliances	Public investment in foundational science, venture capital funding arrangements to support ongoing research and commercialisation.
Strategic alignment of stakeholders at sector or national level	Links to venture capital, and major supply chain and food services partners in the production and commercialisation of new differentiated grain-based products.

Solution, product, or system innovation	Establishment of the THG, a vertically integrated production, processing and commercialisation enterprise with ongoing R&D.
Scope of impact (and metrics)	Potential health and nutritional benefits related to the consumption of differentiated grain products, estimated by one study to amount, to date, to *c.* 300 million Australian dollars.

CHALLENGE/OPPORTUNITY

More than two billion people worldwide are affected by malnutrition of micronutrients (vitamins and minerals), but problems relating to poor diet are not limited to the poor. Developed countries are experiencing epidemic levels of metabolic diseases caused by the over-consumption of over-refined foods (Fang-Jie and Shewry, 2011).

Biofortification of agricultural produce using selective breeding has been proposed as a key strategy to address micronutrient deficiency. Beyond producing sufficient yield, farms will be expected to produce a stable supply of high-quality, nutritious food (Godfray *et al.*, 2010). An example of such food quality improvement is the breeding of high-fibre barley; however barley is not widely consumed as a food grain and research is underway to develop similar nutritional benefits in staple grains such as wheat and rice.

An additional scientific challenge is that starch content is the major determinant of cereal grain yield, and all breeding efforts that affect starch synthesis, also affect grain yields. Additionally, starch also affects the processing properties (e.g. bread making) of grains (Fang-Jie and Shewry, 2011).

The global functional foods market size in 2015 was USD129.39 billion. The Asia-Pacific market led the global industry and accounted for over 40% of total revenue that year. The dietary fibre market segment is expected to grow at a compound annual growth rate of 8.4% (Grand View Research, 2016).

Apart from increasing consumer awareness, a key driver for these changes is the recommendations from governments for increased consumption of wholegrains in diet and the increasing trend of submissions and approvals by the FSA in the USA and EFSA in Europe for novel dietary fibre ingredient health claims. Recent studies show that consumers are willing to pay more for certain product attributes of functional foods, such as health benefits (Di Pasquale *et al.*, 2011).

INNOVATION

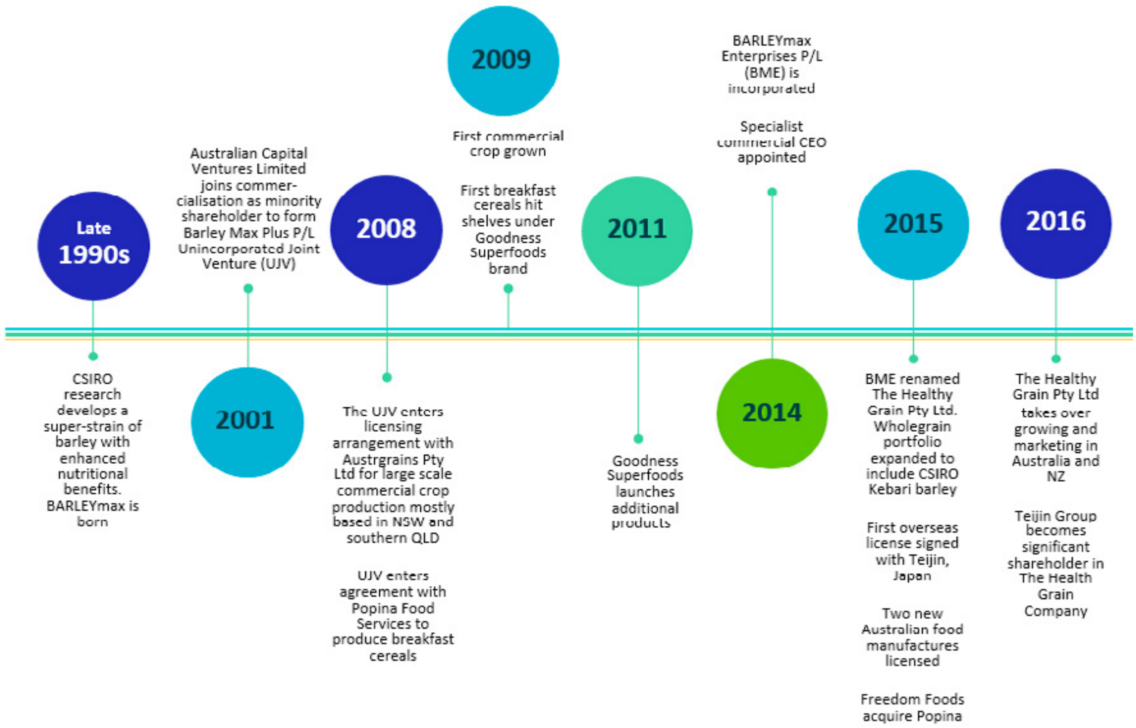
This case describes the interconnected series of technical and institutional innovations involved in the introduction and market uptake of new food products with enhanced nutrition properties using BARLEYmax™ grains. The technological innovations include the development of new barley varieties with nutritional benefits, and the adaptation of agronomic practice and post-harvest storage and handling required by a new grain variety.

The institutional innovations include a venture capital funding arrangement to support ongoing R&D and commercialisation, the establishment of a separate and secure value chain, and the creation of a spin-off company to market the product. The innovation process described below unfolded over a 20-year period, with market uptake and spread over the past seven years.

INNOVATION PATHWAY

The critical component of the innovation pathway for BARLEYmax™ was the technology commercialisation process, initiated by public investment in grain varieties with special traits. However, equally critical were considerable private investments that allowed further technological development and post-harvest handling and market development activities. The key steps in this pathway include the following (see also Figure 1):

Figure 1. Timeline of significant milestones in the commercialisation of BARLEYmax™ (The Healthy Grain Pty Ltd, 2017



Publicly funded research phase. CSIRO's nutritional grains work in the 1990s originally commenced in wheat, which reflects its importance in Australian agricultural grain production and as a staple part of the Australian diet. However, the wheat grain is complex and the research progress was relatively slow. A decision was made to push ahead the nutritional grain research using a simpler grain, such as barley.

In the late 1990s, CSIRO researchers started to assess new non-GM barley grains for the potential to improve health by delivering high levels of resistant starch and other dietary fibre components. This work led to the identification of the barley mutant gene, which was subsequently developed into the barley variety Himalaya 292, known as BARLEYmax™ (BARLEYmax Joint Venture, 2009).

Venture capital investment and laboratory and clinical trials. In 2001, CSIRO formed an unincorporated joint venture (UJV) with Canberra-based Australian Capital Venture Ltd. A number of organisational names were registered between 2001 and 2013, including Barley Plus P/L, Ascentia P/L, and BARLEYmax™ UJV.

An extensive programme of experimental studies including human trials was undertaken to test the grain's nutritional attributes and their effects on indices of human health. CSIRO also investigated new techniques and possible modification of infrastructure and storage management, as studies on Australian barley varieties had shown the effect of storage temperature, seed moisture content and storage time on barley quality. Safe storage limits for preserving BARLEYmax™ quality were determined (Cassells *et al.*, 2007).

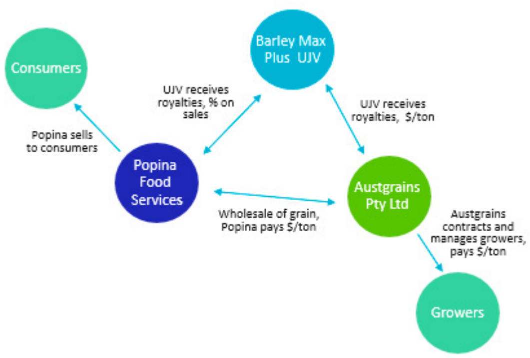
In order to successfully commercialise BARLEYmax™, the creation of an integrated, identity-preserved supply chain was required under which farmers are contracted to grow the crop, a processing partner is engaged to collect the crop and process it to the required consistency and food companies are licensed to market and sell products incorporating the grain.

The UJV signed agreements with two Australian companies, Austgrains Pty Ltd and Popina P/L to grow and sell products in Australia and provide health benefits to Australians.

Early commercialisation and technology refinement. In 2008, the UJV licensed Austgrains Pty Ltd as the supply chain partner to allow commercial scale production of the grain. This arrangement, later abandoned as being overly complicated, was based on the understanding that launching a new niche product required supply chain management experience not available in the UJV. Under the agreement, Austgrains arranged growing, provided logistics, grading and preparation, and the supply of the grain to the food manufacturer (Popina), creating the integrated, identity-preserved supply chain. Under this business arrangement, the UJV had no direct engagement with Popina, although it received a royalty on products sold (see Figure 2).

The first commercial products, developed by Popina Food Services in the form of breakfast cereals and snack foods, became available for sale in 2009.

Figure 2. Early commercialisation arrangements for BARLEYmax™



Commercialisation refinement and expansion. BARLEYmax™ has seen ongoing R&D since its first commercial release. CSIRO developed a BARLEYmax2 variety to address issues with grain size and yield, while retaining its nutritional characteristics. CSIRO holds five patents WO2002/037955, WO2003/094600, AU2006202440, WO2011/011833 and WO2012/103594 related to its barley nutrition enhancement research.

The BARLEYmax™ grain has been trialled in South Africa, Europe, and the USA, Canada and Chile, and the BARLEYmax trademark has been protected in a number of countries, including the USA.

In early 2014, BARLEYmax™ Enterprises P/L was incorporated and a CEO appointed, and in 2015 the company was renamed The Healthy Grain Pty Ltd (THG) as it acquired options to expand its nutrient dense wholegrain portfolio to include the ultra-low gluten Kebari™ barley.

The company also changed its earlier commercialisation model, by taking responsibility and control for the production of grain and processing in Australia and New Zealand and selling directly to food manufacturers. Under the current model, CSIRO receives no royalties or licence fees, but instead has taken equity in THG, with the expected return on investment to be realised through an appreciation in value of the firm (ACIL Allen, 2017).

During this period, Popina launched additional products on the Australian market and two new Australian food manufacturers were licensed to manufacture food products, resulting in a diversification of products available to the consumers. In 2015, Popina was acquired by Freedom Foods, providing additional capacity to meet the growing demands of Popina customers and the capability to grow into China and Southeast Asia. In 2016, the Teijin Group became a significant shareholder in THG, providing AUD8 million of capital, and in 2017 started test-marketing BARLEYmax™ products in Japan.

In summary, the BARLEYmax™ commercialisation process involved moving the new barley grain and the products produced from it from being a commodity to a differentiated, premium product, with the potential to generate much higher returns to the licensed producers and food manufacturers and the investors in the research, thus providing incentives for growers, processors and manufacturers.

IMPACT EVIDENCE

The BARLEYmax™ grain contains twice the dietary fibre of regular grains, four times the resistant starch and has a low glycaemic index (GI). A series of experimental studies, including human trials, have shown that a range of foods produced with BARLEYmax™ as their key ingredient produced positive changes in a range of biomarkers of bowel health (Bird *et al.*, 2008). There is evidence that a high intake of dietary fibre contributes to reduced risk of weight gain and obesity, along with reduced risk of Type II diabetes (WHO, 2003).

Key economic and social benefits of BARLEYmax™ were identified in an assessment conducted by Deloitte Access Economics in 2014. The case study estimated benefits as high as $300 million. The major drivers of these benefits were the savings in years of life lost to disease and the savings of years of Australian lives lived with disease. Four key impacts were identified:

Social impact	
Improved health outcomes	The BARLEYmax™ fibre content and low GI are associated with weight control and reduction in the risk of developing Type II diabetes, cardiovascular disease and colorectal cancer. Consumers benefit by avoiding the burden of chronic disease and healthy life years lost due to illness associated with nutrition.
Environmental impact	
Higher farm price delivered	CSIRO research resulted in higher-quality grain, for which growers are paid a higher unit price than conventional barley.
Price premium for final product	Due to the improved health properties of BARLEYmax™, at the end of the supply chain a breakfast cereal containing the grain can be sold at a higher price compared with otherwise equivalent breakfast cereals on the market.
Reduced health system costs	Improved health outcomes are associated with a reduction in health system costs borne by taxpayers. This impact comprises savings in medical treatment to control or manage an illness, which BARLEYmax™ consumption could help prevent, such as Type II diabetes.

CONSEQUENCES

CSIRO has used the technology and lessons learned with BARLEYmax™ research to develop a high-amylose wheat, which is being commercialised through the joint venture partnership Arista Cereal Technologies, and is investigating nutritional benefits in other grains. The research has also created an option for Australian grain producers to develop new export markets for BARLEYmax™ and HA wheat, or for CSIRO and partners to expand food production and processing overseas, increasing economic benefits to the system and health benefits to consumers. Freedom Foods is set to launch BARLEYmax™ in the US this year, and Teijin Group has developed more than a dozen cereal and cereal bar products to launch on the Japanese market in the near future.

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EAST AFRICAN DAIRY DEVELOPMENT PROJECT'S DAIRY HUBS

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SUMMARY

Over the past several decades, there has been significant investment by the international development community and national governments to improve smallholder dairy production in East Africa, especially Kenya. Rather less attention, however, has been paid to development of effective input and output markets and services and well-functioning value chains. As a result, smallholder dairy farmers in East Africa often have poor access to the inputs and services that would enable them to become more productive and profitable. They can also have poor access to formal markets for their milk, and where access to these markets does exist, their bargaining position is generally weak. At the same time, demand for milk is rapidly growing in the region, especially from the rapidly increasing urban middle class, and per capita consumption is set to double in the next ten years.

The recurring challenge has been the identification of a viable approach that improves small-scale dairy farmers' access to inputs and services and enhances their market access thereby making more quality fresh milk available to East African consumers. One such approach is the dairy hub, initially developed and piloted by the NGO Heifer Project International Kenya (HPI-K) in Kenya in the 1990s and then scaled up and rolled out in several East African countries by the East African Dairy Development project (EADD) since 2008. EADD is funded mainly by the Bill and Melinda Gates Foundation (BMGF) and implemented by a consortium led by Heifer International and including TechnoServe, Africa Breeders Total Cattle Management (ABC-TCM), the International Livestock Research Institute (ILRI) and the World Agroforesty Centre (ICRAF). The project has established dairy hubs in Kenya, Uganda, Tanzania and Rwanda.

The original hub model, developed by HPI-K during the pilot phase in Kenya and known as the chiller hub, consisted of a group of farmers who came together to invest their financial and social capital in a company that owns a chilling plant and associated facilities. The eventual aim was that the chilling plant would develop into a sustainable, viable farmer-owned business that could operate without further project support. The model placed ownership of the chilling plant and its oversight with the farmers, while the business and technical aspects of running were left to professional staff. Milk processors were contracted to buy the milk and the farmers were paid monthly. Businesses and organisations that provide goods and services needed by dairy farmers were encouraged and facilitated to cluster around the chilling plant – this was known as the hub; in some cases they received support and training to increase their capacity. Alternatively, these goods and services were supplied directly through the company that owns the chilling plant, for example through the establishment

of a company-owned agro-vet shop. The goods and services provided could often be availed by farmers using a 'check-off' system – a simple credit scheme whereby the amount farmers owe is deducted from their monthly milk payments.

As the hub concept was scaled up through the EADD into neighbouring countries with less developed dairy sectors and more challenging environments, a wider range of hub approaches emerged which were more suited to these situations. These included processor-owned chillers, hybrid models where farmers owned the central chiller and processors owned satellite chillers, hubs that collected milk but did not have a chiller and sold their milk in the local, informal sector and hubs which did not collect their milk in a central facility and sold it in the local, informal sector.

After two decades of experience with the hub approach, more than 100 hubs have been established in four countries in East Africa. By 2010, the original pilot chiller hub had 6000 members, 1880 farmers regularly supplying milk, received 30,000 kg of milk a day in peak season and paid out over USD1 million a year to farmers. Of the hubs established through

EADD, although there have been some failures, many are reported to have developed into profitable businesses.

In addition to providing goods and services directly aligned to dairy farming, hubs have also developed to provide access to a broader range of products including financial services, such as savings and loans, and family health insurance. The existence of the hubs is also credited with stimulating wider economic growth through the emergence of various businesses not related directly to dairy, around the hubs.

Table. Patterns of Innovation and Impact processes Summary table

Initiator	HPI-K and BMGF answer to smallholder dairy development.
Critical features	Creating a critical mass of smallholder dairy farmers, which have a strong collective voice and can benefit from economies of scale. Initially strong emphasis on 'farmer-owned milk chiller selling milk to processor hub' blueprint model, which over time evolved to a more flexible and varied approach to hubs.
Role of research	Hub approach based on established economic theory and practice: business clusters, introduced and popularised by Michael Porter[5], with the underlying concept, agglomeration economies, having its origins in Alfred Marshall's book, *Principles of Economics* (1890). Incorporates the results of years of smallholder dairy research by ILRI and ICRAF in its production and husbandry technology offerings.
Operational alliances	HPI-K in partnership with TechnoServe, ILRI, ABS-TCM and ICRAF with initial funding from USAID and later the BMGF.
Strategic alignment of stakeholders at sector or national level	Operational linkages between farmer producer organisations, project proponents, milk processors and a myriad of private- and public-sector (dairy sector-related) service providers.
Solution, product, or system innovation	Facilitation of businesses and other organisations that supply goods and provide services to dairy farmers, including on credit using a check-off system with milk as collateral.
Scope of impact (and metrics)	First chiller hub has 6000 members, 1880 farmers regularly supplying milk, markets 30,000 kg milk a day in peak production season with payments to farmers exceeding USD1 million annually. Four hubs established by HPI-K in pilot phase in western Kenya; 108 hubs established through EADD during scale phase in Kenya, Uganda, Rwanda and Tanzania.

5 Porter, M.E. (1990). The Competitive Advantage of Nations. New York: The Free Press.

CHALLENGE / OPPORTUNITY

Over the past few decades, development projects and government policy have encouraged and supported smallholders to become small-scale dairy farmers. This approach has been particularly successful in Kenya where upgrading from keeping local humped cattle to keeping crossbred dairy cows and using technologies, such as cut-and-carry zero-grazing systems and cultivated fodder crops, has been taken up on a large scale.

Operating as individuals, however, smallholder dairy farmers in East Africa still face many challenges that limit their productivity, and their capacity to supply quality milk to value chains that supply the rapidly growing demand from urban consumers. Farmers have limited access to productivity-enhancing, high-quality inputs and services, including feed, breeding and artificial insemination (AI), animal health and financial services. Lack of credit is not only a barrier to access to new technologies and production practices, but also to access to routine inputs such as feed. The vast majority of dairy farmers have just a few animals and produce too little milk to make it viable for milk processors to collect from them as individuals. Poor roads and lack of other infrastructure, such as milk coolers and reliable electricity supplies, exacerbate the situation. In addition, those that have access to output markets generally have weak negotiating positions and are subject to volatile prices. Seasonal glut may even lead to the temporary disappearance of these markets.

At the same time, demand for milk by consumers, especially in rapidly growing urban centres, is steadily increasing. With growing populations, more people living in urban areas and increasing incomes, demand for milk and dairy products in East Africa is set to continue to rise for the foreseeable future. In Kenya, per capita consumption is projected to double to 220 litres a year by 2030. In Uganda, per capita consumption has more than trebled over the past few decades, and still has considerable potential for further growth. The Tanzania Dairy Board meanwhile aims to more than double per capita consumption to 100 litres a year by 2025[6].

The challenge and opportunity is therefore to identify an approach that enables smallholder dairy farmers to enjoy economies of scale and better access to input and output markets, is attractive to businesses and organisations providing the goods and services needed by farmers, and contributes to rapidly rising demand for dairy products. The dairy hub approach, developed and piloted by the NGO Heifer Project International Kenya (HPI-K) in western Kenya in the late 1990s, and further developed and rolled out throughout the East Africa region over the past 10 years by the East Africa Dairy Development project (EADD), has been one proposed solution to this conundrum.

INNOVATION

Dairy hubs, as developed and used in East Africa, are networks of input and service providers who together meet the needs of a cluster of several thousand, mainly smallholder dairy farmers. Hubs usually centre on some sort of physical milk collection facility. This might be a central milk chiller with a number of 'satellite' milk collection points, but it can also involve simply bulking milk without chilling. In most cases, fresh milk is bought by a processor although in more remote areas it can also be channelled to the local, informal market.

The focal point of the hub provides a critical mass of dairy farmers from a defined geographical area (about 30 km radius) who together represent a market for input and service providers. The hub approach enables economies of scale to be realised by dairy farmers, for-profit businesses and other organisations, such as government extension services, non-governmental organisations and donor-funded projects and programmes which have an interest in the smallholder dairy sector. By

6 http://www.thecitizen.co.tz/magazine/businessweek/Campaign-to-increase-milk-consumption-in-TZ-begins/1843772-3471202-d9ac99z/index.html

coming together as a group, individual smallholder farmers have enhanced negotiating power with milk buyers and input suppliers. The hubs should also reduce transaction costs and make communication easier and more effective.

The range of inputs and services made available through the hub varies but can include feed, breeding and AI, dairy equipment, animal health, milk transporting, advisory services and financial services. The latter can include provision of goods and services on credit with repayment through a check-off system, whereby the supplier is paid directly from deductions made from the farmers' regular, usually monthly, payments for milk supplied to the hub. A well-functioning hub can increase the productivity and profitability of smallholders' dairy enterprises and create local jobs, directly at the hub and indirectly through the businesses and services that cluster around it. In this way, it can strengthen the local economy, supporting a wider range of non-dairy businesses and services.

An important function of the hubs is quality control of milk, which can include checks for adulteration, contamination, and other quality or public health risks. Typically, individual batches of milk are quality checked before being accepted and added to the bulk tank. If it passes the quality check, milk supplied by individual farmers, or small-scale transporters who combine milk collected from several producers, is weighed and a receipt is issued documenting the weight of milk delivered.

There are a range of hub models. The original model, developed and piloted by HPI-K in western Kenya in the 1990s – an area where the dairy sector was long established – emphasised farmer shareholders of the company that owned the chilling hub, marketing centre and often some of the associated services, such as agro-vet shops and animal health and breeding services. As the hub approach was scaled up and out through the EADD project, a number of different types of hub have evolved that are better suited to more challenging and less developed dairy production environments. These include processor-owned chilling hubs, farmer-owned central chilling hubs with processor-owned satellite chillers, farmer-owned hubs without chillers, and hubs which target local, informal markets rather than supplying milk processors.

INNOVATION PATHWAY

From the 1960s onwards, smallholder dairy farmers in Kenya were encouraged by the government to keep dairy cattle and to join dairy cooperatives that supplied the state-owned milk processor Kenya Cooperative Creamery (KCC). At that time, KCC enjoyed a near monopoly in the processing of milk. Many of the co-ops were supplied with milk coolers during the 1980s but less than half were still functional 10 years later. A problem affecting many co-ops was poor governance, late and erratic payment to producers, corruption and even outright theft of members' funds. Generally, farmers lacked the managerial and technical skills needed to run milk chillers and the associated facilities and business arrangements.

Along with other donor-driven structural reforms, the Kenyan dairy industry was liberalised in 1992, which paved the way for private dairies to become established. At the same time, informal and illegal milk hawkers started operating by buying raw milk at the farm gate and selling it on to local consumers. KCC struggled to compete with the new players, with the situation being exacerbated by corruption and mismanagement. In 1999, KCC finally collapsed leaving debts to smallholder dairy farmers for unpaid milk of over a billion of Kenyan shillings. Despite these bad experiences, farmers were still keen on dairying and wanted to establish their own milk collection and marketing centre. They approached their local government Livestock Development Officer for advice, who put them in touch with HPI-K.

HPI-K staff helped farmers register a new cooperative in 1997. They also carried out a feasibility study for the proposed milk collection and marketing centre. This indicated that such a facility would be feasible provided farmers committed to supplying it with their milk on a daily basis, resisting the temptation to take advantage of seasonal opportunities to sell at higher prices to milk traders who call at their farms.

HPI-K concluded that the way to help ensure this commitment was to require the farmers to invest both financial and social capital, the former by buying shares in the facility and the latter by taking an active part in its shaping and running. Also, because the business and technical aspects of running a milk collection and marketing centre would require specific skills, knowledge and expertise, it was deemed essential to have well-qualified professional staff running the business and technical aspects of the facility.

The model that emerged, known as a chilling hub, was overseen by a board of directors made up of elected members representing the farmers and representatives from HPI-K. HPI-K helped the cooperative set up a new company to own and run the chiller and associated facilities. Originally, the plan was for the farmers to buy shares equivalent to 60% of the initial costs, with HPI-K contributing USD400,000, USAID contributing USD50,000 and Tetra Pak, a multinational company that provides dairy equipment, providing the plant as a loan. It proved, however, impossible to convince farmers to invest at the outset and HPI-K had to put up most of the money with the understanding farmers would eventually repay this loan: it took 10 years, but eventually the farmers did repurchase all the shares.

Building on their experience gained in piloting hubs in western Kenya, in 2008, the NGO HPI was awarded a USD42.8 million grant by the BMGF for the first five-year phase of a planned 10-year project to revitalise dairy value chains in East Africa. The project was called the EADD, and its objective was to double the incomes of 179,000 smallholder dairy families in three countries, Rwanda, Kenya, and Uganda. One of the project components was focused on improving market access. To do this EADD proposed to organise and strengthen milk producer organisations to grow into hubs.

To implement EADD phase I, which ran from 2008 to 2013 (including a one-year extension with an additional grant of USD8.5 million), HPI partnered with a combination of public- and private-sector partners: TechnoServe, ILRI, ABS-TCM and ICRAF. TechnoServe led the project's business development and market access aspects including the procurement and financing of chilling plants, technical support to hubs, and business development service providers. Phase II, which runs to 2018, was funded through a further grant of USD25.5 million from BMGF.

A slightly changed financing model was used by EADD. The total cost of establishing a chilling hub is around USD150,000. Initially, farmers were expected to contribute 10% of the investment cost with EADD providing an interest-free loan for a further 30%. This loan was intended to act as a guarantee to enable banks to provide a commercial loan for the remaining 60%. It was found, however, that the farmers did not take the loans seriously. EADD therefore changed to a different model. Farmers initially contributed 20% of the total cost of a chilling hub with EADD again providing a further 30% as an interest-free loan. This was designed to enable a building to be built and the hub to start operation but without the costly chilling plant. Later, when the hub was up and running and operating as a viable business, a bank was approached to provide a commercial loan for the remaining 50%, which enabled the chilling plant to be installed. During the lifetime of the project, a number of variants of the hub model evolved. These include: processor-owned chillers; hybrid models in which farmers own the central chiller and processors own satellite chillers; hubs that bulk their milk and target local, informal milk markets (unprocessed milk sold within a 60-kilometre radius); and hubs that do not bulk milk and target local, informal markets. In Kenya, all hubs are based on farmer-owned chillers while in Uganda all four types exist.

Timeline.

1992	Dairy sector liberalised in Kenya; new private milk processors emerge.
1997	First chilling hub established at Siongiroi, western Kenya followed by three more in the same area over the next four years.
1999	KCC collapses leaving farmers owed billions of Kenyan shillings in milk payments.
2008	EADD phase I launched in Rwanda, Kenya and Uganda, scaling-up and out 'hub approach'.
2012/2013	Planning for EADD phase II.
2013	End of EADD phase I.
January 2014	Launch EADD phase II, scheduled to run until 2018 in Kenya, Uganda and Tanzania.

IMPACT EVIDENCE

The first chilling hub was established at Siongiroi in Kenya in 1997. By 2010, the dairy plant was wholly farmer owned with 6000 members, 1880 of whom regularly supplied milk to the hub. Peak milk intake was 30,000 kg a day, and annual payments to farmers exceeded USD1 million a year. The original overall stated objective of EADD was to double the dairy-derived incomes of 179,000 farming families living on small, one to five acre farms by 2017 through interventions that enhanced both dairy production and market access with dairy hubs being a key component. In phase II, which runs from 2014–2018, the objective is to reach an additional 136,000 farmers by creating 16 new hubs in Uganda and ten in Tanzania. It is difficult to determine the extent to which this objective has been achieved. Milk prices received by farmers have approximately doubled during the project lifetime but the contribution of EADD and the hub model to that increase is hard to ascertain.

By June 2012, 68 dairy hubs had been established in Kenya, Uganda and Rwanda, and more than 189,000 farmers had been registered with hubs. However, the proportion of registered farmers who were active – defined as delivering milk to the hubs – was, overall, less than 20%: 25% in Kenya, 18% in Uganda and 5% in Rwanda. A follow-up study carried out at the end of 2014 revealed that the number of active farmers in Kenya was unchanged from 2012, while in Uganda it had more than doubled. Rwanda is no longer a project country for EADD phase II. Tanzania, a new country for phase II, had 2,285 active farmers. After more than six years of what is now envisaged as an 11-year project, the total number of farmers delivering their milk to a hub was less than 55,000, or 30% of the original target for the end of the project (originally 2017, now 2018).

One reason for this small percentage is that during dry spells or droughts, the price offered to farmers by informal traders is higher than that paid by the hub. For example, in 2012, a drought year, the hub at Kabyiet – a long-established dairy area in western Kenya and one of the most mature hubs – paid farmers between KES 27 and 35 per litre, while informal traders paid KES 35 to 40. The volume of milk delivered to the Kabyiet hub varied considerably, from a peak of 36,000 litres a day in 2010 to a low of 3,500 litres a day in 2011/2012. In 2014 this had stabilised to 14,000 litres a day. These fluctuations are attributed to the effects of drought and stiff competition by alternative buyers.

Success criteria used by EADD include whether hubs are profitable and whether they 'graduate' from project support to the ability to function independently as viable farmer-owned businesses. In total, during EADD phase I, 82 hubs were supported by the project. At the end of that phase, 51 had exited the project and were reported in 2015 to be running without any support from EADD. Of the remaining hubs supported in phase I, 29 continued to receive support from EADD during phase II, and two were dropped because of unspecified 'poor governance' issues.

At the end of 2015, of the 57 hubs with which EADD engaged in phase II, six hubs (two in each country) were reported to have made a net loss. Despite this, on aggregate, the hubs in each country are reported to have made a net profit in 2015, ranging from 2.9% of milk sales for Kenya, to 3.3% for Tanzania, and 14.0% for Uganda. In March 2015, of the 21 hubs established at the start of EADD in Kenya in 2008, 11 were reported to be profitable with an average gross margin of 15%. Comparable data is not available for the other countries.

CONSEQUENCES

The establishment of well-functioning dairy hubs has enabled farmer members to benefit in a range of ways that extend well beyond farming. Previously, most banks regarded small-scale dairy farmers as being too risky to advance loans to. In response, EADD has facilitated the establishment in some locations of community banks, and farmers' monthly payments are made into their accounts. This has enabled these farmers to have access for the first time to modern banking services, including options for savings and loans. In addition to being able to obtain dairy inputs and other household and family needs on credit, using the check-off system, farmers can also apply for larger loans. Independently of the hubs, farmers can now also obtain loans from commercial banks which recognise the farmers' milk delivery and payment records as collateral.

Another benefit some hub members can enjoy is health insurance. Previously small-scale dairy farmers tended to build up debts when they or their families needed health care. To pay off these debts they sometimes had to sell productive assets – animals and even land – which could have serious consequences for future prosperity. Now, through some of the hubs, members can buy health insurance for their families, with the monthly subscriptions (around USD18 for a large family) being deducted from their monthly milk payments. As well as avoiding the need to sell assets, the existence of health insurance means that farming families are more willing to seek out professional health care earlier.

The different types of hub models that have evolved also have consequences. For example, the Uganda hubs became profitable much earlier than the Kenya hubs. One reason for this could be that many of the Ugandan hubs did not build up the high debts generated by Kenyan hubs associated with installing costly chilling plants. The hub model variants that have evolved in Uganda, which included processor-owned chilling plants or, in the case of hubs targeting informal local markets, no chilling plants, may represent better, lower risk models, especially for countries with less developed dairy industries.

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EAST COAST FEVER INFECTION AND TREATMENT METHOD

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SUMMARY

This case study describes the development of a live vaccine against East Coast fever, a tick-borne disease of cattle caused by *Theileria parva*. Technological breakthroughs in the 1950s and 1960s led to a control measure commonly known as 'infection and treatment' method (ITM). The widespread deployment of ITM, however, was stalled for decades because key development and donor agencies focused resources and efforts on a frontier science research agenda rather than on the delivery of an existing solution. This resulted in an effective and simple control measure being side-lined by the search for recombinant vaccine solutions in a newly established international research centre that ultimately failed to produce the needed technological breakthrough. ITM received renewed attention when a public-private sector mechanism revisited the technology for field deployment and development impacts. The establishment of GALVmed in the early 2000s, as a platform to engage the private sector in the commercialisation of existing public science solutions, eventually formed sufficient political alignment and incentives to create an effective vaccine production and delivery mechanism.

Table. Patterns of Innovation and Impact processes Summary table

Initiator	Research commissioned to solve major livestock disease.
Critical features	Low-tech solution ignored for decades. Commercialisation only achieved by the establishment of a public-private sector platform GALVmed.
Role of research	Development and validation of ITM for the control of ECF.
Operational alliances	Alliances initially absent, but latterly GALVmed facilitated partnership with the private sector.
Strategic alignment of stakeholders at sector or national level	Considerable policy commitment to provide solutions aligned with commercial opportunities for treatment delivery.
Solution, product, or system innovation	System innovation to deliver product and service innovation.
Scope of impact (and metrics)	Potential for sub-sector wide impact. Over 1.5 million doses of MC administered in eastern and southern Africa.

CHALLENGE/OPPORTUNITY

The challenge was the control of a tick-borne disease of livestock widely prevalent in eastern and southern Africa, East Coast Fever (ECF). ECF causes major economic losses in the region, where it has been regarded as one of the most serious constraints to improving the livestock industries of the region. The disease can cause high mortality in cattle, particularly affecting improved dairy and beef cattle, as well as affecting zebu cattle in pastoralist areas and ranches. There is an extensive literature on the disease (see for example Norval *et al.*, 1992; Perry and Young, 1993; Lawrence *et al.*, 2004; and Gachohi *et al.*, 2012). An economic impact assessment of the disease was undertaken in 1989 by Mukhebi *et al.* (1992), which estimated total regional losses due to the disease to be USD168 million, which included an estimated mortality of 1.1 million cattle.

INNOVATION

The commissioning by the Department for International Development (DFID) of the Cambridge Economic Policy Group, led to the development of what was initially called a draft Global Animal Health Alliance, but which evolved, in April 2003, to become the Public Private Partnerships on Livestock Vaccines for the Poor. This recognised that there was a failure in developing country markets to generate and deliver animal health technologies, and particularly in targeting the poor. The study discussed the concept with various actors in the private sector and reported that major pharmaceutical companies such as Merial, Intervet and Pfizer would be willing to participate in an alliance and to contribute expertise and intellectual property rights (IPR) to the development of specific products, subject to appropriate funding and management structures being put in place. The onus was put on the donors to reach agreement on the concept, and to identify appropriate funding and management arrangements. This prompted DFID to explore various options, and it went on to facilitate the establishment of the Global Alliance for Livestock Vaccines (GALV) in 2004 with a bespoke legal and institutional framework and its first business plan. It was envisaged that GALV would work in a similar way to the GAVI Alliance, a similar organisation but with a human health agenda.

DFID provided a GBP300,000 grant in an inception phase for GALV as it picked up the public-private partnership mantle on animal health technology refinement and delivery, including the ITM vaccine for ECF. Then GALV became GALVmed (Global Alliance for Livestock Veterinary Medicines). The change of name reportedly reflected recognition by the management and board of GALVmed that although vaccines were important, the development of other types of veterinary medicines, including drugs, would also be relevant to their agenda. As seed funding from October 2004 to October 2008, DFID injected some GBP2.6 million to get the organisation off the ground.

The establishment of a functional international public-private partnership to address the perceived market failure of animal health technologies and their delivery to the livestock enterprises of the poor has been one of the most significant changes in livestock sector development in recent years. While this narrative cannot comment on the overall performance of GALVmed, there is no doubt that it is now firmly set on the path of ensuring that ECF-ITM is produced sustainably, and effectively delivered.

INNOVATION PATHWAY

1950s to early 1960s. East African Veterinary Research Organisation (EAVRO) under the East African Community before Kenya's independence. A research capacity in ECF and the first indications that protection using live parasites, combined with extended antibiotic therapy, might protect cattle.

Mid-1960s to mid-1970s. EAVRO post-independence, the UNDP-supported FAO project led by Matt Cunningham developed a live parasite vaccine concept, using a multiple of parasite strains and using a single injection of long acting antibiotic. The golden years of infection and treatment (ITM) research, and the birth of the Muguga cocktail (MC).

Late 1970s to early 1990s. The end of the FAO project at EAVRO Muguga, coincides with the inauguration of the CGIAR and its disease research institution ILRAD; the start of the reorientation of the ECF vaccine agenda to sporozoite and eventually schizont vaccines. An exit of resources and scientists from former EAVRO. Period focuses on refining the ITM technique, studying the parasite dynamics and strain variation, and developing molecular tools to refine the ITM procedure. The start of the wilderness years with respect to field application of ITM.

1980s to late 1990s. Multiple initiatives in other countries of the region. Inputs in funding and projects from the Netherlands, Belgium, DANIDA, UK. Studies in Tanzania, Uganda, Zambia, Zimbabwe. A series of valuable regional workshops on ECF epidemiology initiated, coordinated by ILRAD, FAO and conducted under the auspices of the AU. ILRAD and ILCA become ILRI, under new leadership. The first commercial scale MC batch produced at ILRI. The wilderness years continue.

The Noughties. The DFID study of animal health research priorities for poverty reduction leads to the birth of a Public Private Partnership of what was to become GALVmed. The wilderness years continue, as ILRI produces a new batch (08) of MC at the request of AU/IBAR. AU/IBAR chaired an ECF regional task force, comprising government representatives of the four countries currently using the ECF MC vaccine (Malawi, Kenya, Tanzania and Uganda), GALVmed, ILRI and Pan-African Veterinary Vaccine Centre (PANVAC); opened tenders for MC manufacture and distribution. Manufacture won by the Centre for Ticks and Tick-Borne Diseases (CTTBD). The wilderness years continue.

. GALVmed moves into a coordinating and facilitating role both for the rehabilitation of CTTBD and the extension of new MC initiatives into other countries in the region with renewed financial support from DFID and BMGF. GALVmed also pursues registration of MC in different countries. New delivery initiative launched in Tanzania with USAID support. Private-sector delivery strengthened in Kenya with variable results based on highly differentiated business interests of pastoralist and dairy sectors. Still no recombinant vaccine alternative emerging.

It has been extremely difficult to secure and maintain registration of the MC. The MC has been registered in both Kenya and Tanzania, but these registrations have apparently lapsed. GALVmed has contributed to the process by helping with the development of registration dossiers, but the major challenge is an insistence by the authorities on GMP capacity for vaccines. There are guidelines on GMP for veterinary vaccines (see for example Todd, 2007), but it seems that these are interpreted differently by each country. Currently neither ILRI nor CTTBD meet GMP standards for vaccines. It is considered by some that this compliance failure is in part a reflection of misalignments between the different Directorates of Veterinary Services and the relevant local regulatory body in the countries concerned.

In this environment, and with the AU advocating its role as an umbrella for future ITM deployment, GALVmed then helped oversee a tender process under AU for regional ITM production, in which CTTBD emerged as the winner. While GALVmed undoubtedly welcomed its new role as a key player, it then also had to deal with the reality of resuscitating a twice-collapsed institution, and do this in a politically charged environment. At the beginning of this process there was sufficient of the ILRI08 batch left to satisfy the needs of the region, but this was followed by a shortage of ECF-ITM in 2014. On top of this, the re-equipping of CTTBD took about three years. GALVmed took its time with the resuscitation process, and ensured that its first vaccine batch (MCL 01) was produced by the CTTBD before opening its doors to the world's media in December 2014.

IMPACT EVIDENCE

ITM, in particular the MC, has indeed had many direct and indirect impacts. The direct impacts on cattle have been survival of animals, and have thus contributed to the livelihoods of many who have had their cattle immunised. The indirect impacts have been many, in some cases of greater long-term contribution to science and capacity development.

However, importantly, the direct impacts have not been on the scale that they could have been, nor in the production systems in which there is arguably the greatest need, nor over the time scale that could have been anticipated.

That said, there is no other vaccine to prevent ECF despite over 40 years of heavy investment and research. While this is hardly an indicator of success, the reality is that no other vaccine has yet been developed to protect against ECF in the field. At the time that the ability to protect cattle with this live vaccine was first demonstrated, work started at ILRAD, then continued at ILRI, to develop a new recombinant vaccine. Some partial success was achieved with a sporozoite vaccine, based on the surface protein p67 (Musoke *et al.*, 2005), giving a reduction in the severity of disease in immunised cattle, but there was inadequate protection to justify further development of this approach. Research continues at ILRI on a novel recombinant vaccine with support from the Bill and Melinda Gates Foundation (BMGF) and others.

The MC immunisation provides long-term, some consider life-long, immunity in the field. Over 1.5 million doses of MC have been administered in eleven countries in eastern and southern Africa. The breakdown of this figure by country, production system and cattle type is not available. The greatest impact appears to have been in Tanzania, in part due to the commitment of the group championing its use in and around Arusha, and in part due to the unique demand in the pastoralist communities in northern Tanzania and southern Kenya. These have been documented extensively by Di Giulio *et al.* (2009).

The MC vaccine is still only registered in Malawi. The vaccine had previously been registered in Kenya and Tanzania, but these registrations have lapsed. Nevertheless it is used in both of those countries, and in Uganda, through importation under special permit. The MC is also being used in DRC, South Sudan, Rwanda, and Burundi. The ITM technology is also used in Zambia, using the Katete and Chitongo stocks of *T. parva*, rather than the MC. ITM technology has also been deployed on a commercial basis in Zimbabwe, using the Boleni stock of *T. parva* and without the use of tetracycline.

It is argued by some that inadequate advantage was taken of the 1996 milestone of MC production at a commercial scale by ILRI, and particularly ten years later with production of the ILRI 08 batch in 2007. ILRI was generally considered to be (and, some argue, remains) the only institution in the region with the human, financial and technical resources necessary for the complex MC production process. Some have argued that ILRI even had an international responsibility to take a leadership role and continue producing stabilates. Opposing this was ILRI's management at the time, which felt that moving into vaccine production was a risk to ILRI's role and credibility as an international research institute. Furthermore ILRI is not a registered vaccine producer and does not have the structures to monitor and oversee vaccine production required to meet GMP guidelines. In addition, influential parts of the regional government authorities supported what they saw to be a more politically correct pathway of MC production under the auspices of the AU.

CONSEQUENCES

There is no doubt that the funding and training opportunities presented by the work of NVRC, ILRAD and ILRI, as well as research institutions in Tanzania, Uganda, Zambia, Malawi and Zimbabwe played a significant role in capacity building of individual scientists across the region. It is less clear that it had a substantial impact on institutional capacity, with the clear exception of ILRAD and ILRI, which attracted the cream of aspiring scientists, arguably at the expense of their national institutions.

While ECF-ITM was largely responsible for the birth of GALVmed, it does not rank it as its greatest success in vaccine delivery. This position is held by its vaccine programme for Newcastle Disease for poultry, in which GALVmed, building on the ITM experience, has engaged several private enterprise manufacturers and deliverers.

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FOOT AND MOUTH DISEASE ERADICATION IN THE PHILIPPINES

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SUMMARY

This case study examines the process and practices that led to the eradication of Foot and Mouth Disease (FMD) in the Philippines. The origin of this was that results from publicly funded research and economic analysis provided 'evidence' that FMD eradication in the Philippines would yield sufficient returns to expected costs, and therefore offered a worthwhile investment of public funds. This analysis also showed that while control and eradication would be beneficial to smallholder producers, a significant portion of the benefits would accrue to the large-scale commercial livestock sector. Eradication is not a one-off investment but requires continued investment to protect the FMD-free status of the country, once achieved. Sustained public funding of FMD surveillance and control would have been difficult to justify, particularly given the commercial orientation of the expected benefits. These results not only suggested that considerable scope existed for the government to involve the private sector more actively in financing national FMD control efforts, but also provided a platform for dialogue between the public and private sector. This dialogue resulted in the direct participation of the commercial sector in the national FMD eradication Task Force and agreement on long-term complementary public- and private-sector investment in eradication and control activities and facilities. The system established and the subsequent eradication of FMD in 2011 continues to deliver productivity improvements, impact to smallholders, and access to new markets for the livestock sector as a whole.

Table. Patterns of Innovation and Impact processes Summary table

Initiator	Cost-benefit research reveals opportunities for private and public investment and collaboration.
Critical features	Clear evidence of benefits for the private sector stimulates co-investment in control measures that also have no cost and benefits to smallholders.
Role of research	Testing and validating control measures. Monitoring disease incidence.
Operational alliances	Mainly among public-sector veterinary services, private-sector producers and exporters and smallholders in the implementation of system-wide control and eradication measures.
Strategic alignment of stakeholders at sector or national level	Strong alignment between public and private sector at a national level with significant public investment in infrastructure.
Solution, product, or system innovation	System innovation in the form of a sector-wide FMD eradication, monitoring and control regime.
Scope of impact (and metrics)	Sector-wide impact with significant economic and social returns.

CHALLENGE/OPPORTUNITY

The first component relates to the challenge of the eradication of FMD in the Philippines. Livestock diseases present a threat to the production of animal source foods, and in some cases a threat to human health. Only two diseases have been eradicated from the face of the earth, namely smallpox (eradicated in 1980) and rinderpest (eradicated in 2011). However, there have been other national and even regional successes. One disease which is high on the list of many countries in terms of the impacts it has on international trade is FMD of ruminants, pigs and wild ungulates. It has been eradicated from North America and most of Europe, but remains endemic in much of the developing world. However, there have been some successes in its eradication in Asia. Indonesia mounted a very successful programme during the period 1974–81, which led to the eradication of the disease from Bali and Madura in 1978, and from South

Sulawesi and East Java in 1981. The last case of FMD was reported in Kebumen, Central Java in December 1983, while the last vaccination in Java against FMD was at the end of 1985. All of Indonesia was declared free in 1986 (Soehadji and Setyaningsih, 1994). This has provided inspiration for other countries in the Southeast Asian region, including the Philippines.

The second generic component of the challenge is the planning and resourcing of disease eradication. The status quo in most industrialised countries has been that substantial investments of public money from national coffers would be effective in progressively controlling and eventually eradicating a major livestock disease from a given country, and that this public investment would yield international public good. This mind-set was popular with veterinarians pursuing the good intentions engendered in the Hippocratic Oath, and was promoted by a global international organisation (OIE). What the mind-set did not take into consideration was the amount of resources required for such an initiative, the likelihood of success under different funding scenarios, the distribution of benefits to be gained from the eradication of the disease among the various public- and private-sector stakeholders for which the disease was of prime importance, and the implications of the benefit distribution on control options and the sustainability of disease control and eradication. In addition, while there was strong and enthusiastic leadership of the public-sector disease control body in the country concerned, there was not the capacity to lead and undertake the complex economic analyses necessary to answer these key questions raised.

INNOVATION

Following completion of an economic impact assessment of the control of FMD in Thailand, the National FMD Task Force (NFMDTF) in the Philippines commissioned an economic impact assessment to help guide their planned eradication programme. The benefit-cost analysis concluded that eradication would yield substantial benefits, with benefit-cost ratios ranging from 1.6 to 12 depending on the scenario. The results also showed the disparity in the distribution of costs and benefits; while the public sector was contributing 100% of the costs of control, the commercial sector stood to capture nearly all of the benefits from FMD eradication. This had a significant implication. The result suggested that policy makers would be justified in expecting the commercial sector to contribute to the eradication effort, whether directly or through taxation. Eradication is not a one-off investment but requires continued investment to protect the FMD-free status of the country once achieved. Sustained public funding of the necessary FMD surveillance and control may not remain feasible, particularly given the commercial orientation of the expected benefits. Participation of direct beneficiaries in the commercial sector would provide a more sustainable alternative. This result allowed the NFMDTF, and others, to lobby for substantial investment by the private sector in the FMD programme. This led to the establishment of a coalition for the progressive control of the disease, and consolidation of disease freedom once it was achieved in different regions of the country.

The key players in the establishment and operation of this coalition were the heads of the National FMD Task Force, who provided effective strategic leadership and acted as champions of FMD eradication, actively pushing and advocating the eradication programme. The Department Secretary and Director both gave full political support to the Task Force to allow them to carry out their tasks, and facilitate support to their activities. Regional field offices and local government units were given key responsibilities and resources, which encouraged their support of the Task Force and its actions. Various components of the private sector, most importantly hog producers' groups, worked in hand in hand with the government to support the FMD eradication programme.

Other changes that were introduced in addition to those resulting from the economic impact assessment were: change of vaccine type after results of vaccine matching emerged; the focus on pigs for vaccination; the shift to FMD oil vaccine only; some operations research on vaccination; and animal movement management across islands. At a later stage when FMD outbreaks were diminishing and becoming sporadic, a risk pathway was developed to study how FMD was being spread. This opened the door to further adjustments and fine tuning in the control measures used.

The NFMDTF paid particular attention to developing strong networks with all the different stakeholders, making them feeling welcome and part of the process, and respecting the diverse opinions offered. This was particularly important with the widening of engagement with different private-sector groups as investors, and in managing the interface between the public and private sectors. The NFMDTF essentially acted as a network through which different stakeholders were connected and invited to participate in the programme. This was a unique example of a public-private partnership, as well as a partnership of different public-sector agencies. This had to extend to include the consumers of pork products when FMD was made a public health and food safety issue in the press, which stressed the importance of sourcing meat from healthy animals, and that all emerging meat should be duly inspected.

On several occasions during the FMD control and eradication programme, the NFMDTF held large formal consultations, at which stakeholders were able to contribute, and duly expressed their support or criticised the programme. The practice of responding to farmers became a normal operational procedure so that farmers were not left with unanswered queries. There was an observed trend that the poorer the farmers were, the greater the feedback given on various aspects of the programme, including vaccination results.

INNOVATION PATHWAY

The idea of eradicating FMD from the Philippines had been on the cards for many years. A certain amount of public funding had been allocated, and an eradication timetable had been developed. The initiation of a regional coordination office for FMD control in Southeast Asia in 1997 under the auspices of OIE (World Organisation for Animal Health[7]), and funded by the governments of Australia, Japan, and Switzerland, opened the door to a more analytical and transparent approach to the reporting and understanding of FMD dynamics and impact in the region. The Philippines, being a member of the SEAFMD campaign, was bound to the agreements forged under this campaign hence this provided a basis for the government to continue and strengthen its eradication efforts. In 1998 an initial study was undertaken (led by the International Livestock Institute, ILRI) to review the evidence of the economic impacts of the disease in countries of the region, and to undertake a case study of the economic implications of FMD freedom in Thailand (Perry *et al.*, 1999). During the Phnom Penh meeting of OIE's regional coordination unit for FMD in SE Asia in 1999, ILRI was approached by the national coordinator of the FMD control programme in the Philippines, Carolyn Benigno, who requested that a similar study be undertaken there, including capacity building and training in economic impact assessments.

[7] http://www.rr-asia.oie.int/about-us/sub-regional-representation/

An initial visit to the Philippines was made by ILRI scientists in November 1999, who held meetings with the National FMD Task Force (NFMDTF) chair and her staff, and the FAO officer Ray Webb. A full study visit was made in 2000, during which meetings were held with a wide range of stakeholders in both the public and private sectors. The team developed a set of scenarios, based on the plans and timetable of the Government of the Philippines, and more optimistic and pessimistic assumptions, each discussed in detail with stakeholders in the country. The study included an analysis of the distribution of the benefits, a component which had a substantial impact (Randolph *et al.*, 2002). The NFMDTF chair and the NTSMDT disease information management specialist subsequently travelled to ILRI in Kenya for a period of analysis and in-service training on cost-benefit analysis.

The study illustrated that while the FMD control programme was funded entirely from public-sector government coffers, in eradication scenarios, the major beneficiaries would be the private-sector pig producers, traders and marketers; the commercial swine sector was estimated to capture 84% of the benefits generated by the public investment in eradication, versus 4% by backyard swine producers. This was used very effectively by Carolyn Benigno and her colleagues to lobby for private-sector investment in FMD control efforts, and to bring them into the control programme leadership and decision-making.

The study, and in particular the distribution of costs and benefits, changed the approach to FMD control entirely. The benefit-cost analysis showed quite clearly that the government of the Philippines provided all the programme costs (PHP 532 million), but the public benefits to eradication were just PHP 151 million (12% of benefits accrued). In contrast the major benefits (84.2%) went to the commercial pig sector in the form of avoided production costs, avoided prevention costs and avoided treatment costs. This information was used by the National FMD Task Force (NFMDTF) to lobby various private-sector entities to contribute to the eradication programme with both financial and human resources.

The NFMDTF was being asked by government how long would budgetary allocation for FMD control would be required; was it worth it; and who benefits? The study proved to be a turning point for the Philippines FMD control and eradication programme. When the results clearly indicated the benefits of FMD eradication and that the producers stood to benefit from it, the Task Force Chair presented the study in as many fora as possible to convince policymakers that the investment was worthwhile and to convey a message to private producers that they would benefit given an FMD-free setting. That turned the tide as producers came together and became active in the consultation process, became vigilant to meat importations as well as vaccines of doubtful quality, which they thought would jeopardise the FMD status of the country. They assisted substantially in funding activities of the Task Force, contributing to public awareness campaigns and paying for the salaries of checkpoint guards assigned to man ports of FMD-free areas. Suddenly, the Task Force became a force to be reckoned with. The NFMDTF had tremendous support from the producers and this continued until the last zone was declared free in 2011, leading to the whole Philippines being recognised as FMD free.

The following list itemises contributions to the eventual eradication of FMD from the Philippines:

- mass vaccination programmes begin: 1970s
- new national strategy introduced: 1996
- OIE regional coordination unit for FMD in SE Asia introduced: 1997
- concept of economic impact assessment introduced into OIE-coordinated SE Asia regional FMD initiative: 1998
- regional economic impact study and Thailand benefit-cost analysis completed: 1999

- request to ILRI for economic impact assessment in the Philippines: 1999
- national discussions on scenarios and cost implications for eradication developed: 1999
- cost-benefit analysis completed: 2001
- publication of economic impact analysis paper: 2002
- platform for discussions with the private sector: 2003– 2005
- agreement of private sector to join task force: 2004
- FMD eradicated from the Philippines: 2011.

IMPACT EVIDENCE

An evaluation of the investments made by Australia in the FMD control and eradication programmes was published in 2010 (Mcleod, 2010). This draft document reviews the roles of livestock in the region, and the economic impact studies that have been carried out (including the study reported in this brief).

The last case of FMD was seen in the Philippines in 2011. In the 83rd General Session of OIE in May 2015, the Philippines officially received recognition as a country free from FMD 'without vaccination'.

CONSEQUENCES

Today, markets have opened up for the Philippines, such as those in the Middle East and East Asia. Local producers have also upgraded their facilities to get accreditation from the importing countries. Plans are afoot to establish high grade facilities in provinces (and not just private undertakings) to encourage smallholder farms to have their animals processed at these facilities and have their produce exported as well.

As the programme progressed, and FMD eradication was recognised as the emerging product, animal health officers at various levels gained confidence about the prospects of eradicating other diseases, opening the door to new health initiatives. Importantly, senior technical officers in the programme also developed other skill sets, especially in negotiation, project management and organising activities.

FMD eradication was high on the list with the Department of Agriculture, as producers groups had been very critical. The raising of awareness of their importance as true partners helped the NFMDTF operationally, as the producer groups then became allies in the eradication programme. If there were planned importations (such as vaccines from an unknown company), the producer groups assisted NFMDTF in pressuring senior government not to allow this.

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FORAGE IN INDONESIA

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SUMMARY

This case study covers six research projects involving Indonesian and Australian research institutes that aimed to increase smallholder production of beef cattle through improved animal breeding and feed management practices in South Sulawesi and Lombok, Indonesia. The work was funded by the Australian Centre for International Agricultural Research (ACIAR) and AusAID (now DFAT) from 2000 to 2012. The work follows a traditional transfer of technology approach, with the development/testing of animal and forage management practices (Phase 1), piloting (Phase 2) and scale out (Phase 3). The projects pursued innovation through local participatory research processes, capacity building in integrated farming approaches for government and research agencies, and policy engagement. The projects demonstrated significant improvements in animal production and household income, however higher level policy change to support broader impacts failed to materialise.

Table. Patterns of Innovation and Impact processes Summary table

Initiator	Project commissioned to scale research findings.
Critical features	Extension methods and farmer organisational development promotes technology.
Role of research	Development and evaluation of technology and farming systems options.
Operational alliances	Local research and extension organisations and farmer groups.
Strategic alignment of stakeholders at sector or national level	Weak links to private sector and local and national policy agencies.
Solution, product, or system innovation	Created local farming systems solution with limited spread.
Scope of impact (and metrics)	Limited to project domain.

CHALLENGE

The domestic beef production system, though an important part of provincial economies, has low productivity in Indonesia (Waldron *et al.*, 2013). Demand for beef has outpaced supply since the 1990s, with Indonesia increasingly reliant on imported beef (Hadi *et al.*, 2002). The Government had invested significantly in infrastructure to support live imports (ports, commercial feedlots) however the devaluation of the rupiah after the Asian Financial

Crisis made live imports uneconomical. Many commercial feedlots were forced to close, while local prices soared, leading to the slaughter of productive females and a decline in domestic herd populations (Hadi *et al.*, 2002). In 1999, the Government of Indonesia introduced a goal to become self-sufficient in cattle production (Waldron *et al.*, 2013).

Most production is in traditional systems and by smallholder farmers who use cattle as a form of savings which are sold to cover large or unexpected expenses (Hadi *et al.*, 2002; Waldron *et al.*, 2013). While the government aimed to increase beef sufficiency nationally, they also wanted to ensure smallholders were able to benefit from this market opportunity and support poverty reduction.

This challenge has a number of interconnected elements: low efficiency animal production and husbandry systems; ineffective and poorly regulated livestock marketing systems; a supportive policy environment on the one hand, but also trade policies with potential to distort domestic markets.

Substantial research had been done on improved livestock feed practices. However, the reported benefits of using forages to improve livestock production had not been enough to convince farmers to devote resources to forage production (Pengelly *et al.*, 2003).

INNOVATION

The projects had three linked dimensions to support innovation in smallholder cattle production that evolved over time:

- The development of the Integrated Analysis Tool, a simple model incorporating crop, soil and Bali cattle growth models with labour and income requirements to explore trade-offs and dependencies within mixed crop-livestock systems. The tool was designed to quantify the benefits, costs and constraints to increasing cattle production through forage production and use, and became a participatory research and communication tool for use with farmers, university staff and government extension agencies. Options for increasing cattle production were modelled and results discussed with farmers as a way of developing a broad set of locally adapted practices that could significantly improve cattle production.
- The development of a set of simple practices to support improved cattle production at the individual and farmer group level (based on previous research, IAT outputs and participatory research). This included the introduction of forage materials to support improved animal nutrition, and animal husbandry and management practices to increase breeding rates.
- Establishing a network of project extension officers. Local extension services did not have the resources, technical capacity or motivation to provide the in-depth ongoing support to farmers the project needed to foster ongoing adoption of practices. Drawing on the insights of earlier research, 24 recent university graduates were employed to act as project extension officers, referred to as the On Ground Team (OGT). The rationale was that the OGTs would work closely with farmers to support adaptation and adoption, but more importantly provide a mechanism to foster skills and knowledge that would be absorbed into the Indonesian extension or livestock services departments.

INNOVATION PATHWAY

The six projects can be grouped into phases. These phases were not planned from the outset – although there is a logical progression to the projects, as each built on the achievements and progress of the last – it is only in retrospect that they have been labelled as a programme of work. It is also worth noting, that there are many other projects outside of those described here that contribute to a broader effort to increase cattle production in Indonesia. All projects collaborated closely with Indonesian universities and government departments.

Phase 1: Understanding the farming system, identifying intervention points (2000–2004; AUD1.3 million[8] across three projects). The first phase of research focused on understanding the smallholder farming system in the study areas, interactions and trade-offs between cropping and livestock activities, and identifying potential areas of intervention. At the end of this phase of work, a University of Queensland-led project had identified and tested a series of animal breeding and management practices, while two CSIRO-led projects had identified options for improving animal feeding through forage management, developed the Integrated Analysis Tool (IAT) and defined a set of potential practices to support improved cattle production.

Phase 2: Testing the 'best-bet package' and approach to working with farmers (2005–2008; AUD0.9 million across one project). Further refining and building on the IAT, this project, led by CSIRO, sought to develop, test and apply tools and knowledge sharing techniques appropriate for farmers and extension; and communicate outputs of research to smallholder farmers (see above).

The project was deemed successful at providing proof of concept on how to support smallholders to adopt forages as part of improving their cattle production without detrimentally impacting crop production, and providing wider labour savings and economic benefits (Lisson *et al.*, 2010). With the concept proven, focus turned to expanding the reach/dissemination of the impacts and understanding adoption processes.

Phase 3: Scaling out and up – supporting dissemination at local and policy levels (2007–2012; AUD2.2 million across two projects). The final phase of research balanced a research goal to examine the processes of diffusion, adoption and household decisions relating to the package of practices; and an extension goal to support broader dissemination of the practices through replication and policy influence. A network of recent graduates were employed to act as project extension support, working closely with farmers and farmer groups to support adoption and adaptation. Stakeholder engagement occurred formally through a committee of representatives from provincial and district government agencies (Livestock Services, Extension, the Regional Body for Planning and Development); representatives from the Governor's Office; senior administrators from partner universities; and traders.

This project focused on incremental change within the cattle production system. The teams took proven and recognised strategies for cattle management, and applied and adapted them to new areas, using participatory approaches that attempted to overcome past constraints (pilot to scale out/up). Three different approaches were used to support the process.

Locally, participatory research methodologies, replication of project activities in new areas, and dissemination through local networks were central to fostering adoption of new practices. The project focused on provision of improved information and resources to farmers – both to support improved cattle production and to support improved bargaining positions with traders. Beyond this, it was unable to address the dynamics of local cattle markets which can be a major constraint for smallholders.

Second, there was strategic engagement with key policy and programme designers at provincial and district levels, formalised within project advisory committees. The intention was to engage throughout the project with these key decision makers, fostering a sense of interest and ownership within key government departments for some of the project outputs/approaches.

Third, the project sought to build capacity in relevant research, services and extension agencies to support the continued application of project approaches post project. This was targeted through the Indonesian research team members, who held ownership of the project approaches and it was an-

8 Funding for each phase is based on ACIAR funding only and excludes cash or in-kind contributions by partner agencies. Amounts are based on project listings at https://www.aciar.gov.au/.

ticipated would integrate the principles and practices into other projects and through university curricula. The second group targeted for capacity building was the OGTs who, it was hoped, would take the skills and knowledge into the Indonesian extension or livestock services departments or other relevant areas post project.

IMPACT EVIDENCE

An impact assessment was commissioned into ACIAR's forage research in Indonesia in 2010 – prior to the completion of the final phase. Martin (2010) notes the challenges in conducting an impact assessment while the final set of projects were ongoing and adoption of technologies was still at a relatively early stage, however was favourable in assessment of benefits flowing from the research. The assessment estimated an internal rate of return of 19 percent, and a benefit:cost ratio of 20:1; more if the Indonesian government formally supported extension after the projects finished (Martin, 2010). Analysis in Lombok since the projects finished suggests many anticipated changes within policy and extension failed to materialise, or were applied in ways that subverted the aims of the original work regarding farmer ownership and empowerment (Dahlanuddin *et al.*, 2016).

The main scientific output of the project was the development of the Integrated Analysis Tool. A review of the contribution of the IAT, and systems modelling more generally to CSIRO's R4D work, noted significant impacts at the farm level (continued use of practices by farmers, and recall of farmers of the principles and discussions held at the workshop), as well as influence on the approach and methods being used as part of teaching and research at Indonesian partner universities (Connor *et al.*, 2015).

The OGT model was assessed as a successful approach to extension that could increase the probability of adoption, and support faster and more widespread adoption, suggesting it could be used by other projects (Martin, 2010). However, without supplementing this support after the project through existing, permanent extension mechanisms, the ongoing sustainability of the project success is less clear.

There is evidence for increased cattle productivity, increases in income and reduced labour spent in cattle production stemming from adoption of the practices in both Sulawesi and Lombok (Lisson *et al.*, 2010; Dahlanuddin *et al.*, 2016). A commissioned review considering the role and impact of farming systems modelling in R4D in 2012 noted 'a strong impression of success' indicated by widespread practice adoption, livelihood benefits, changing mechanisms for cattle sale, ongoing cooperation between research and extension agencies, and government policy support (Connor *et al.*, 2015).

CONSEQUENCES

When the projects ended in 2012, there were mixed predictions regarding the sustainability of project impacts, with significant hope and uncertainty over continued support through the Livestock Services Department and extension services. However, the support generated has not visibly translated into actual policy change in the ways anticipated (or recommended) by the projects.

There is a general consensus among the team members interviewed[9] that there were meaningful household benefits locally, but limited success or reach of the project beyond key project sites. One interviewee described a depth of impact, but not breadth: significant and lasting impact for champion farmers, that is, some of their scale out farmers and farmer groups who were directly involved. However, there was a geographic/social limit to how far this would spread, and the design of the project that focused on replication and farmer-to-farmer communication, while effective locally, was not going to work more broadly. The reliance on policy and extension to support further scale out did not materialise.

[9] Three Australian-based team members were interviewed in June 2016. Time and geographic constraints prevented additional interviews with Indonesian team members. None of the team members interviewed are currently working in Indonesia, though two had maintained informal links to Indonesian colleagues.

It may be plausible to suggest the body of work, at least in Lombok, has supported a strong research network and community of livestock researchers that have continued to foster incremental changes at the household and community level. Adequate assessment of this is not possible with the data currently available. With assessment of the wider suite of ACIAR livestock work, which is broadening over time to include more explicit incorporation of market systems, different impact stories may knit together.

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GOLDEN RICE

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SUMMARY

This case study examines the development of Golden Rice (GR), a biotechnology invention that promises to address Vitamin A Deficiency (VAD) in the rice-consuming populations of Asia. To date, however, it has had limited success, has not been accepted in the market, and is not cultivated and consumed. Despite promising a technological solution to a humanitarian problem, the issue of GR as a suitable intervention for VAD is being conflated with broader societal concerns and socio-political issues over genetically modified organisms (GMO), food sovereignty and the future of agriculture in developing nations.

GR is affected by high levels of conflict and political contestation around the introduction and diffusion of biotechnology in agriculture. It suffers from questions over legitimacy, and its framing as a scientific necessity and moral obligation by proponents of the technology has not been able to overcome societal values and the challenge of alternative solutions. At present the potential of GR to address VAD remains just that, a possible future option, as the science of crossing GR into local varieties and testing for efficacy and safety and the controversy around GM, and resistance to GR introduction in the target countries, continue.

The case of GR illustrates that technological solutions are insufficient on their own to create the benefits sought, without addressing the larger, institutional and socio-political features of the agri-food systems into which they are delivered.

Table. Patterns of Innovation and Impact processes Summary table

Initiator	Public biotech research to fortify beta-carotene content in rice to reduce VAD.
Critical features	‘Golden Rice Humanitarian Board’, allow public research institutions in developing countries free access to the proprietary technologies available only in public-sector rice germplasm, and provide the seed at no cost to smallholder farmers.
Role of research	Inclusion of daffodil genes and a bacterial gene into the rice genome. Ongoing research to resolve beta carotene content, crop yield, and performance issues.
Operational alliances	Public research transferred the rights to a private multinational biotechnology organisation, only to have all legal rights donated to a Humanitarian Board to allow ‘freedom-to-operate’ in developing countries, thereby foregoing potential commercial benefits from its adoption.
Strategic alignment of stakeholders at sector or national level	Global consortium of international public research, private seed companies, and philanthropic foundations.

Solution, product, or system innovation	Possible biotech solution to VAD caught in science –policy controversy as part of the debate for and against GM crops.
Scope of impact (and metrics)	No producers or consumers have yet adopted GR.

CHALLENGE/OPPORTUNITY

Rice is the most commonly available staple food, consumed by a large part of the world's human population, and supplying around 20% of all human food energy. In many societies, where rice is the primary food, people are affected by malnutrition of micronutrients, including vitamin A deficiency (VAD). In the early stages, VAD causes night blindness and dry eye syndrome, limits growth, and compromises the immune system, which untreated leads to complete blindness and ultimately child mortality (Mayer *et al.*, 2008). Globally, in 2014, nearly 30% of children up to six years old were affected by VAD, with the highest rates found in sub-Saharan Africa and South Asia, with nearly 50% affected (Bongoni and Basu, 2016).

Supplementation and fortification-based interventions have been used for two decades to address VAD. Although such interventions show success, they have not been able to eradicate the problem to date, mainly due to the significant and expensive distribution logistics required, which are insufficiently developed in poorer countries and may be disrupted due to economic crisis or political instability. Experience with vitamin A supplementation programmes revealed that coverage achieved over the past decade in 82 priority countries is growing, but has been patchy, with year-to-year fluctuations (UNICEF, 2016).

Biofortification of food crops has emerged in the past decade as a potentially cost-effective and sustainable intervention to address a number of micronutrient deficiencies. Biofortified crops are intended to be distributed through the traditional pathways of agriculture and local trade. The GR inventors state that for its continued deployment following introduction little more will be required than the costs of the normally reliable seed production systems. Production costs would be no different from any other rice (Beyer, 2010).

INNOVATION

Despite significant technological and institutional developments, the innovation of transforming diets has not taken place. Opposition to GMO and GR in particular is set to persist for the foreseeable future, and so is the insistence by GR proponents that it is a global good. Hence, despite regulatory delays, the vocal opposition to GR, and the ongoing R&D required to create viable GR variants suited to local conditions, the effort to bring GR to market continues. The key technological, intellectual property (IP) and institutional developments can be summarised as follows:

Technological dimension. Conventional breeding cannot produce a biofortified rice, because although pro-vitamin A is present in the green parts of the rice plant, no known strain makes it in its seeds, leaving genetic modification as the only option. In 1999, researchers inserted three genes into rice that enabled it to produce beta-carotene, the precursor to vitamin A, which the body converts into vitamin A (Dove and Savoie, 2000). In the first version of GR (GR1) the gene of normal rice was modified by incorporating the genes *psy* (*phytoene synthase*) from daffodil and *crtI* (*carotene desaturase*) from the soil bacterium (*Erwinia uredovora*). This resulted in rice grains that were golden in colour and contained enhanced levels of beta-carotene (Bongoni and Basu, 2016).

However, the most successful strain created in 2000 produced only 1.6 micrograms of pro-vitamin A per gram of rice – so little, that an average 2-year-old would have needed to eat several kilograms of GR a day to reach the recommended daily intake

– a fact much publicised by opponents of the technology. The argument went that GR simply did not work (Greenpeace, 2001).

The low beta-carotene yield was solved by Syngenta scientists, by replacing one of the daffodil genes with one from maize, creating what is known as GR2. The latest version of golden rice produces enough beta-carotene in the endosperm of the rice plant to provide 50–60% the daily recommended allowance of vitamin A from as little as 72 g of golden rice grains, which is equivalent to one serving of rice (Enserink, 2008).

Studies have shown that the beta-carotene contained in GR is the same as the beta-carotene found in other foods in terms of effectiveness in transferring to vitamin A. Other studies demonstrated that the added genes in golden rice were not associated with potential allergies or toxicity, that GR was unlikely to impact the biodiversity, and that production of beta-carotene in the rice endosperm does not give GR a variability in traits that will enhance its survival compared to its wild-type counterpart (Moghissi, Shiqian, and Yinzuo, 2016).

Additional research in the project is being conducted to develop GR with even higher beta-carotene (Zeigler, 2014), and applications for safety review of GR2 have been submitted to the US Food and Drug Administration, Food Standards Australia and New Zealand, and Health Canada (IRRI).

Intellectual Property arrangements for commercial and public use. Innovation occurred in institutional arrangements, specifically regarding intellectual property ownership and transfers. After the initial research undertaken by public institutions, a public-private partnership was formed with Syngenta to navigate product development and existing patent protections. Syngenta reduced the number of patents involved, secured free licences, established managerial and marketing structures and developed plants optimised to meet regulatory requirements (Potrykus, 2010).

The developments concerned the strategic assembly of multiple innovation components owned by multiple entities. GR involved multiple inputs of methods and materials potentially covered by patents owned by other entities. An initial Freedom-To-Operate analysis was undertaken, which identified a group of patents and patent applications, and tangible property (TP) issues that might be relevant. It was subsequently determined, however, that few patents pertaining to GR were applicable in developing countries, and the same was true for several TP issues (e.g. material transfer agreements). Core patents were licensed to Zeneca, which already owned its own plant-biotechnology-related patents. Zeneca then negotiated access to all possibly necessary patents, including IP from Bayer, Monsanto, Novartis, Orynova, and Zeneca Mogen (Kowalski, 2015).

By strategically assigning their IPR in the GR technologies to Syngenta, the inventors enabled

Syngenta to accelerate access to technologies and facilitate humanitarian licensing, which enabled transfer to public research institutions in developing countries.

Public bodies involved in the exploitation of GR. Two complementary institutional bodies were established under the agreement by which Syngenta licensed GR back to its inventors: a ‘Humanitarian Board’ including the inventors, donors, and the director of HarvestPlus, and a ‘Golden Rice Network’ that acts as technology holder to distribute technologies and materials to applicants once the transfer has been approved by the Humanitarian Board. Established as an independent structure, the Golden Rice Network, however, included several of IRRI’s national agricultural research systems partners.

The focus of the CGIAR shifted to large multi-stakeholder partnerships with the private sector who hold the resources and IP required for cutting edge biotechnology research. In the space of rice biofortification, CGIAR effort was concentrated on iron and zinc biofortified rice research coordinated by IRRI, and the GR project, led by IRR (IRRI, 2016; IRRI, 2015). In 2003, the CGIAR launched HarvestPlus, a global programme of biofortification research. That same year the Bill and Melinda Gates Foundation, the largest donor of HarvestPlus, launched its own rice biofortification challenge, the ProVitaMinRice Consortium, building on the GR project outputs and institutional framework. These initiatives not only intersect, but the Humanitarian Board has over time grown in size and broadened its mandate over the Golden Rice project and HarvestPlus and PVMR consortia (ProVitaMinRice Consortium, 2008).

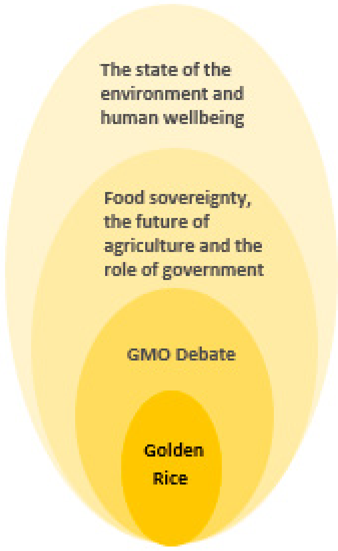
INNOVATION PATHWAY

Context. Significant challenges to GR have arisen in the public sphere, where the GR discourse is polarised and hostile. In the Philippines, protesters have destroyed experimental plots of GR. In India, where GR critics have framed GMO as a threat to Indian identity and national interest, activists vow to stop its adoption even if the government allows its release (Rouhi, 2013; Fuchs and Glaab, 2011).

Support for GMO is underpinned by its identification with the notion of 'progress', i.e. with 'universal, a-historical claims that genomic technology and transgenic crops represent "progress for humanity"'. Proponents of GM crops argue that the technology can make a vital contribution to increasing agricultural production, improving livelihoods, and enhancing food nutritional quality in the developing world. The moral argument is that GM food production is needed to feed the hungry, and resistance to adopt the available technologies for food security constitutes a crime against humanity (Allow Golden Rice Now Society).

Critics believe agricultural biotechnology undermines food security. Food production and distribution are competitive, controlled and often exploitative enterprises both in local and geopolitical arenas, and GR and similar biofortified crops are seen as a short term strategy that in the long term endangers the health of humans, the environment and biodiversity (Small, 2014).

Figure 1. The contested spaces of the GR debate



Additionally, access to knowledge in agricultural biotechnology is heavily restricted by patents. Today, five major groups of large multinational agri-biotech companies have the necessary capital and control access to most of the technology needed to do commercial research on GM crops, presenting a formidable concentration of material and discursive power that can influence agri-food governance and policy arrangements (Nuffield Council on Bioethics, 2004; Fuchs and Glaab, 2011).

Citizens and consumers in many parts of the world consider such concerns relevant to decisions about introducing GM crops and foods. In many countries, particularly in Europe, consumer backlash has led to delays in regulatory approval of GM foods and crops and financial losses for agricultural biotechnology corporations. It is also suggested that the question of the co-existence of GM with conventional and organic crops has become the new battlefield for contending policy agendas: between an agrarian-based rural development versus a neoliberal agri-industrial paradigm (Dibden, Gibbs, and Cocklin, 2013).

Timeline. GR provides an unusual example in agricultural biotechnology development in so far as the original technology was developed by public institution researchers, who transferred the rights to a private multinational biotechnology organisation, only to have all legal rights donated to a Humanitarian Board to allow 'freedom-to-operate' in developing countries, thereby foregoing potential commercial benefits from its adoption. Syngenta licensed the rights to GR2 to the Humanitarian Board on World Food Day in 2004. The then head of research at Syngenta recognised that, given consumers' distrust, there was no money in it (Zeigler, 2014).

The idea for golden rice was born at an international agricultural meeting in the Philippines in 1984, where, over beers at a guesthouse one evening, a group of plant breeders discussed how gene technology might benefit rice. The answer they arrived at was 'yellow endosperm', referencing the colour of beta-carotene and VAD.

Throughout the 1980s, the Rockefeller Foundation funded a number of exploratory studies, but not until 1992 did scientists settle on the idea of reintroducing the biochemical pathway leading to beta-carotene into rice, but putting it under control of a promoter specific to endosperm. In 1999, Ingo Potrykus from the Swiss Federal Institute of Technology (ETH) in Zürich and Peter Beyer, from the University of Freiburg, succeeded in making golden rice by splicing two daffodil genes and a bacterial gene into the rice genome.

Between 1996 and 1999 Beyer's lab received funding through a European Commission contract that also included agrochemical giant Zeneca (later Syngenta), stoking controversy and supporting the opposition's view that GR was an industry PR ploy and Trojan horse to get GMO accepted (Brooks, 2010). The role of 'Golden Rice' became the iconic science-policy controversy of the decade, summoned by both sides in debates for and against GM crops (Brooks, 2011).

In 2001, Potrykus and Beyer licensed their technology to Syngenta for commercial use, which was justified as necessary in order to negotiate unforeseen intellectual property restrictions that threatened to block progress. Golden Rice as a global public good was saved by means of a 'Humanitarian Licence', which would, under the guidance of the 'Golden Rice Humanitarian Board', allow public research institutions in developing countries free access to the proprietary technologies available only in public-sector rice germplasm, and provide the seed at no cost to smallholder farmers (Dubock, 2014).

In 2001, the GR technology was transferred to IRRI and other public research institutes in the Philippines, Bangladesh, India, and Vietnam, the countries chosen as the best candidates for the crop's launch, for back-crossing into local varieties. Both GR1 and GR2 had been created with Japonica cultivars favoured for scientific research, but which performed poorly in Asian conditions (Brooks, 2011).

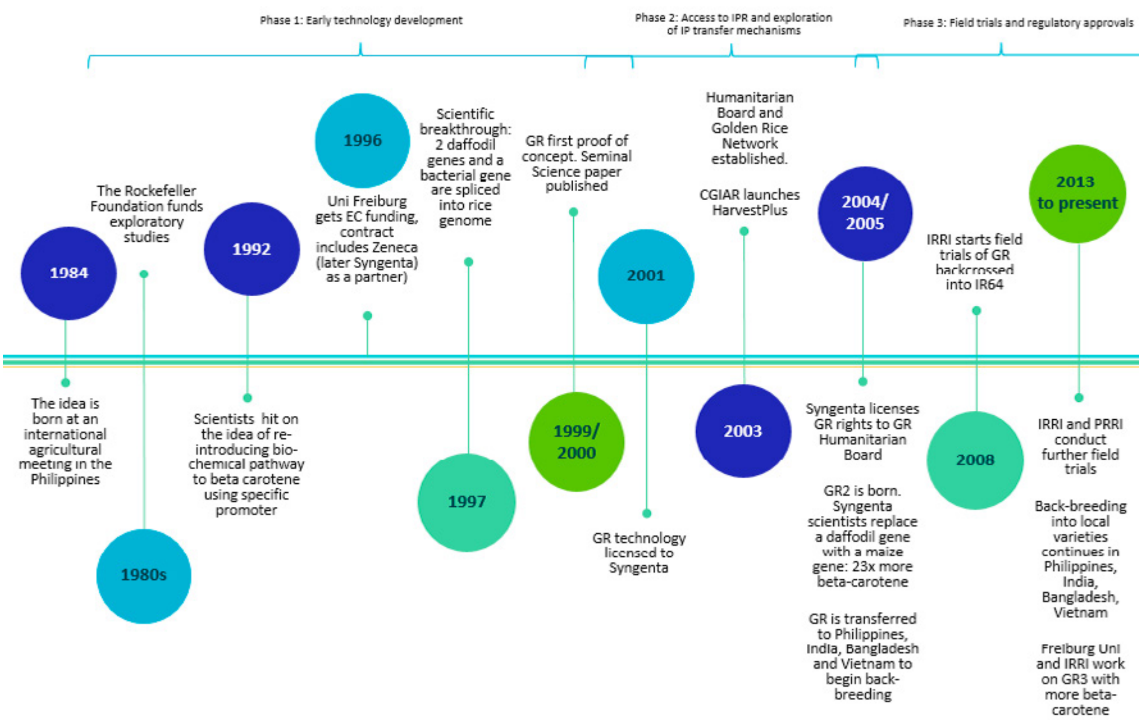
Since 2008 the trait has been transferred from the original cultivar into selected locally adapted rice varieties. This is being undertaken by a consortium of research institutions in the target countries of Philippines, Vietnam, India and Bangladesh. However, technical challenges remain. GR is still in research and development, following completion of the regulatory requirements of the partner countries. IRRI continues to work with national research agencies, but release of GR may be another five years away (Stone and Glover, 2017).

In early April 2008, researchers at IRRI started the first confined field trial in Asia with a GR1 backcrossed into a widely used Indica variety, IR64. The only other outdoor studies had been done in Louisiana in 2004 and 2005. Multi-location field trials were not undertaken until 2013. IRRI and the Golden Rice project worked with the Philippine Rice Research Institute on field trials spanning three growing seasons at five sites across the Philippines. Unfortunately the GR selected for testing did not grow as well as local varieties (Eisenstein, 2014).

GR is closest to launch in the Philippines, however the technology is not ready, and is not expected to be ready for several years. The best varieties are still experiencing poor crop yields and performance compared to rice without the GR trait (Stone and

Glover, 2017). Even if field trials are successful, there are no guarantees that GR will eventually be approved in the target countries. What little GM technology HarvestPlus supports is a 'hedge', in case the political and regulatory climates shift (Enserink, 2008).

Figure 2. Innovation timeline for Golden Rice



A number of authors, including one of the inventors, explain the reason for the delay as being regulatory in nature. Regulation of GMO crops is time consuming and expensive and differs from nation to nation. Additionally, the application of the cautionary principle under the Cartagena Protocol in Biosafety is seen by proponents of GM technologies as a tool for those who want to stop scientific development that they dislike (Dubock, 2014; Portykus, 2010).

This position however denies that other factors may prevent GR uptake, even once regulatory clearance has been achieved in the target countries. Little work has explored the intangible cultural values of groups in the developing world that are likely to influence perceptions of GM food risks, and the assertion by GMO proponents that the key to public acceptance is a matter of education may be false (Finucane and Holup, 2005). Both opponents and proponents of the technology are complicit in decontextualising and disembedding GR, as if it were a generic GM solution. However, it is rice – the most widely consumed and arguably most culturally weighted crop in the world (Stone and Glover, 2017).

IMPACT EVIDENCE

Given no consumers have yet adopted GR, the resulting impact to date is nil. Real-world studies on GR are still lacking, and it is unclear how many people will plant, buy, and eat golden rice. The FAO considers biofortification a useful adjunct approach to reducing hunger and malnutrition, but considers the more sustainable path forward to be about prioritising biodiversity for nutrition and agriculture (FAO, 2013).

In the Philippines, where GR is most heavily promoted, the Vitamin A supplementation programme achieved 83% full coverage among the target population in 2014, up from 69% in 2000. Similar improvements are observed in Bangladesh and Vietnam, although not in India (UNICEF, 2016), which suggests that as GR progresses to market, it reduces in significance as the solution to a global health crisis to a possible, supplementary approach in specific areas that may be hard to reach.

CONSEQUENCES

The difficulties involved in the launch of GR provide clear lessons on the complexities and process of biofortification of crops through the GM pathway. The inventors, though fully cognisant of the GM debates raging in their home countries and elsewhere, did not anticipate the level of rancour the development of GR would provoke, nor were they initially aware of the maze of existing IP rights challenging their progress.

The significant efforts expended by the Humanitarian Board and its research and donor partners to influence public opinion through the media towards GR acceptance as a public good suggest that some understanding may have been gained that sound technology and favourable regulatory and policy outcomes alone are insufficient for social innovations to occur. Additionally, notwithstanding the ongoing obstacles to GR release, the scientific knowledge and potential future applications from this rice GM biofortification project over 30 years are likely to be substantial.

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MARINE STEWARDSHIP COUNCIL

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SUMMARY

This case study describes the establishment and evolution of the Marine Stewardship Council (MSC), an independent non-profit organisation, established to address the problem of unsustainable fishing and to safeguard seafood supplies for the future.

Technological improvements, more and larger boats, and rapidly increasing demand led to huge increases in fish catches throughout much of the 20th century. However, the collapse in 1992 of the Grand Banks cod fishery, off the east coast of Canada, and declining white fish stocks in the North Sea, served as a wake-up call to the global fishing community.

In addition to causing severe decline of fish stocks, industrial and large-scale commercial fishing was also associated with a significant problem of bycatch, including fish, marine mammals, turtles and sea birds. Some fishing methods, such as bottom trawling, were also damaging to the environment. From the 1980s onwards, potentially negative environmental aspects of fishing started to gain greater attention from both the fishing industry and environmental groups, and the media brought them to the attention of the wider public.

The MSC was established in 1997 to address the problem of unsustainable fishing and to safeguard wild-caught seafood supplies for the future. It does this through an assessment and certification process of seafood products against a *Fisheries Standard* that was designed to assess whether a fishery is well-managed and sustainable. Products are identified at the point-of-sale by the blue MSC logo. Seafood businesses that handle these certified products are identified with *Chain of Custody* certificates, to ensure traceability of these products back to MSC-certified fisheries.

Two large organisations, an international conservation NGO, WWF International, and a multinational company, Unilever, that at the time owned well-known fish brands Birds Eye and Iglo, provided the initial leadership that led to the formation of the MSC. Although the two organisations had different motivations – conservation and commerce – they shared the same objective, . At the same time, Greenpeace, an independent global environmental campaigning organisation, was running an oceans campaign, targeting companies including Unilever that used fish oil.

In 1993, WWF had been involved in the formation of the Forest Stewardship Council (FSC), an international, not-for-profit organisation to promote responsible management of the

world's forests through market-led incentives. Lessons learned from this experience informed the governance structure of the MSC. In particular, the FSC's membership model was avoided in favour of a leaner foundation model, chosen to enable the MSC to adapt and act quickly.

In February 1997, the MSC was formally registered at Companies House, UK, as a private company with an international board of trustees. MSC then ceased to be a project of WWF and Unilever, becoming a registered charity and an independent non-profit organisation.

Since the first fishery was certified in 2000, over 12% of all the world's marine wild-caught seafood is now MSC certified and the 'blue tick' logo can be seen on fish counters and in restaurants throughout the world.

There is some evidence that fish stocks in MSC-certified fisheries are increasing more than uncertified stocks. There is also evidence that demand for certified fish from major retailers is encouraging fisheries to seek certification.

Table. Patterns of Innovation and Impact processes Summary table

Initiator	Global commercial and environmental fishery concerns leverage the opportunity of growing ethical consumer behaviour.
Critical features	Market-led, voluntary, independent, assessment and certification system for well-managed and sustainable fisheries with labelling of certified products at point-of-sale and traceability for product supply chains. Similar to FSC but without potentially limiting membership model, thereby enhancing flexibility and faster responses from a leaner organisation.
Role of research	Basis of certification (Fisheries Standard) based on best available science and regularly reviewed and updated. Ongoing research on impact of MSC certification on fish stocks and environmental impact of fisheries.
Operational alliances	Initial alliance between WWF and Unilever provided leadership to get concept off the ground. Prompt establishment of MSC as independent, standard-setting and certification body, structured as not-for-profit charity, enabled buy-in from fishing, processing and retail businesses other than Unilever, and also other stakeholders.
Strategic alignment of stakeholders at sector or national level	Initial partners, WWF and Unilever: strategic alliance of large, well-known, international NGO and multinational company with different motivation but common interest. Organisational strategy, principles and Fishery Standard developed through wide stakeholder consultation. Stakeholders from industry, science, international organisations and NGOs involved in governance arrangements at various levels. Draft assessment reports and other policy documents open to public scrutiny and comment.
Solution, product, or system innovation	Independent wild-caught fishery assessment, certification and labelling programme, supported by science and technology advances and commercial interests, progressing system innovation across the wild-caught fishery sector.
Scope of impact (and metrics)	12% of wild-caught seafood is MSC certified with market value of USD5 billion per year (2016). Since 2000, more than 1200 improvements, need for which identified during assessment process, made by certified fisheries. Some evidence that biomass of stocks increases in years after certification, and that demand for certified products by major retailers is influencing behaviour of fishery managers.

CHALLENGE/OPPORTUNITY

From Medieval times until the mid-twentieth century, fishing methods remained remarkably similar. By the mid-19th century, systems of transporting highly perishable fish limited their use to near where they were caught, unless it was in dried, salted or smoked form. The result was that for millennia fishing had little impact on fish stocks. An early game changer was the advent of commercial refrigeration, which arrived in the UK in 1861. Combined with rapidly rising urban populations there was now a growing demand for cheap fish and with refrigeration and the coming of the railways, a more effective means of meeting that demand. Later, the rapid spread of domestic refrigerators and freezers following the start of their mass production in the 1940s further increased demand and the ubiquitous fish finger first appeared in the 1950s.

Nets and lines made from synthetic fibres were first used in 1936 with the introduction of PVC. This paved the way for larger nets, which lasted longer than those made of natural materials. Fishing methods however, remained largely unchanged until the 1950s, when freezer trawlers were introduced which had the capacity to gut and freeze huge amounts of fish during prolonged stays at sea. At the same time, industrial fishing emerged and the catch was also converted into fish oil and fishmeal for use as a fertiliser and animal feed.

In the 1960s, trawlers started to benefit from radar, electronic navigation systems and sonar and by the 1980s, satellite technology, which enabled trawler captains to pinpoint fish shoals precisely which they then caught in enormous nets – some up to 50 miles long. With the advancement of technology and more boats, fish catches continued to increase through the 1980s but then in 1990 they fell sharply.

The collapse of the Atlantic northwest cod fishery (also known as the Grand Banks cod fishery), off the east coast of Canada, served as a wake-up call to the global fishing community. After 500 years of fishing, which had shaped the Newfoundland people's livelihoods and culture, the Canadian government declared a moratorium on the fishery in 1992 after stocks fell to an estimated 1% of earlier levels. Prior to the moratorium, from the 1960s, inshore fishers had complained to the Canadian government about the increasing number of foreign trawlers operating in the fishery. The government's response was to extend the offshore fishing boundary in a number of steps from 3 miles offshore to eventually reaching 200 miles by 1976. Although this reduced the number of foreign boats, more US and Canadian trawlers took their place and the pressure on cod stocks continued. The collapse was attributed to overfishing, poor understanding of the stock and its ecology, and lack of appropriate policies. Originally intended to last 2 years, with the hope that the stock would soon recover, the ban on large-scale fishing remains in place today, 25 years later.

At the same time as the collapse of the Canadian fishery, it was estimated that the North Sea cod stock had declined to 15% of its estimated 1970 level. Fish stocks are calculated using standardised approaches based on estimates including fishing mortality and Spawning Stock Biomass (SSB), although these are subject to considerable uncertainty.

In addition to causing severe decline of fish stocks, industrial and large-scale commercial fishing was also associated with a significant problem of by-catch, that is, the capture of non-target species including fish, marine mammals, turtles and sea birds. Some fishing methods, such as bottom trawling, can also be highly damaging to the environment.

From the 1980s onwards, potentially negative environmental aspects of fishing started to gain greater attention from both the fishing industry and environmental groups. By the early 1990s, these issues were regularly being brought to the global public's attention by the media, helping to create demand for more responsibly sourced seafood. This was all part of the broader ethical consumer movement that has emerged and grown rapidly over the past

20 years and seen the mainstreaming of Fairtrade and organic produce, and enhanced welfare egg and meat ranges, among other consumer concerns.

One way of addressing the problems outlined above is to empower consumers to make informed choices so they can confidently identify and buy fish and other seafood that is caught in well-managed and sustainable fisheries and avoid products from fisheries that use environmentally damaging practices. This was the opportunity that the MSC was established to address.

INNOVATION

The MSC operates as an independent not-for-profit organisation. It was established in 1997 to address the problem of unsustainable fishing and to safeguard wild-caught seafood supplies for the future. It does this through an assessment and certification process: seafood products that meet its Fisheries Standard, designed to assess whether a fishery is well-managed and sustainable, are identified at the point-of-sale by the blue MSC logo. Seafood businesses that handle these certified products are identified with Chain of Custody certificates, which are designed to ensure traceability of these products back to MSC-certified fisheries.

Seafood labelled as MSC certified at the point-of-sale enables concerned consumers to purchase fish and other seafood sourced from fisheries that have been independently assessed and certified as being sustainable and well-managed. Similarly, retailers and food outlets can demonstrate their green credentials to their customers by selling seafood that is sourced responsibly, which may give them a commercial advantage among ethical consumers.

The MSC Fisheries Standard has been developed and is periodically reviewed in consultation with scientists, the fishing industry, international organisations and conservation groups. Key stakeholders, including small producers, developing country stakeholders and those who will be directly affected or may be disadvantaged by any change, are proactively contacted and invited to contribute to the review. Any proposed revisions are also put up for public consultation. All comments received are included in a synopsis of the revisions: for new standards, a second round of consultations explains how the comments were taken into account.

The MSC considers that it is developing and revising its Fishery Standard based on the latest understanding of internationally accepted fisheries science and best practice management. It is based on three core principles:

1. *Sustainable fish stocks*: The fishing activity must be at a level, which ensures it can continue indefinitely.

2. *Minimising environmental impact*: Fishery operations must be managed to maintain the structure, productivity, function and diversity of the ecosystem.

3. *Effective management*: The fishery must comply with relevant laws and have a management system that is responsive to changing circumstances.

Assessments and certification are undertaken by independent third-party conformity assessment bodies (CABs), which must meet best practice guidelines for standard-setting agencies as set out by the ISEAL alliance (the global association for sustainability standards) and the Food and Agriculture Organization of the United Nations (FAO). CABs are typically specialist, for-profit companies.

To determine if each principle is met, 28 performance indicators (PI) are used by the CABs to score the fishery. To be awarded the MSC blue logo, each PI has to score a minimum of 60 out of 100. If the score is below 80, then one or more conditions that the fishery must meet within a stated timeframe are specified.

Certification is voluntary and is open to all fisheries involved in the wild capture of marine or freshwater organisms. Fisheries that wish to be certified, first appoint a CAB to assess their practices against the MSC standard. This involves a pre-assessment evaluation of the fishery, full assessment and further annual surveillance audits to assess compliance with the MSC Fisheries Standard. If successful, the fishery is certified for up to 5 years, subject to the annual surveillance audit.

The cost of a full assessment is in the range USD10,000 to 500,000[10], depending on complexity: these fees are paid directly to the CAB. In addition to paying the fees of the CAB that carries out the assessment, organisations that use the MSC blue logo have to pay annual fees on a sliding scale of up to GBP1600 (USD2040) a year for consumer-facing products. In addition, royalties of up to 0.5% of the net wholesale value of sales are also payable to the MSC. A full assessment takes about 18 months to complete.

As part of the assessment process, in addition to peer review, the MSC posts draft full assessment reports on its website, which are available for public consultation for a 30-day period. During this period anyone, including stakeholders and the general public, can submit comments. Such a report typically runs to around 200 pages and includes detailed rationales for scores assigned by the audit team for each of the PIs. Once finalised 'public certification reports' are posted on the MSC website and are freely available for access by the public.

INNOVATION PATHWAY

The concerns of three organisations in the early to mid-1990s were critical to the establishment of MSC: Worldwide Fund for Nature (WWF), Greenpeace and Unilever. At this time, WWF was beginning an oceans campaign focused on increasing marine protection and enhancing appropriate fisheries management. This increased the organisation's interest in fisheries certification.

Previously, in 1991, WWF had begun a process that led, in 1993, to the establishment of the Forest Stewardship Council (FSC). The FSC is an international, not-for-profit organisation to promote responsible management of the world's forests through market-led incentives. It does this by setting standards for forest products. FSC's 'tick tree' logo indicates to consumers that labelled products are certified under the FSC system. The establishment of the FSC demonstrated to WWF that it was possible to align the interests of timber users, traders and representatives of environmental and human rights organisations.

In the early 1990s, senior managers at Unilever, one of the world's largest multinational consumer goods companies, were worried about the threat to dependable fish supplies for their highly successful Birds Eye and Iglo brands of fish products, notably fish fingers. They were especially concerned about the stability of North Sea whitefish stocks.

At the same time, Unilever and other large companies were being targeted by Greenpeace, which was also running an ocean campaign. Greenpeace's focus was industrial fishing for sand eels in the North Sea which were processed into fishmeal for animal feed and fish oil. They were concerned that this was leading to a depletion of this important food on which many larger fish, sea birds and marine mammals depended. Greenpeace wanted Unilever and the other companies to stop selling products containing or derived from fish oil. They also wanted a scheme whereby the origin of all fish was labelled. Unilever considered this labelling scheme to be unworkable but the campaign helped to further focus the company's attention on this issue.

The UN's Food and Agriculture Organization's Code of Conduct for Responsible Fishing, an inter-governmental non-binding regulatory regime, was unanimously adopted on 31 October 1995. Mike Sutton, head of endangered seas programme, WWF International, wanted to go further, however; he was looking for an industrial partner to support a market-driven system to protect fish stocks, in a similar manner to the recently established FSC.

[10] http://www.fao.org/docrep/010/ai002e/AI002E05.htm.

Sutton had an initial conversation with a PR consultant to Unilever in a London media club in September 1995. This led to further discussions with Unilever senior management and a series of workshops between the two organisations which culminated in February 1996 in a statement of intent jointly published by WWF and Unilever to establish '*an independent Marine Stewardship Council which will create market-led economic incentives for sustainable fishing.*' The statement noted that the two organisations had '*different motivations, but a shared objective: to ensure the long-term viability of global fish populations and the health of the marine ecosystem on which they depend.*'

Following the statement of intent, Coopers and Lybrand were engaged to lead a process of consultation from which the MSC's organisational blueprint and implementation plan emerged. A key decision was not to emulate the FSC's governance model, based on individuals and organisations as members, but rather to use a foundation model. This decision was designed to overcome perceived problems FSC had with stakeholder engagement. It was concluded that membership might constrain MSC, limiting its potential to adapt and act quickly.

In 1997, MSC was launched as an independent, non-profit organisation registered as a charity in the UK, without membership but with a board of trustees (BOT) and chair, a technical advisory board appointed by the BOT, a stakeholder council and a secretariat that coordinated a standards council. The 11 person board is currently made up of representatives of major seafood companies, a supermarket, an international organisation, academics and researchers, a government fishery manager and a non-governmental conservation organisation. Members are drawn from North America, Australasia, Africa and Europe.

In 2004, two independent reports were published that reviewed MSC's work to date. Both called for demonstration of proof of impact with one stating: 'The MSC claim is that fisheries it certifies are both well-managed and sustainable. We find that the claim of sustainability is not justified and should be removed. Instead, MSC should recognise that it is certifying best practices with the understanding that these will continuously improve towards a long-term goal of achieving sustainability.'

Among the responses to these criticisms, MSC introduced independent peer review of the third-party assessments, strengthened training of certifiers, redefined the Fisheries Standard and took various steps to increase accountability and transparency. The latter included increasing the diversity of board members to include representatives of the capture, processing, science, markets and NGO sectors. Later, transparency was increased further when the draft assessment reports and annual audit reports were published on the MSC website with the opportunity for anyone to submit comments.

In 2013, MSC established a monitoring and evaluation (M&E) team to track the impacts of its programme and evaluate how effectively they were delivering on their mission. They developed a theory of change: that consumer desire and market demand encourage fisheries to achieve MSC certification, and that the efforts of these fisheries to demonstrate sustainability result in positive on-the-water change. In addition, since 2011, MSC has published annual Global Impact Reports with the fifth edition published in 2017.

Timeline. Summary of key events influencing MSC's establishment and some of its major milestones.

1950s	**Introduction of industrial trawling**.
1992	**Grand Banks cod fishery collapse**: Northern Cod biomass fell to 1% of its earlier level; Canada's federal government declared a moratorium on fishing.
1993	**Forest Stewardship Council (FSC) established** to promote responsible management of the world's forests by setting standards on forest products, and certifying and labelling them as eco-friendly.

September 1995	**Conversation between** head of endangered sea programme, **WWF** International (Mike Sutton) and PR consultant to **Unilever** (Simon Bryceson) focused on potential disastrous environmental and commercial consequences of depletion of common species and whole fisheries under threat.
February 1996	**WWF and Unilever published Joint Statement of Intent** to establish an independent Marine Stewardship Council to create market-led incentives for sustainable fishing, building on the recently established FSC model.
Early 1996	Coopers and Lybrand **developed organisational blueprint and implementation plan for MSC.**
February 1997	**MSC formally registered at Companies House**, UK as private company with international board of trustees. MSC ceased to be a project of WWF and Unilever, becoming a registered charity and an independent non-profit organisation.
December 1997	Consultation in Virginia, USA **developed principles and criteria of sustainable fishing**, leading to assessment and certification process and creation of MSC blue label.
1998	**First independent chairman and an international board of trustees recruited**: John Selwyn Gummer, former UK Minister for the Environment, became the MSC's **first chairman**.
March 2000	**First MSC-certified fisheries**: Western Australia Rock Lobster and Thames, UK Herring.
2001	**First Stakeholder Council and a Technical Advisory Board formed (TAB)**: TAB thrashed out detail of fishery assessment methodology, the certification and accreditation of assessment bodies (before this became a third-party activity), plus management of complex stakeholder interactions.
2001	**Chain of Custody standard launched** providing traceability from ocean to plate.
2002	**100^{th} MSC-labelled product** in shops.
2003	Sainsbury's (UK supermarket) **commits to only stock certified wild catch** by 2010.
2004	**Two independent reports (for Pew and Packard Foundation) called for demonstrated proof of impact**. MSC respond by introducing independent peer review; strengthening certifier training; and redefining the standard.
2004	Mexican Baja California red rock lobster became the **first certified fishery in the developing world**.
2005	**Certification of Alaska pollock, world's largest whitefish fishery, a 'game changer'** with millions of tonnes of sustainable whitefish delivered to market.
2005	**First tuna fishery certified**.
2005	UK's Thames herring fishery became the **first fishery to renew its certificate**: MSC certification lasts 5 years after which a new assessment is needed.
2006	**MSC fisheries standard revised**.
2006	**First MSC-labelled fish went on sale in Japan**.
2007	**First fishery fails to achieve MSC certification due to lack of data on stocks**: North Eastern Seas Fisheries lobster fishery
2007	**1000^{th} MSC-labelled product launched**. KLM in the Netherlands became the **first airline to introduce MSC-certified fish** on its flights.
2007	Oregon pink shrimp became the **first certified shrimp fishery**.
2009	**DNA testing introduced to facilitate traceability back to certified fisheries**.
2010	Mars Petcare launched the **first-ever MSC-labelled pet food**, in Europe. Fish and chip shops in the UK adopted MSC-certified products.
2011	Pick n Pay in South Africa became the **first African retailer to commit to sustainable sourcing**. **Birds Eye Iglo announced its entire cod and haddock fish finger range would carry the blue MSC label**.

2011	Annual **Global Impact Reports** launched by MSC.
2012	**MSC Fisheries Standard reviewed again**.
2014	**Fully-revised v2.0 Fisheries Standard launched** after 2 years of preparation and a year-long consultation with fishing industry experts, scientists, NGOs and MSC's wide network of partners: more emphasis on bycatch mitigation and vulnerable marine ecosystems; touches for the first time on labour issues.
2015	Zoneco scallop fishery in Zhangzidao became the **first-ever certified fishery in China**.
2016	Over **20,000 seafood products available with the MSC ecolabel**, sold in around 100 countries Number of **Chain of Custody certificate holders exceed 3000**.
2017	Over **12% of the world's marine wild-caught fish is MSC certified**, almost 300 fisheries in almost 40 countries worldwide are certified to the MSC Standard.

IMPACT EVIDENCE

MSC's fifth edition of its annual Global Impact Report, published in 2017, shows that around 12% of wild-caught fish with a market value of USD5 billion a year was MSC certified and could be traced back from plate to certified fishery. In total 296 fisheries are currently certified with 17 having been suspended, 16 voluntarily withdrawing from MSC certification during 2016 and a further 67 in the process of being assessed. DNA testing shows that less than 1% of MSC-certified products were mislabelled compared to a global average of 30% (Pardo *et al.*, 2016).

Between 1997 and 2014, about half of all fisheries which undertook pre-assessments, the results of which are not made public, did not go on to pursue full MSC assessment: this is likely because the pre-assessments revealed to the fishery managers that they were unlikely to become certified or the conditions attached to certification would be too onerous and so there was no incentive to proceed. This is considered by many to be a major flaw as consumers cannot avoid fisheries which are unable or unwilling to meet the requirements for certification, except by avoiding all uncertified fish.

After the initial certification, fisheries have to undergo annual surveillance audits to ensure they continue to meet the requirements of the audit: the 17 that have failed these annual tests did so mainly due to failure to keep target stock sizes at the required maximum sustainable yield level, or to maintain or improve management systems, such as harvest control rules. Fisheries that are certified to the MSC environmental standard for fisheries manage target stocks in a way that ensures their ongoing productivity. Stocks in MSC-certified fisheries are not overfished, and a fishery must be able to demonstrate this in the rigorous, independent, scientific, peer-reviewed process required to achieve MSC certification. Certified fisheries that do not meet this globally accepted definition either have their certificate suspended, or withdrawn entirely.

Between 2000 and 2015, out of 189 certified fisheries, 39 made one or more improvement specified in the full assessment: this was mandatory for them to retain their certified status. These mostly related to research improvements, such as mapping location/intensity of fishing and bycatch estimates, and technical actions, such as spatial closure and gear modifications. More generally, since 2000, 94% of MSC-certified fisheries have been required to make at least one improvement, resulting in more than 1,200 examples of change.

To assess whether MSC-certified fisheries can be considered sustainable[11], the 2017 report includes

[11] The MSC Standard considers a fishery to be sustainable if it targets stocks with biomass fluctuating around biomass maximum sustainable yield (BMSY) or higher, and harvests these stocks at a rate that can continue indefinitely. If stock biomass is below its target range, a fishery may still be considered sustainably managed if fishing effort is adequately reduced so that the target population can start rebuilding.

results of an analysis of 100 MSC-certified fisheries using independent stock assessments taken from a public database. The MSC's conclusion was that: '*In nearly all regions, stocks targeted by certified fisheries have higher biomass in the years following certification … This is not always true for other, non-certified, stocks in the same regions … By comparing recent snapshots of stock health with values from 2000, when none of the stocks examined were MSC certified, we can see that stocks have higher biomass in years following certification in nearly all regions. This suggests that either a desire to obtain MSC certification incentivised better stock stewardship, or that the MSC label was sought as recognition of efforts made to recover stocks to healthy levels of biomass.*'

CONSEQUENCES

The case of Lidl, a rapidly growing low-cost supermarket based in Germany, provides a good example of demand stimulating fisheries to seek to become certified. When Lidl first started to stock MSC-certified products in Germany in 2006, although certified Alaskan pollock – the main wild-caught species consumed in the country – was available, there was no source of certified herring, the second most consumed species. Lidl made it clear to their supply chain that they wanted certified herring. At the same time, Lidl's main competitor, Aldi, also started selling MSC-certified products, adding to the pressure on suppliers. Within 5 years nearly all North East Atlantic herring fisheries were either certified or in the process of assessment. This example appears to support MSC's theory of change.

The North Sea cod fishery provides an interesting example of the public-private alliances that are being formed to achieve MSC certification. North Sea cod is mainly consumed in the UK. Estimated cod stocks in the North Sea reduced from 270,000 tonnes in the 1970s to 44,000 in 2006, but following measures agreed between the EU and Norway to limit fishing effort, stocks had recovered to 149,000 tonnes by 2015. Measures taken to allow the fishery to recover included modification of fishing gear, closures for specified periods and sea area closures to protect spawning females.

A coalition made up of fishing companies and organisations, seafood processors and retailers, including Sainsbury's, Marks and Spencers, Tesco and Morrisons, submitted the North Sea cod fishery for MSC assessment in May 2016. Consortium members are making financial and in-kind contributions towards the cost of the assessment. Financial support has also come through a grant from the Seafish Strategic Investment Fund (SSIF). The SSIF is a UK Non-Departmental Public Body (NDPB) set up by the *Fisheries Act 1981* to improve efficiency and raise standards across the seafood industry. It is widely expected that North Sea cod will become certified by MSC in 2017.

MSC only certifies wild-caught seafood. Production from aquaculture has increased rapidly over recent decades, from negligible amounts prior to 1980 until 2014, when for the first time aquaculture provided more fish than capture fisheries. Encouraged by the achievements of MSC, the Aquaculture Stewardship Council (ASC) was established by WWF and the Dutch Sustainable Trade Initiative (IDH) in 2010. Following approaches similar to MSC, its objectives, which are also broadly comparable to MSC, are to:

- Recognise and reward responsible aquaculture through the ASC aquaculture certification programme and seafood label.
- Promote best environmental and social choice when buying seafood.
- Contribute to transforming seafood markets towards sustainability.

As of June 2017, ASC had certified 8836 products produced on 469 farms in 64 countries with a total production of 1.18 million tonnes, and also issued 1228 Chain of Custody certificates.

In 2015, MSC and ASC signed a memorandum of understanding to further their collaboration and identify added value for partners handling both ASC and MSC-certified products. One manifestation of this collaboration was the inaugural Seafood Futures Forum, held during the Seafood Expo Global 2016. The Forum showcased efforts to build consumer demand for responsibly produced and sustainably sourced seafood.

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MASS MARKETING OF THE TREADLE PUMPS IN BANGLADESH

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SUMMARY

This case study examines a programme led by an NGO, International Development Enterprises (IDE), to facilitate smallholder access to irrigation in Bangladesh. IDE took proven manual pump technology and sought to facilitate functioning markets for manufacturing, installation and maintenance that would persist independently of IDE support.

This case demonstrates an NGO-led, social entrepreneurial pathway to foster innovation, underpinned by locally appropriate technology design. At the household level, significant production and income benefits were recorded from the relatively small investment required to purchase a pump, providing autonomy to small farmers on water timing and amount, without the additional costs of fuel. Over the long term the treadle pump can be seen as an intermediary step towards mechanical pumping, with increased income enabling purchase of cheap diesel pumps from China as they became available.

The treadle pump is also said to have contributed to the restructuring and development of water markets in Bangladesh, challenging established monopolies of large landholders in water access.

Table. Patterns of Innovation and Impact processes Summary table

Initiator	NGO promotes an existing appropriate technology solution.
Critical features	Intervention to strengthen the market to supply goods and services. Involved a number of changes in approach before arriving at technology and marketing arrangements that suited poor households.
Role of research	No formal role of research. Relied on appropriate engineering designs sourced within the NGO community.
Operational alliances	Worked closely with local small-scale manufacturers and maintenance providers. Collaborated with other NGOs.
Strategic alignment of stakeholders at sector or national level	Brokered agreement at a national level to remove subsidies on small-scale irrigation in order to provide market incentives to the private sector.
Solution, product, or system innovation	Delivered a low-cost product, but in the process disrupted existing water markets by enabling the poor to participate in these.
Scope of impact (and metrics)	Approximately 1.3 million treadle pumps installed. From a total donor investment of USD10 million an investment of USD40 million was leveraged from smallholders who purchased the pumps, and this investment generated a net return of USD150 million a year.

CHALLENGE/OPPORTUNITY

In the 1970s and 1980s, the economy of Bangladesh was almost solely dependent on agriculture (Downing and Polak, 2000). Agricultural production was precarious and the country was reliant on imports to meet food needs (Hall *et al.*, 2007). A lack of access to irrigation was seen as one of the key barriers to agricultural growth (Orr *et al.*, 1991). Several programmes by large international agencies, such as the Swiss Agency for Development and Cooperation (SDC) and World Bank, introduced programmes to support access to small diesel pump sets and the provision of training to mechanics as a way of supporting improved access to irrigation. The agricultural production sector could be characterised by small land holdings (less than 0.5 ha, Hall *et al.*, 2007) and an abundance of rural labour (Palmer-Jones, 1997). Diesel pump sets were expensive (approx. $500 at the time, Hall *et al.*, 2007) and suited to irrigating relatively large areas of land (Palmer-Jones, 1997). Programmes that focused on diesel pumps therefore favoured larger, wealthier farmers, and led to greater inequality as these farmers captured water markets and controlled water access (Heierli and Polak, 2000; Polak and Yoda, 2006). There was a significant gap between the traditional methods of surface water irrigation, and the emerging ground water irrigation enabled by tube-wells and pumps.

In the mid-1970s, the Government of Bangladesh introduced programmes to introduce a hand pump to improve drinking water access. Most of the hand pumps installed were used for irrigation instead, demonstrating a demand for manual irrigation technologies (Downing and Polak, 2000). The key challenge was to find mechanisms to enable access to irrigation by poor farmers. This required the design of appropriate technology and necessarily spanned the length of the marketing and distribution practices in manufacturing as well as water markets.

INNOVATION

Two types of innovation are evident in this case: the design of the treadle pump, and IDE's approach to facilitating capacity and demand across the market chain. The treadle pump is a 'human-powered, twin cylinder pump head with a bamboo or PVC tube well' (Orr *et al.*, 1991, p. 1). The operator stands on two levers and uses their body weight to move the levers up and down. The volume of water pumped varies depending on a range of factors, such as the operator, water depth, and width of piping with estimates varying from 1 to 5 litres per second (Orr *et al.*, 1991) and 0.6 to 0.8 litres per second (Shah *et al.*, 2000). Even the lower estimates make it more efficient than hand pumps (Shah *et al.*, 2000). Importantly, the pump is relatively cheap to purchase (USD12–15, Shah *et al.*, 2000) and only requires the cost of labour to operate. It was designed to be easily manufactured using material available locally (Orr *et al.*, 1991).

The second innovation was the careful facilitation of a market chain by IDE.[12] This involved partnering with manufacturers to ensure quality products; facilitating a network of village traders to promote and sell pumps; training and field support to mistris (well drillers) to ensure competent and correct installation of pumps; and mass marketing through a range of channels to promote the pumps. Although more commonplace now, such an approach, incorporating business principles and active encouragement/collaboration with the private sector, was less common at the time.

INNOVATION PATHWAY

Though IDE is often credited with the success of the treadle pump in Bangladesh, examination of how events unfolded highlights the parallel processes and key decisions that shape how innovation unfolds – even before IDE had been founded. Central to the success of how the process evolved was IDE's ability to be adaptive and responsive to changing circumstances.

[12] IDE is an international NGO founded in the early 1980s by Paul Polak. IDE's approach is underpinned by commercial marketing principles and frames 'poor farmers' as customers who need to be able to purchase technology without subsidies or handouts which undercut the private sector and prevent proper market functioning and create dependencies on projects (Hall *et al.*, 2007).

This case demonstrates the potential of market systems and the role for social entrepreneurs, backstopped with sound technology in facilitating and navigating markets to benefit poor households. Agricultural engineering expertise, embedded within local NGOs, underpinned the development of the treadle pump and other alternatives. IDE drew from this pool of possible engineering solutions and facilitated market and regulatory environments to support the uptake of the pump in a way that was sustainable and suited to the dynamic of rural Bangladesh at the time.

Critical to this pathway was the facilitation of multiple interests to remove subsidies, and the flexibility to adjust the pathways and mechanisms as required: switching from rower to treadle pump; from high-quality to market segmentation and cheaper products. The following outlines the key phases of the Treadle Pump innovation pathway.

Design and development of manual pump technology and the networks for technology supply chain and marketing (1977–1986). Design efforts that led to the treadle pump can be traced back to 1977, to the NGO Rangpur Dinajpur Rural Service (RDRS).[13] RDRS were trying to implement programmes to improve agricultural production, but were finding a lack of access to irrigation was a key constraint. They made the development of low-cost pumps a priority (Orr *et al.*, 1991). A Norwegian agricultural engineer volunteering at RDRS led the research programme. Three different designs were attempted with limited success. In 1980, a visiting USAID engineer suggested using a stirrup device so that both feet could be used to power the pump – although this design was not incorporated, the idea led to the development of the treadle pump, which also incorporated elements of earlier (failed) designs (Orr *et al.*, 1991). The new design spread rapidly through Northern Bangladesh (Orr *et al.*, 1991). RDRS worked with a handful of manufacturers across five districts to produce the pump.

At the same time, the rower pump was developed by the Mennonite Central Committee and was gaining some popularity in Southern Bangladesh (Orr *et al.*, 1991; Hall *et al.*, 2007). In 1984, IDE started a programme to support the development of a market around the rower pump, which they considered easier to manufacture, even though it was slightly more expensive than the treadle pump (Orr *et al.*, 1991). IDE established the Manual Irrigation Coordination Committee, which brought together all the organisations promoting manual irrigation in Bangladesh, and the committee was able to remove subsidies for manual pumps, which they felt distorted the market and set up unsustainable systems (Polak, nd.). IDE worked with manufacturers to ensure quality control; facilitated networks for pump dealers and installers; and entered into a range of promotional activities. This process would form the foundation for future efforts with the treadle pump (Polak, nd.).

1984 brought a pivotal point, when a parastatal company that contracted small farmers for tobacco production engaged IDE. The company wanted IDE support to introduce rower pumps *and* treadle pumps as part of the set of inputs provided to contracted farmers (Polak, nd.). IDE agreed and installed equal numbers of treadle and rower pumps. The farmers preferred the treadle pumps, which were cheaper and easier to operate than the rower pumps (Orr *et al.*, 1991). This triggered an identity crisis for IDE, which recognised the value of the treadle pump, but had built its identity around the rower pump; according to IDE's founder they realigned their identity from a rower pump organisation, to an '*organisation dedicated to opening access to affordable irrigation water to small poor farmers*' (Polak, nd., p. 2).

Treadle pump market establishment and quality control (1986–88). The experience in promoting the rower pump directly informed how IDE went about promotion of the treadle pump. IDE acted initially as a wholesaler, partnering with selected manufacturers to produce high-quality pumps, branded by IDE and sold to village dealers (Polak,

[13] RDRS was originally founded to provide support to Bangladeshi refugees returning after the War of Independence. After initially focusing on humanitarian relief, their focused turned to improving agricultural production (Orr *et al.*, 1991).

nd.). Full time field staff were employed to provide training and support to dealers and *mistris*, ensuring effective installation and operation and supporting sales. As the local system became established, field staff would gradually withdraw their support and move to a new area (Polak, nd.). Promotional activities included printed material, but emphasised special movie screenings and performances of tailor-written pieces promoting the pump, in addition to providing hands-on demonstrations. It is estimated that sales of the treadle pump increased from 1,800 in 1980/81, to 64,000 in 1988/89 (Orr *et al.*, 1991, p.23).

Responding to the market: segmentation of product lines and withdrawal of direct involvement (1988–90). The popularity of the pumps encouraged competition from private manufacturers and dealers associated with IDE, and therefore free from their quality control standards (Orr *et al.*, 1991). The result was a significant decline in the quality of pumps sold and a lowering of prices – but also a decline in demand for IDE-branded treadle pumps by 40 per cent (Mehta, in Orr *et al.*, 1991).

Rather than continue to focus only on high-quality pumps, IDE released three standards of pumps, with lifespans between two and seven years; the cheapest has been their most popular pump (Polak, nd.). With the market established, IDE began to withdraw its direct involvement, but continued to partner with other NGOs to facilitate treadle pump programmes (Polak, nd.). In the 1990s, an estimated 100,000 pumps were being sold each year (Heierli and Poklak, 2000).

IMPACT EVIDENCE

Few impact assessments for this story are publicly available, and all focus mostly on household level benefits from adoption. Shah *et al.* (2000), drawing on many earlier studies, note the following household impacts as a result of treadle pump ownership: increased cropping intensity; increased diversity of crops grown; more intensive cultivation; increased yields and a conservative average household income increase of USD100 per year.[14] Orr *et al.* (1991) estimate between USD120–440 per year income benefit to pump owners; a high return on investment and internal rate of return of 50.9 percent.

Heierli and Polak (2000, p. 38) note the main 'loser' in the supply chain is the manufacturers, with profit margins as low as 50 cents per pump, though there is no discussion to indicate why manufacturers got on board with such low margins.

Importantly, Shah *et al.* (2000) also highlight that the technology was, as intended, of benefit mainly to poorer, smallholder farmers. The balance of control and access to irrigation was, therefore, tilted back, somewhat, to poor farmers. Some concerns have been raised, however, about the increased burden on household labour, especially women (Palmer-Jones, 1997).

CIDA and SDC were the primary donors for IDE in Bangladesh through the 1980s and 1990s, and for a total donor investment of USD10 million, Polak and Yoda (2006, p. 429) estimate an investment of $40 million was leveraged from smallholders who purchased the pumps, and this investment generated a net return of USD150 million a year.

CONSEQUENCES

Detailed, independent and updated analysis on what kind of change this has led to is lacking – particularly as it relates to the development of manufacturing capacity or broader supply chain. At the farm level, the introduction of the treadle pump has supported significant changes. As a first step, it wrested control of water resources to smallholder, poor farmers – providing access and discretion over timing and amount (Orr *et al.*, 1991).

With increased availability of cheap diesel pump

[14] The average annual income increase was calculated by Shah *et al.* (2000) based on intermediary indicators such as increase in crop yield, changes in cropping patterns and cropping intensity. Shah notes there was significant variation between regions and households. Orr et al (1991, p. 55), state rural per capita income in Bangladesh to be USD160 per year.

sets from China, and given the increased income of treadle pump owners, Polak and Yoda (2006) suggest more smallholder farmers were able to afford mechanical pumps, that is, that treadle pumps are an intermediary step to improved technology. This in turn, they suggest, contributed to the development of water markets in Bangladesh (Polak and Yoda, 2006).

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NOVACQ™

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SUMMARY

A primary tool for increasing productivity in the agribusiness sector is improving the nutrition of farmed animals to enhance their growth rates and disease resistance. CSIRO and Australian industry partners saw an opportunity to improve the sustainability and productivity of Australia's prawn farming industry through developing a more sustainable prawn feed.

Novacq™ is a technology that reduces dependency on wild-harvest fishmeal for the global prawn farming industry. Through a combination of technological and institutional innovations, new economic, social and environmental impact opportunities were opened up within the prawn market. CSIRO developed deep relationships with its Australian and international partners to capitalise on the new feed technology. This opened up a series of further research questions and commercialisation opportunities for CSIRO and the companies. These partnerships continue and create the conditions for ongoing innovation in the future.

Table. Patterns of Innovation and Impact processes Summary table

Initiator	Applied research develops non-marine sources of protein for fish feeds.
Critical features	Commercialisation with Australian and Vietnamese companies at a time of rapid, publicly backed aquaculture sector growth.
Role of research	Technology development, licensing and trouble shooting and incremental improvement.
Operational alliances	Partnership between research and SME.
Strategic alignment of stakeholders at sector or national level	Strong alignment with public investment in aquaculture sector development.
Solution, product, or system innovation	Product innovation that is creating significant market disruption. Now licensed in a number of Southeast Asian countries.
Scope of impact (and metrics)	Large-scale economic and environmental impacts already documented.

CHALLENGE/OPPORTUNITY

Population growth, increasing Asian migration into Australia and the growing affluence of countries in the Asia-Pacific region are increasing the demand for protein and Australian aquaculture products. Australian consumption of seafood has increased 1% annually, from 13 kg per person in 2000 to 15 kg per person in 2012–2013. Global consumption has increased at an annual rate of 3% since the 1950s, and by 2050 demand is expected to double (Frost and Sullivan, 2016).

However, globally, 31% of fish stocks are over-exploited, and an additional 58% are fully exploited and in danger of overexploitation (FAO, 2016). Global stocks of wild prawns have been under increasing pressure and are continuing to decline. Serious overfishing of prawn populations and associated environmental degradation were discovered in the majority of countries studied, although Australian prawn fisheries are ranked as some of the best managed.

The current unsustainability of fisheries can bealleviated by an expansion of aquaculture farming. It will require the production and use of larger volumes of feeds. However, fishmeal and fish oils generated from wild catch have traditionally provided a major component of aquaculture feeds, putting further strain on fish stocks, and driving up the cost of fish meal and oil.

Farmers, thus, increasingly look to the use of additives in aquaculture feeds to compensate for the loss of nutrients as the amount of fish meal decreases and to prevent disease, maintain animal wellbeing and increase growth rates. The aquaculture feed additives market in Australia, estimated to be worth $3.9 million in 2015, is expected to grow at a CAGR of 3.2% to reach $4.5 million in 2020 (Frost and Sullivan, 2016). However, until recently practical replacements for fishmeal and fish oils were largely ineffective as they were unable to provide the nutrition required to quickly grow large prawns that are able to compete in the market with prawns grown on feed that is based on fish products (Glencross *et al.*, 2014).

INNOVATION

In the late 1990s, CSIRO undertook research on the role of microbes in prawn nutrition. Recognising that the microbial communities played a dominant role, scientists spent the following decade learning how to manipulate the microbial systems to make them more productive and to stimulate them to produce a novel bioactive product that could be incorporated into prawn feed. This research resulted in the technological innovation of a high-value prawn feed ingredient. Novacq™ is a bioactive additive that stimulates a prawn's metabolic pathways to improve nutrient absorption. Marine organisms are used to convert the carbon in low-value plant waste into a bioactive material that is harvested, dried and used as the food additive. The additive is so effective that it can reduce prawn diet protein levels and replace fishery resources in prawn feeds without performance loss. Laboratory and green and clear water trials undertaken consistently demonstrated growth rate improvement of around 40%, improved resistance to pathogens and improved feed conversion rates of 20 to 30% (Briggs, 2014).

Once this technological innovation had reached a proof of concept stage, CSIRO worked in partnership with industry to refine and apply the innovation through commercialisation partnerships. CSIRO established a licence for use of Novacq™ by prawn feed mills. This licence comprises a standard operating procedure including instruction detailing how to produce Novacq™ and incorporate the additive into regular prawn food. Licences are regional and exclusive, meaning that only one vendor can sell Novacq™ in any given geographic region. The exception to this approach is that the licence granted to the Australian firm Ridley allows it to market and sell Australian-produced Novacq™ anywhere in the world.

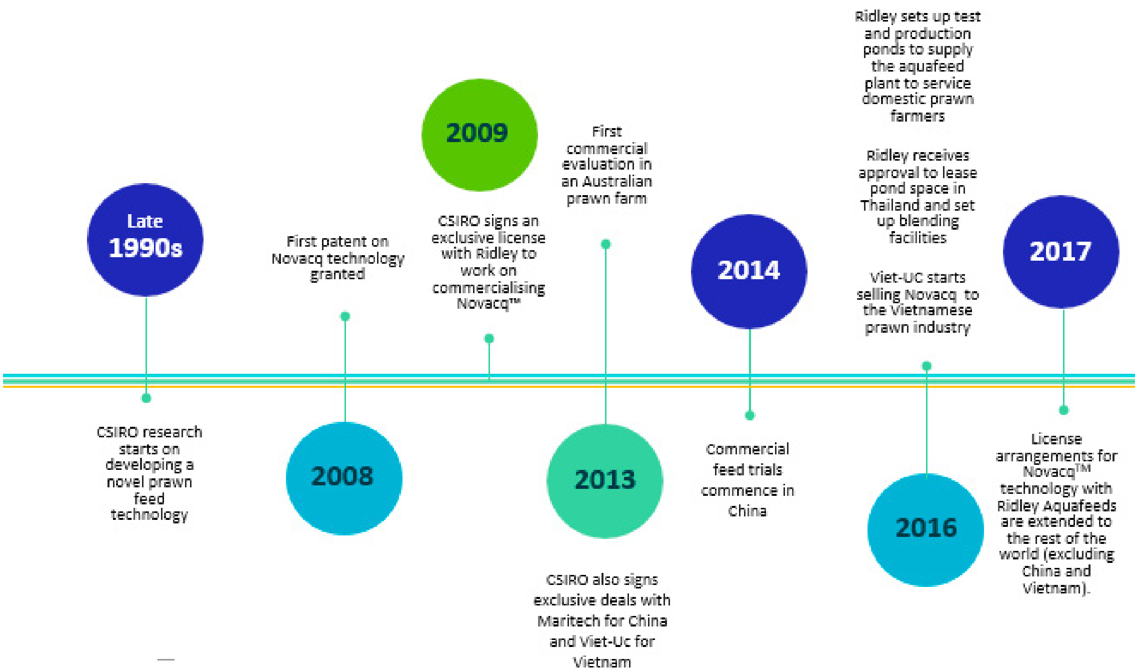
CSIRO signed exclusive licences with three commercial businesses: Ridley AgriProducts can produce and market the raw material in Australia, Indonesia, Malaysia, the Philippines and Thailand (extended to the rest of the world in 2017), and

Maritech company for China and Viet-UC company for Vietnam (Briggs, 2014). These partnerships enable the scale-up of production and adoption of Novacq™ for Australian prawn farmers and international markets. Additionally, since Novacq™ is based on agricultural by-products, it has opened up a new market in agricultural waste that did not exist before. The Novacq™ IP and commercialisation have led to institutional innovations and deep international partnerships that are likely to provide future opportunities for R&D.

INNOVATION PATHWAY

For over 20 years CSIRO has worked closely with the Australian and international prawn farming industry on a range of issues critical to the Australian and global prawn industry. This has included research on environmental and health management, selective breeding, domestication and nutrition. The aim of these partnerships was to increase prawn farming yields and support prawn farmers meet market demands.

Figure 1. Novacq™ innovation timeline



The development of novel prawn feed technology commenced in the late 1990 when CSIRO researchers were trying to understand the role of microbes in nutrient cycling in tropical mangrove ecosystems and prawn ponds. Over the next decade, researchers learned how to manipulate the microbial systems to maximise the productivity of the microbes and stimulate them to produce a novel bioactive product that, when incorporated directly into the feed of prawns, resulted in significant growth benefits (Glencross and Preston, 2013). The Novacq™ technology was born. The research resulted in three patents: AU 2008201886, AU 2009225307, and AU 2015201193.

Table. CSIRO novel prawn feed research capabilities and activities

Capability	Activity
Microbiology and nutrient dynamics	Modelling nutrient dynamics and controlling the production of marine microbial biomass.
Organic chemistry	Characterisation of bioactive compounds.
Crustacean nutrition	Determining the dietary requirements of crustaceans and formulation of feeds containing Novacq™.
Feed technology	Optimising the production, harvesting and processing of Novacq™.
Media communications	CSIRO made media outreach a core part of its strategy to increase awareness among the prawn industry about the benefits of Novacq™. CSIRO undertook a concerted media campaign over the second half of 2013 and into 2014, which saw coverage of Novacq™ in major Australian news outlets.

Source: ACIL Allen Consulting; CSIRO

In 2009 CSIRO signed an exclusive licence with Ridley to work on commercialising Novacq™. The first commercial evaluation in an Australian prawn farm was undertaken in 2013 with Australian Prawn Farms Pty Ltd in Queensland.

In early 2016, Ridley secured a lease on a 7.5 hectare site at Yamba to set up test and production ponds to supply the Ridley Aquafeed plant at Narangba with sufficient Novacq™ to effectively service domestic prawn farmers and to conduct further trials with the ingredient (Shrimp News International, 2016). Funding for post-harvest processing systems, including packing systems, silo and shed storage, infrastructure and pond works were approved by the company as the capital requirements for this commercialisation project.

Over the following 12 months, Ridley engaged in a process of continuous improvement to all production facets to increase harvest yield, efficacy, reduce commercial costs and determine optimum inclusion rates of Novacq™ into Ridley feeds. This stage also included full cycle technology transport to overseas Ridley production sites, commencing in Thailand.

In late 2016, Ridley received internal approval to lease 10 hectares of pond space in Thailand and develop Novacq™ production there, and received approval from the Thai government to build two blending facilities in Thailand; this involved a partnership with a Thai engineering firm to design the operation. Further institutional innovation is likely to occur through the strategy to scale-up production in Thailand, including providing an opportunity for revenue to local farmers through hire or purchase of ponds for Novacq™ production and to generate positive trial data to prove the value proposition to farmers and develop a pull-through marketing strategy (Ridley, 2016). Work continues with CSIRO to further develop the Novacq™ R&D programme and target other applications and unlicensed territories.

In Vietnam, Viet-UC has been the key CSIRO partner. Its Novacq-based feed factory is anticipated to begin selling to the broader Vietnamese prawn industry in 2017 (AFR, 2016). However, this part of the innovation pathway for Novacq™ is only part of a much broader pattern of innovation by the company. Initially employing CSIRO technology in developing its shrimp seed stock hatchery, Viet-UC has continued to expand its R&D relationships with Australian institutions and businesses, including a sensor technology company and a water bio-remediation company.

These partnerships have resulted in ongoing research and technology driven developments, including antibiotic-replacement therapy for aquaculture, sonic-based automatic feeding, and a solar salt pond. These developments allowed Viet-UC to acquire exclusive licensing for selective breeding of white shrimp and black tiger prawns in Vietnam, and therefore build a reputation for producing the highest-quality shrimp in Vietnam. With its Australian R&D partners, Viet-UC is a good example for Australian innovation-based agricultural joint ventures. (Asia News Monitor, 2017).

IMPACT EVIDENCE

Since use of Novacq™ only started in 2013, benefits to date are moderate, but interest in the technology is expected to drive strong uptake in Australia and internationally. However, a number of drivers restrain the market, which may affect the scale of the impact that will be achieved. These include competition from Asian countries in developing additives of comparable quality; the increased cost of feeds that include additives, which may discourage routine use by farmers; and the difficulty in having new feed additives accepted by farmers who already have well-established and tested additives and feeds (Frost and Sullivan, 2016). The table below summarises the impacts that are expected to be achieved.

Environmental impact	
Protecting existing fish stocks	Decreased reliance on fish meal as inputs for production in Australian Prawn Farms helping to preserve global fish stocks.
Supporting a more sustainable prawn industry	Use of Novacq™ reduces feed costs in the production of farmed prawns. Development of Novacq™ decreases need to purchase fish meal, thereby helping to preserve global fish stocks.
Reduction in agricultural waste	Reduction in waste is achieved through utilisation of agricultural by-products to produce Novacq™.
Economic impact	
Improved productivity	Use of Novacq™ targets increases in the farmed prawn industry's production across Australia and internationally, thereby adding significant value to the industry. Use of Novacq™ increases production efficiency of farmed prawns through increased growth rates of up to 40 per cent when using industry standard diets. An independent assessment estimates the benefit to the Australian industry from the use of the novel prawn feed to be around $368 million between 2014 and 2023–24.
Increased employment	The licencing of Novacq™ has delivered increased employment opportunities in Australia with one Australian supplier, Ridley, hiring an additional eight staff for the Australian pilot production site with more to follow in Thailand.
Social impact	
Access to better quality, cheaper prawns	Australian consumers will have access to competitively priced, higher-quality prawns as a result of the superior size and health of farmed prawns and prawn production productivity gains as a result of CSIRO prawn breeding projects and use of Novacq™.
More reliable income streams	Using prawns with improved fitness reduces the risk of stock losses and subsequent loss of income associated with poor production environments and diseases. This may become particularly important for communities which are vulnerable to income loss from aquaculture, such as aquaculture and fishing communities in Vietnam's Mekong Delta.

Source: ACIL Allen Consulting; and CSIRO 2013; 2014

CONSEQUENCES

The Novacq™ case illustrates ways in which the technological innovation of an ecologically sustainable aqua feed and the institutional arrangements required to bring it to market have provided the partners with the insights and tools for ongoing innovations of new types of products and services. As the Novacq™ commercialisation partners refine their products and production and harvesting processes through ongoing R&D and trials and the development of new infrastructure, new capabilities emerge that will lead to new innovations in the industry.

The strong partnerships developed over decades between the international and Australian partners have already opened up specific new research and business opportunities. Viet-UC has signed an agreement with CSIRO to expand its R&D programme to include white, and black tiger prawns, catfish, super intensive products, and disease screening, as well as continuing Novacq™ research. In Ridley's case, its recent joint venture agreement with a Thai feed mill will provide it with an unrivalled opportunity to learn about the Thai prawn feed industry and market, and to test customer acceptance and performance of a novel feed ingredient. Ridley also signed a long-term research development alliance with CSIRO in 2017, and an extension of the licence agreement under which the company can now produce and market Novacq™ globally. Novacq™ is being trialled in species other than crustaceans, and within 10 years it is predicted that the feed of many species could be supplemented with Novacq-type products.

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ORANGE FLESHED SWEET POTATO IN SUB-SAHARAN AFRICA

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SUMMARY

This case study examines the substantial investments that have been made in the development and promotion of biofortified orange-fleshed sweet potato (OFSP) as a complementary approach to reducing Vitamin A deficiency (VAD) in sub-Saharan Africa (SSA). VAD is a serious public health concern in many countries, which can cause blindness and increase mortality. Breeding breakthroughs in high-yielding OFSP varieties, combined up to 50-fold increases in beta-carotene levels with drought tolerance and adaptation to local conditions. It was also identified that to combat VAD, these technological breakthroughs needed to be coupled with improved access to OFSP varieties, and education to build awareness about the nutritional and health benefits of OFSP to improve the adoption, production and consumption of OSFP among rural households. Through the involvement of a major philanthropic foundation, significant investment has been directed to large advocacy and educational campaigns promoting household consumption of OFSP and associated value-chain development in countries where sweet potato is either the staple crop or an important secondary staple. To date, the primary evidence of OFSP impact comes from such interventions in Mozambique and Uganda, where investigation of scaling-up showed that the project led to OFSP adoption rates of 61–68% among project households, improved Vitamin A knowledge at the household level and significantly increased (nearly doubled) Vitamin A intake among targeted women and children. Notwithstanding the continuing large investments, recent evaluations point towards the need to ensure the timely availability of quality planting material, address regional differences in consumer preferences, and create dual strategies to increase consumption of OFSP among the rural poor and develop value chains, among others, for OFSP to achieve the pervasive impact desired in SSA.

Table. Patterns of Innovation and Impact processes Summary table

Initiator	Research commissioned to reduce vitamin A deficiency through biofortification of sweet potato.
Critical features	Upscaling of research product through significant investment by philanthropic foundations in solving system and market failures at local levels; nutrition education at the community level.
Role of research	Development and validation of solutions (in particular agronomically competitive varieties and seed systems).
Operational alliances	Alliances were initially absent, but following the discovery research phase the investment by a philanthropic foundation facilitated wider local value-chain based partnership.

Strategic alignment of stakeholders at sector or national level	Links to private sector and policy often limited to project-level agencies or representatives.
Solution, product, or system innovation	Local production and value-chain innovations that struggle to scale beyond the immediate project investment domain.
Scope of impact (and metrics)	Thus far, largely limited to project domain.

CHALLENGE/OPPORTUNITY

Vitamin A deficiency (VAD) is widespread in the developing world and particularly prevalent in young children. Globally, 250 million preschool children are estimated to suffer from VAD. Annually approximately 250,000 to 500,000 Vitamin A-deficient children lose their sight, half

of them dying within 12 months of going blind as VAD weakens their resistance to infections.

Night blindness in pregnant women, caused by VAD, is associated with an increased risk of maternal mortality.

Interventions that focus on increasing the intake of Vitamin A can be direct (nutrition-specific) such as supplementation and food fortification; or indirect (nutrition-sensitive), for example, dietary diversification and biofortification (Ruel *et al.*, 2013). Each of these approaches has its own strengths and weaknesses and thus they should be regarded as components of a suite of complementary strategies. Supplementation with Vitamin A for children 6–59 months of age (to reduce morbidity and mortality associated with illnesses) and for pregnant women (to prevent night blindness) is recommended in countries where VAD is a public health problem.[15] However, such interventions alone can be unsustainable, primarily due to the associated costs and reliance on uninterrupted funding (Underwood, 2004). Food fortification of commonly eaten foods has been very successful in developed countries, but its full potential is still untapped in developing nations since regular access to packaged foods is required, and quality assurance systems need to be in place together with effective public-private partnerships (Bégin *et al.*, 2001). Dietary diversification, i.e. consumption of a wide variety of nutritious food, promises long-term impact as it targets multiple nutrients and establishes behavioural changes, but maintaining access to a diverse diet is difficult for resource-poor populations (Nair *et al.*, 2016).

Biofortification is an agriculture-based intervention that refers to the process of breeding micronutrients into food crops to increase their nutritional value. While an initial investment is needed for the development and adoption phases of biofortified varieties, the recurring expenditures are said to be low, and varieties can be shared and adapted internationally (Nestel *et al.*, 2006). It has the potential to be more cost-effective than supplementation or fortification (Meenakshi *et al.*, 2007) and has been suggested as a sustainable and feasible way of reaching malnourished populations in remote rural areas, although the prospective benefits of biofortification vary across the life cycle of individuals and are not equivalent for all age groups (Bouis *et al.*, 2011; Saltzman *et al.*, 2013; De Moura *et al.*, 2014; Bouis and Saltzman, 2017). For biofortification to have a measurable and significant impact on nutritional status, the crop under consideration needs to be an important local staple food that is regularly consumed.

The following sections summarise how biofortified orange-fleshed sweet potato (OFSP) is being used to explore possible solutions to addressing VAD in Sub-Saharan Africa (SSA).

[15] http://www.who.int/elena/titles/full_recommendations/vitamina_supp/en/

INNOVATION

Sweet potato is an important food security crop in Africa, grown mainly by smallholder farmers. An estimated twenty four million tonnes of sweet potato are produced annually in SSA (Low *et al.*, 2017b). It is a fast-maturing, vegetatively propagated crop that gives relatively good yields under minimal input and can be grown across a range of climatic conditions (Grüneberg *et al.*, 2015). It is also a good source of carbohydrates, fibre, and micronutrients. Most varieties in SSA are white- or yellow-fleshed with no or low levels of β-carotene, the precursor to bioavailable Vitamin A. However, some orange-fleshed varieties with naturally occurring higher concentrations of β-carotene exist and therefore prospects for improving the β-carotene levels of sweet potato were quite good (Nestel *et al.*, 2006).

This available genetic diversity has been used to conventionally breed biofortified varieties, circumventing the regulatory, political and biosafety issues associated with transgenic approaches. The β-carotene rich varieties, known as OFSP, have a visibly different colour and can be effective in providing Vitamin A to consumers. OFSP was the first biofortified crop grown in farmers' fields in SSA (Low *et al.*, 2015) and has been the poster child for biofortification efforts.

The innovation had several components, including activities to increase the production, adoption and consumption of OSFP among rural households as well as interventions to raise the income of producers. As part of the 'scaling-up' process, strategies were used to enhance the inclusion of stakeholders.

Research and technology: High-yielding OFSP varieties (with high dry matter content) were produced through conventional breeding, with β-carotene levels of 30–100 ppm, as opposed to 2 ppm in local varieties (HarvestPlus, 2012). To enhance adoption, breeding efforts were accelerated to produce agronomically competitive varieties that were more drought-tolerant and adapted to local conditions, without compromising β-carotene levels.

Seed systems and agronomic practices: Multiple varieties of OFSP vines were grown by the International Potato Center (CIP) often in collaboration with NARS and disseminated through NGOs (both national and international) to farmers together with training on growing techniques, crop management, storage practices and the maintenance of vines for planting stock between growing seasons.

Demand creation and education: This component focused on socio-cultural aspects such as behavioural change, both for farmers to adopt biofortified OFSP varieties and for consumers to be willing to accept OFSP. An 'orange brand' was built through awareness about the nutritional benefits of consuming OFSP and other Vitamin A-rich foods, i.e. nutritional and health value for the consumers (through group trainings, radio programmes, community theatre performances, farmer testimonies, billboards and signs in local markets, and other advertising). Both agricultural extensionists and nutrition extensionists were involved. A pyramid structure was used with extensionists working for NGOs further training community volunteers, called promoters.

Marketing and product development: Creating markets for OFSP roots and processed products was emphasised to ensure sustained adoption, i.e. economic value for the producers and traders. Farmers were linked to traders; training of traders was carried out to facilitate their understanding of OFSP's role in addressing VAD, how they could profit from trading in OFSP, and how they could promote OFSP consumption.

INNOVATION PATHWAY

Biofortification has received marked attention in the CGIAR under the umbrella of HarvestPlus that was launched in 2013 (building on the CGIAR Micronutrients Project and the Biofortification Challenge Program) (Bouis and Saltzman, 2017).

In 1995, CIP, the Kenya Agriculture Research Institute and the International Center for Research on Women initiated OFSP research and introduced OFSP among women's groups in Kenya as part of a larger effort to investigate women-based approaches for addressing micronutrient deficiencies. A pilot study found that a) nutrition education (and not just new varieties) was fundamental for enhanced frequency of intake of Vitamin A-rich foods by young children; b) many OFSP varieties had yields comparable or more than the existing local white or yellow varieties; and c) adults preferred varieties with higher dry matter content while children favoured more watery varieties; in contrast the orange colour was universally liked (Hagenimana *et al.*, 1999). This led to breeding programmes selecting for higher dry matter content varieties and incorporation of nutritional education in the implementation strategy.

In 2001, under the leadership of CIP, 40 agencies from the agricultural research institutes, nutrition and health agencies came together to form the Vitamin A for Africa (VITAA) partnership to raise awareness and promote the enhanced production and use of OFSP in seven African countries (Anderson *et al.*, 2007).

The Towards Sustainable Nutrition Improvement (TSNI) Project, a 2-year intervention launched in 2002 in Mozambique, advocated the substitution of white fleshed varieties with OFSP. The project was a collaboration between Michigan State University, the Nutrition Division of the Ministry of Health, World Vision-Mozambique, Helen Keller International, the Southern African Root Crops Research Network (SARRNET), the National Agronomic Research Institute of Mozambique (INIA), and funded by the Micronutrient Initiative, the Rockefeller Foundation, USAID-Washington, and HarvestPlus (Low *et al.*, 2005). While most households did not eliminate WFSP, they did produce both white- and orange-fleshed varieties and 83% of the intervention households reported OFSP had higher yields than WFSP (Low *et al.*, 2007a). Participant and consumer surveys were conducted that indicated there was general awareness of the health benefits of OFSP. By the end of the second year, there was market demand for OFSP and it was the cheapest source of Vitamin A on markets in the project area (Low *et al.*, 2007b). An important issue identified by the project was how to create a strategy that would encourage sufficient home consumption of OFSP but still allow for the surplus to be sold at markets.

The TSNI project was expensive on a per beneficiary basis. To determine if this approach could be taken to scale in a cost-effective manner, a large-scale intervention, Reaching End Users (REU) project was implemented. REU promoted OFSP in Mozambique and Uganda between 2006 and 2009 using two different levels of timing and intensity of extension contact (HarvestPlus, 2010). The less intensive model, where extension and nutrition education activities were scaled back in the second year to cut costs, was found to be just as effective as the more intensive one (de Brauw *et al.*, 2015). This lighter integrated intervention was then employed for a fuller scaling-up project in 2012 on increasing OFSP consumption for 225,000 households in 13 districts in Uganda (HarvestPlus, 2013).

Existing knowledge of sweet potato production helped with the introduction of OFSP, in regions where sweet potato is either the staple crop (Rwanda, Malawi, Uganda) or an important secondary staple (Mozambique). The distinct orange colour of OFSP had implications for marketing and promotions since it differentiated it from the white varieties and acted as a signal that allowed customers to identify the product's nutritional quality. On the other hand, the orange colour has proved to be an issue with OFSP processed products, especially in countries where quality assurance systems are not in place (for example, the orange colour can be mimicked with food colouring).

Initial attempts to release best-bet OFSP varieties developed elsewhere (e.g. Peru and China) were unsuccessful and uptake was low (in spite of being higher yielding than the local varieties), since the varieties were either susceptible to local virus strains (Uganda and Kenya) or unable to survive the dry season (Mozambique). Recognition of the need for local adaptation, coupled with 'accelerated breeding', standardised data analysis and genomic projects helped address a bottleneck in uptake by farmers. New OFSP varieties were bred and two varieties that were moderately virus resistant were released in Uganda in 2007 (Low *et al.*, 2017a), while 15 improved varieties (with increased drought tolerance) were released in Mozambique in 2011 (Andrade *et al.*, 2010).

Sweet potato is generally considered a 'women's crop' (although men still frequently control access to land and labour) and thus investing in this crop was considered to have potential to improve women's incomes. Additionally, women are the caregivers of young children and play a major role as the 'gatekeepers' of family nutrition. These gender dynamics were taken into consideration to encourage OFSP adoption and consumption, and both male and female farmers were targeted for nutrition and agronomic messages. In Mozambique, it was observed that female nutrition extension workers were more successful than their male counterparts in delivering nutrition messages (HarvestPlus, 2012).

In Mozambique and Uganda, where marketing linkages were made and local value chains were supported under the REU project, it was possible to create a market for OFSP. However, OFSP uptake has been limited in countries like Tanzania, where interventions were focused on breeding new varieties and promoting household consumption while market development received less attention (Waized *et al.*, 2015). It is essential to emphasise economic value for producers and traders, in addition to nutritional and health value for consumers.

Delivery systems for promotion and utilisation of OFSP varied by country, but almost always multi-sectoral and multi-disciplinary partnerships were involved, including NGOs, government organisations, and bespoke research-public-private sector partnerships. Buy-in from national governments (for example, the nutrition division of the Ministry of Health in Mozambique) aided in going to scale.

Substantial efforts were directed towards generating evidence of potential impact to attract donor support. An *ex-ante* assessment indicated that replacing WFSP with OFSP had the potential to benefit approximately 50 million children (based on supply and demand assumptions simulated in seven countries; Low *et al.*, 2001). An OFSP efficacy study by van Jaarsveld *et al.* (2005) demonstrated that daily consumption of OFSP improved Vitamin A liver stores in children. The TSNI project established that an integrated approach comprising agriculture, nutrition, and market interventions increased Vitamin A intake and serum retinol concentrations in young children (Low *et al.*, 2007b). An ex-ante study estimated that OFSP consumption could reduce the disability-adjusted life years (DALYs) burden of VAD by 38–64% (Meenakshi *et al.*, 2007).

Consumer acceptance studies showed that golden bread made by replacing 38% of wheat flour by OFSP was economically viable in Mozambique (Low and van Jaarsveld, 2008) while children in Uganda particularly liked OFSP to a certain extent due to the orange colour (Nagujja and Yanggen, 2005). Willingness-to-pay studies with purchasers in Uganda demonstrated that when provided with information about the nutritional value of OFSP, consumers were willing to pay more for the orange varieties relative to the traditional white ones (Chowdhury *et al.*, 2009).

The timeline of the aforementioned studies coincided with the publication of the *Lancet* 2013 series on maternal and child nutrition[16] that drew renewed interest in the potential of nutrition-sensitive actions, including agriculture, to tackle malnutrition. Significant investment by the Bill and Melinda Gates Foundation (BMGF), together with five other donor institutions, enabled scaling and expanding advocacy campaigns. In 2009, BMGF funds to CIP spearheaded the Sweet potato Action for Security and Health in Africa (SASHA) project to support advanced breeding programmes and seed system research. Sweet potato for Profit and Health

[16] http://www.thelancet.com/series/maternal-and-child-nutrition

Initiative (SPHI), a multi-donor initiative targeting 17 countries, was subsequently launched and partnerships forged with the Alliance for a Green Revolution in Africa and NARS (Low *et al.*, 2017b). Most of the OFSP work is currently supported by BMGF and implemented under the CGIAR Research Program (CRP) Roots, Tubers and Bananas (RTB).

Even so, for OFSP to achieve the pervasive impact desired in SSA, there are significant remaining challenges. One of the greatest is the timely availability of quality planting material at the beginning of the season (de Brauw *et al.*, 2013). OFSP is vegetatively propagated and can be spread through informal channels by farmers, therefore there is often little incentive for the formal seed sector to be involved. Consequently vines are often distributed free of charge in the project interventions, but sustained access can be a problem particularly after the project intervention has ended. Alternative strategies for dissemination need to be developed and tested.

Other issues include enhancing pest and disease management; addressing regional differences in consumer preferences; increasing market demand for OFSP; formalising markets; reducing the geographic distance for farmers to access markets; creating dual strategies to increase consumption of OFSP among the rural poor and parallel development of value chains; augmenting information on consumer preferences; improving storage technology for fresh roots; incentivising private-sector involvement; and, strong policy support from national governments (Jenkins *et al.*, 2015; Waized *et al.*, 2015; Okello *et al.*, 2017).

IMPACT EVIDENCE

The primary evidence of OFSP impacts comes from reports on project interventions in Mozambique and Uganda, where intensive investments were made. The percentage of OFSP, compared to WFSP, sold in four urban markets in Mozambique increased from virtually 0% in 2006 to 18% in 2008 and 50% in 2009, with a price differential in favour of OFSP evolving in three markets (Westby *et al.*, 2011). Further, 82% of the sweet potato purchasers surveyed in 10 markets indicated they would buy OFSP in the future, and more than 50% said they bought it because of its nutritional benefits.

Randomised control trials were carried out under the REU project in Mozambique (Hotz *et al.*, 2012a) and Uganda (Hotz *et al.*, 2012b). Investigation of scaling-up and cost-effectiveness showed that the project led to OFSP adoption rates of 61–68% among project households, improved Vitamin A knowledge at the household level and significantly increased (nearly doubled) Vitamin A intake among targeted women and children (de Brauw *et al.*, 2015). Further in Uganda, the intervention cost USD15–20 per DALY saved, putting it in the 'highly cost-effective' category of intervention as defined by WHO (HarvestPlus, 2010). Research on the health benefits of OFSP has demonstrated that the REU intervention in Mozambique reduced diarrhoea prevalence and duration for children in treated villages (Jones and de Brauw, 2015). However, it is possible that the increased amount of fibre in the diet reduced diarrhoea. Additionally, the severe incidence of VAD at the time of the intervention in Mozambique may have affected the observed morbidity impacts, since no changes in diarrhoea were seen in Uganda, where VAD was much lower and Vitamin A supplementation was relatively extensive.

A study conducted in Kenya illustrated that OFSP adoption improved dietary quality, with women and children in OFSP-growing households having 15% and 18% higher diet diversity scores than for non-growing households (Bocher *et al.*, 2016). More recently, it was shown that linking promotion of OFSP to pregnant and lactating women with health services and enhanced nutrition education improved Vitamin A intake and maternal retinol-binding protein in postpartum women in Kenya (Girard *et al.*, 2017).

CONSEQUENCES

Efforts to develop and disseminate OFSP led to the award of the 2016 World Food Prize to four researchers for their work on biofortified sweet potato.[17] Since 2009, 40 OFSP varieties have been released in 11 countries in East, Southern and West Africa (Tumwegamire *et al.*, 2014). Attempts are underway to introduce OFSP in areas where sweet potato was previously unknown, including more semi-arid regions. As many as 2.89 million households were claimed to have been reached as of September 2016[18] (Low *et al.*, 2017a), although there seems to be some discrepancy regarding adoption levels with scientists predicting higher levels compared to empirical studies (Okello *et al.*, 2017).

Biofortified OFSP offers an additional option in the suite of approaches that may be deployed to improve the Vitamin A status of populations, but it should not be seen as a substitute for existing interventions. Its effectiveness, to a large extent, depends upon bioavailability of micronutrients in the human body that in turn is influenced by food processing techniques and dietary factors such as fat and fibre (La Franco *et al.*, 2014). Furthermore, a crop biofortified for a single vitamin will not provide all the essential nutrients the human body needs. One major criticism of biofortification has been that it could further encourage over-simplification of diets by concentrating micronutrients in a few staple crops and thus hamper efforts to achieve dietary diversification. Another unintended consequence could be the reduction of genetic diversity that could eventually undermine long-term crop adaptability (Johns and Eyzaguirre, 2007).

In conclusion, while there have been significant improvements in the Vitamin A status of the individuals who participated in the project-level interventions, VAD persists. Outside of the project districts, OFSP presence in local markets is limited and many poor farmers do not have knowledge of or access to OFSP. For OFSP to achieve widespread uptake in SSA and overcome constraints to adoption, it is essential to draw on lessons learnt to date.

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RURAL WATER USE EFFICIENCY INITIATIVE, QUEENSLAND

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SUMMARY

This case study describes how a purposeful policy intervention that created a partnership between industry and government enabled water use efficiency to be substantially improved across agricultural sub-sectors in Queensland, Australia, by improving the use and management of available irrigation water' to 'improv[e] competitiveness, profitability and environmental sustainability of Queensland's rural industries' (Bell, 2002, p. 2). The initiative ran over five phases between 1999 and 2016 and aimed to:

i. increase agricultural production by $280 million (equivalent to what would be achieved by supplying an additional 180,000 ML of irrigation water annually over the life of the programme);
ii. create 1600 jobs in regional Queensland;
iii. improve farm profitability and viability; and
iv. reduce run-off of pesticides and nutrients into rivers and streams.

The transformative effects catalysed through shared goals and a monitoring system between government, industry, civil society and research providers in the partnership were critical to this case. The partnership and industry also led delivery programmes that served to organise and incentivise adaptive research and farmer responses and build industry capacity. The partnership architecture has subsequently been used for other natural resources management challenges facing the sector.

Table. Patterns of Innovation and Impact processes Summary table

Initiator	Policy shift in response to prolonged drought and wider sustainability concerns about agricultural practices.
Critical features	Involved a coalition of policy, industry, civil society, and research agencies seeking radical solutions to deliver sustainability with profitability. Anchored around a simple monitoring management system with shared targets.
Role of research	Development, testing and validation of existing and novel WUE solutions.
Operational alliances	Wide-ranging multi-stakeholder partnership.
Strategic alignment of stakeholders at sector or national level	Policy driven, but with very strong alignment of stakeholder agendas at strategic and operational levels.
Solution, product, or system innovation	System innovation enabling the deployment of technical and institutional innovations across the sector.
Scope of impact (and metrics)	Sector-wide impact with significant economic and sustainability returns.

CHALLENGE/OPPORTUNITY

The 'Initiative' was envisaged as a 'partnership between industry and government to improve the use and management of available irrigation water' that would lead to 'improving competitiveness, profitability and environmental sustainability of Queensland's rural industries' (Bell, 2002, p. 2). The first phase of the initiative sought to achieve several high-level benefits from its first four years of operation including, by mid-2003, 'increas[ing] agricultural production by $280 million (equivalent to what would be achieved by supplying an additional 180,000 ML of irrigation water annually over the life of the programme); the creation of 1600 jobs in regional Queensland; improved farm profitability and viability; and reduced run-off of pesticides and nutrients into rivers and streams' (Bell, 2002).

The scope of the challenge is better understood when the Initiative is seen as a response to, and instrument of, a broader State-wide and national water policy reform agenda on water allocation, provision of water for the environment and establishment of rules for a water market. The *Water Act 2000* (Qld.) was introduced to 'define the limits' to water resource availability and allocation between uses (Bell, 2002). Water use efficiency was preferred over construction of new water storages. At this time Australian governments were also significantly reducing investment in public agricultural extension services. In the words of RWUEI partners the Initiative became understood as the 'water reform helper' programme in the context of supporting farm-level and industry-level responses to otherwise 'difficult' reforms. In this way the RWUEI explicitly sought both to improve local production systems (profitability) and facilitate sector-wide adjustment to new public policy and market regimes.

INNOVATION

Despite the top-down character of government policy drivers behind the Initiative, and the central role of the Queensland Government's Department of Natural Resources and Mines, the main innovation lay in the partnership-based coordination and programme delivery arrangements.[19] These involved multiple commodity sectors (and irrigation areas) across the State, government, research and engineering skills providers, rural industry representative bodies, and market-based partners operating in the irrigation retail and technical services sectors. Essentially, the programme relied on a system of devolving responsibility and financial and human resources to rural industry organisations to implement while maintaining a coordinated, more centralised system of accountability, knowledge generation and sharing, and effort prioritisation between the partners and the State.

The advisory committee (partnership group) was described by a key industry participant as a 'bottom-up learning process from day one'. It served as a key mechanism for the timely transfer of knowledge between the industry-run adoption programmes and to minimise duplication of effort through agreed allocation of resources and tasks and the sharing of lessons and information between parties through this forum (Bell, 2002). The remaining architecture of the RWUEI consisted of the adoption programme, tailored to, and by, each of the rural industry groups; a programme of research and development activities; a financial incentives scheme (also delivered with the rural industry groups); and, a programme to address losses from farm storages *and* state water supply and distribution systems.

[19] Representatives of the Queensland Government's Department of Natural Resources and Mines, other government agencies including Department of Primary Industries, rural industry organisations that were users of water for irrigation, originally lucerne and dairy (Queensland Dairy Farmers Organisation), horticulture (Queensland Fruit and Vegetable Growers, later Growcom), cotton (Cotton Australia) and sugarcane (Canegrowers) and Irrigation Association of Australia. Statewide NGO, the Queensland Conservation Council was also a member of the early partnership. In later phases, this core group expanded to include new commodity groups (turf and nursery) and irrigation-based research and development entities (e.g. National Centre for Engineering in Agriculture USQ).

INNOVATION PATHWAY

The evolution of the RWUEI occurred over a number of discrete phases, each requiring a renegotiation of resources, priorities and partners over time. These included:

Phase 1 ($41M) (1999–2003). Programme included (i) adoption (extension) $23M; (ii) research and development $3M (iii) financial incentives $12M, and (iv) addressing losses from farm storages and state water supply and distribution systems $3M (Bell, 2002). The FIS in this stage focused on adoption of soil moisture monitoring equipment and upgrading to more efficient irrigation systems.

Phase 2 (2003–2005/6). Government investment in the FIS was significantly reduced in this period. The programme responded to emerging off-farm environmental impacts under Reef Plan and NAP-SWQ policies. Led to the 'spin-off' of industry-led Farm Management Systems initiative that sought to promote a whole-of-enterprise risk management framework including environmental risks. R&D focused on 'deep drainage' in the Condamine, Emerald and Burdekin Delta areas, and evaporation mitigation trials (QG Productivity Commission Submission, 2005).

Phase 3 (2005/06 to 2006/07). A $2.5M additional target of WUE in packing sheds for horticulture plus $1.5 million per year to target RWUE in South East Queensland region (SEQ-Irrigation Futures). SEQ-IF with new commodity groups (turf, nursery) and leveraged support of community-based regional NRM organisations.

Phase 4 (2010–13). Commenced in 2010, following an extended period of drought across the State. 'RWUE4 continued to promote WUE on farms, however the programme also supported the uptake of energy efficient pumping equipment and irrigation practices intended to reduce electricity use and consequently reduce greenhouse gas emissions' (State of Queensland, 2015

)

Phase 5 RWUE-IF ($8M) 2014–2017 – Additional partners of Irrigation Australia Ltd and the National Centre for Engineering in Agriculture are supporting the industry programmes by enhancing the development and uptake of new technologies and practices in the irrigation sector and improving the technical capacity of irrigation service providers to deliver competent services to their clients.

IMPACT EVIDENCE

Economic returns. Phase 1 returned the same volume of water to the system for $41M via WUE as what $270M of new infrastructure development would have provided (at State cost) (Schmeide and Murday, 2008). It was also reported towards the end of Phase 1 that for every dollar contributed by government for irrigation improvements, irrigators contributed three dollars of private contribution to those improvements (Coutts and Bell, 2003; Bell, 2002). By Phase 4 (2010–13) programme evaluations were reporting continuing high levels of grower engagement but increasing difficulty in making significant inroads on water efficiency gains of the scale reported in Phase 1 and with significant variation across the commodities:

> *"WUE gains were measured as high as 70% in individual enterprises, however, across the program it is estimated that approximately 20 000 megalitres (ML) per year of water savings were gained. This average equates to approximately 1.9% of the estimated total irrigation water use in the program area" (State of Queensland, 2015, p.3).*

Environmental outcomes. One industry interviewee described the shift from modes of intervention in the early stages characterised by largely voluntary, incentivised and co-regulatory responses to the water reform agenda, to working through (private) irrigation retail and technical services sectors, to future phases that seek influence by engaging directly with market (pricing and tariffs for energy and water) and finance institutions. These new modes of intervention help shift the opportunity space for improvement. The RWUE Phase 4 evaluation also suggested that future programmes should consider a tighter relationship between the programme and regulatory arrangements that impact directly on growers' water allocations and obligations to reduce land and water degradation related to irrigation development (State of Queensland, 2015). These changes point to how the RWUEI is continually re-imagined as a way of intervening for change in irrigation communities. Further, the programme itself and the principles that underpin its design and operation are increasingly seen as persistent but flexible components of the broader suite of 'regulatory' or change pathways in the irrigation sector.

Institutional outcomes. The programme has also contributed to better alignment between government, farmer industry bodies and private actors' needs. It has improved the system-level capacity for partnering in the form of a resilient and influential partnership model that is adaptable, responsive and evolving across different policy issue domains such as water quality or groundwater management. A key industry partner characterised this change by describing a new culture in government that recognises: '[they] can't just click their fingers and get change – the *ritual* of partnership is now understood'. The programme has also encouraged a move towards a more integrated service delivery model (e.g. including new, and building the capacity of existing players, in the irrigation 'sector' such as private service providers, retailers and advisors, and linking these actors with farming and research bodies).

CONSEQUENCES

In regards to adoption of the technologies, there have been recorded improvements in availability of appropriate and effective technologies for WUE, and evidence that growers are adopting these and achieving some efficiency gains both at enterprise and area-wide scales. There are concerns that not all growers have been 'reached' and the current efforts may be approaching an adoption ceiling in terms of achieving further water efficiency gains directly through the programme architecture.

The technical complexity of the initiative was relatively modest, involving the development and extension of irrigation technologies and practices that would augment and improve the efficiency and sustainability of existing irrigated farming businesses. This required some concerted R&D efforts in benchmarking, measurement and diagnostic tools for irrigation system performance; new methods and trials for furrow irrigation efficiency; measuring deep drainage; trickle irrigation and other techniques (Schmeide and Murday, 2008). Later phases of the Initiative actively sought a shift towards 'precision irrigation systems' supported by ICTs and decision-support technologies. The real complexity of the Initiative lay, however, in the development and maintenance of the partnership and delivery arrangements of the programme. These arrangements also needed to manage the political complexity of articulating the overlap between the needs of individual farm business, diverse irrigation commodity groups, multiple regions and the State's policy agenda that expanded over the life of the programme.

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SALMON PRODUCTION IN CHILE

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SUMMARY

This case study covers the emergence and continuing development of the Chilean salmon industry. The industry is based on a non-traditional agricultural output and was developed from scratch over a relatively short period of about 35 years. Today, Chile is the second largest salmon exporter globally, with an annual export value of over USD4 billion today, and directly providing 30,000 jobs. Early public investment in the development of commercial salmon farming was part of a then government policy of promoting scientific and technological innovation that adds value to, or generates industries based on the country's natural resource endowment.

The rapid expansion and economic success of the industry, however, outpaced the development of socio-political institutions required for environmentally friendly and sustainable natural resource exploitation, social inclusiveness and equitable outcomes for the local communities. The result was the lopsided growth of an industry, where economic success was favoured over social and environmental considerations. Lack of knowledge about the resource 'loading capacity' in different aquaculture locations, poor understanding of the ecological and biological equilibrium, and limited government regulation and law enforcement capacity of public-sector agencies resulted in the significant infectious salmon anaemia (ISA) crisis in 2007. This case illustrates that free-market processes could not ensure long-term environmental sustainability, and the emergence of the institutions required for a socially inclusive process of development, without government intervention.

Table. Patterns of Innovation and Impact processes Summary table

Initiator	National public policy and investment to generate industries that leverage the nations' natural resource endowments.
Critical features	Coalition of public policy and investment, national and international private sector, and research seeking national development and commercial opportunities.
Role of research	Development, testing and adaptation of existing and new salmon farming, breeding and production solutions.
Operational alliances	Wide-ranging national and international level multi-stakeholder partnerships.
Strategic alignment of stakeholders at sector or national level	Initially national public policy and investment driven, but with strong alignment of major national and international stakeholders at strategic and operational levels.
Solution, product, or system innovation	System transformation enabling the use of technical and institutional innovation across the sector.
Scope of impact (and metrics)	Nationwide impact with significant economic returns.

CHALLENGE / OPPORTUNITY

Salmon aquaculture was one of several non-traditional export sectors promoted from the late 1970s to diversify the Chilean economy away from its dependence on its traditional commodity exports, such as copper and wood. A severe economic downturn in Chile in the early 1980s had led to a recession, banking crisis and social unrest, and the new non-traditional agricultural exports were intended to support the economy's recovery (Barton and Fløysand, 2010). This economic imperative, within the context of the military dictatorship (1973–1990), thus drove the emergence of the sector (Martínez and Díaz, 1996).

The demonstration of commercial viability supported by early public investment in salmon production attracted private investors, putting the industry on a commercial footing. The magnitude of the sanitary crisis between 2007 and 2010 provided the industry with an opportunity to implement new productive models. In parallel, longer-term efforts involving the government, the industry, and the financial sector allowed companies to survive while new laws and regulations laid the foundations for the industry's renewal.

INNOVATION

The establishment, growth and evolution of the Chilean salmon industry into a globally dominant export sector is a case of continuous and multidimensional innovation. It played out as a complex web of interrelated technological developments and social and institutional capacity building that is still ongoing.

The development of the industry saw a number of distinct phases, including exploration and building the capacity to produce, commercial expansion, and the industry's globalisation, including the ISA crisis that prompted further innovation responses in the form of technological changes in production (disease management and environmental protection), new institutional arrangements (regulations), and new organisational capacity to tackle environmental and social issues.

Initiatives were initially led by Chilean public organisations partnering with Japanese, US and other international government and private-sector entities. New investments, primarily from the private sector led by international firms, followed once the early trials had proven successful and an industry based on salmon aquaculture was seen to be commercially viable. Domestic investment became increasingly significant in the sector through the 1990s.

Natural advantages existed from the start with regards to factors of production. The ideal aquaculture conditions to be found in the Los Lagos region in southern Chile were vital to regional development from the early 1980s. The region had been experiencing outward migration and high levels of under- and unemployment, especially among young people, and its traditional agricultural and capture fisheries sectors were stagnating (Grenier, 1984). The activities relating to aquaculture, both directly and in the related support services, led to new employment opportunities and an economic upturn in the region (Barton and Fløysand, 2010).

The constraints for the industry to emerge were the lack of technology and local knowledge base in the form of specialist personnel. The public-sector investments in the earliest period of the industry's development were aimed at filling these gaps.

The free-market model introduced by Chile's then military regime operated on the basis of high levels of private-sector flexibility within the context of union prohibition, low wages and few safeguards for workers. Environmental regulations did not receive special focus until 1994 when the Environmental Law was approved. This low regulatory environment encouraged investment and provided a competitive edge (Barton and Fløysand, 2010).

During the 1990s, successive democratic administrations gradually reintroduced labour and environmental protection measures. The economic imperative however was maintained, and traded off against social and environmental protection, based on arguments relating to reducing poverty and overcoming inequality. It was the globalisation of production, in addition to the ISA crisis, that led to rising national and international oversight of its operations and the introduction of alternative framing of the economy development model in which the salmon industry was situated.

INNOVATION PATHWAY

Phase 1: Exploration and initiation (building capacity to produce). The industry took several decades to master salmon-farming technologies. It solicited technical support from several international organisations with experience in fish breeding and farming and then used its national institutions to acquire, develop and diffuse the technologies. The most important early objectives included introducing scientific knowledge and material and equipment crucial for the establishment of the industry, while building local capacity to develop technologies by training technicians and industrial personnel overseas and later in Chile. Scientific research and technology development and associated capability was concentrated on activities associated with production until the mid-2000s, with limited attention given to understanding ecological and environmental issues.

Although various attempts were made to introduce exotic fish species including salmon in the 19th and early 20th centuries, commercial aquaculture is a relatively new industry in Chile. It was not until the 1960s that efforts were made to establish an industry based on salmon. The Chilean Agency for Agriculture and Fishing, and the Production Development Corporation (CORFO) signed cooperation agreements with Oregon State University and the University of Washington to assess the feasibility and appropriate conditions and locations for fish farming. CORFO was founded in 1939 to promote economic growth in Chile, and manage funds for the promotion of scientific and technological development (Wurmann, 2007).

In 1966, several exploratory missions to the southern provinces of Chiloé, Aysén, and Magellan were undertaken, and in 1967, the Agricultural and Livestock Service of the Ministry of Agriculture signed an agreement with the U.S. Peace Corps (Wurmann, 2007), with the aim to transplant Pacific salmon into Chilean waters. Local government organisations financed additional exploratory work and other background studies, which helped accelerate the growth of salmon farming (UN, 2006).

At the same time, the Japan Fisheries Association (JFA) was examining alternative sources of salmon in the North Pacific Ocean, due to US and Soviet Union restrictions on operating areas and fishing seasons. The Japan-Chile Salmon Project started in 1969, running for 20 years, under a bilateral cooperation agreement between Chile's National Fisheries Service (SERNAPESCA) and the Fisheries Development Institute (IFOP) set up by CORFO in 1964, and Japan's International Cooperation Agency (JICA).

The Japan-Chile Salmon Project was managed by the public sector, and as the technologies and personnel developed by the project were treated as 'public goods', they were free to be diffused. This allowed salmon firms to save on the cost of investment in knowledge development and allowed entrepreneurs to quickly enter into the sector (Mendes and Munita, 1989; Hosono, 2016a).

Domsea Farms Chile, an affiliate of the United States firm Union Carbide, started production of salmon in 1974. The firm used imported salmon eggs and operated an open cultivation system called ranching. However, low returns and poor weather discouraged further investment in salmon farming and it was eventually abandoned.

The Japan-Chile Salmon Project established its first aquaculture facility in 1976 to acclimate chum salmon and cherry salmon in the remote Aysén Region near Coyhaique city. Necessary equipment and parts were airlifted to Coyhaique. The initiative involved not only the transfer of the technology of hatchery process and rearing of fry from Japan, but adaptation of the technology to the local area (Hosono, 2016a). The Project also created a feed section, set up a laboratory, and built a feed factory.

Efforts to establish coho and Chinook salmon runs were also undertaken in Chiloé Island, beginning in 1976 by Union Carbide Comercial Chile Ltda. (later sold to Fundacion Chile). Fundacion Chile also initiated salmon releases in the Magellan and Aysén regions.

In 1978, Nichiro Fisheries of Japan set up Nichiro Chile, which in 1979 launched salmon sea farming near the city of Puerto Montt, the first initiative of its kind by a private company. In 1980, it harvested Chile's first sea-farmed coho salmon, totalling 130 tonnes. Nichiro started exports to Japan in 1985 with just 30 tonnes. By 1988, exports to Japan topped 1,000 tonnes for the first time (Hosono, 2016a).

Early aquaculture focused on a raise and release method in which salmon juveniles raised in fresh water were released into the river and could not be harvested until grown salmon returned to the river after spending 1 to 4 years in the sea. These initiatives faced initial difficulties because of the low return rates of salmon, but results for 1983–1989 Magellan releases were good for both coho and Chinook salmon, with 5% and 2% rates of return, respectively (Hosono, 2016a).

In 1979 in Ensenada Baja, the Japan-Chile Salmon Project for the first time successfully raised salmon to adulthood in floating cages and to obtain offspring. The salmon grew to 3–4 kg in weight, matured, and produced fertilised eggs. The domestic production of chum salmon in 1982 represents the first recorded case of a second generation of transplanted chum salmon in South America. In late 1979, Mytilus imported 110,000 coho eggs, raised them into juveniles at a hatchery in Rio Sur, and cultivated them in the sea, becoming the first Chilean company to domestically produce eggs (Hosono, 2016a).

Between 1982 and 1984, after signing an agreement aimed at evaluating net-pen rearing with regional governmental agencies, Fundacion Chile started rearing Chinook, coho, and pink salmon and rainbow trout with that technology, which had already been successfully used in other countries. This initiative followed the Foundation's buying of several facilities on Chiloé Island that were later transferred to its 100% owned subsidiary, Salmones Antártica Ltd., the first Chilean company to surpass production of 1,000 metric tonnes of salmon in cages by 1987 (Wurmann, 2007).

Fundacion Chile, created in 1976, a semi-governmental organisation formed by the ITT Corporation (United States) and the Chilean Government, was funded with $50 million to explore innovative technologies aimed at creating new business activities, employment, and exports. Apart from Salmones Antártica they also set up Salmones Huillinco (for production of Atlantic salmon smolts), FINAMAR (for production of smoked salmon for exports), and SALMOTEC (intensive farming of cohoes and ranching of coho and Chinook salmon in the Magellan region).

At this point, the industry was characterised by high levels of vertical disaggregation with different firms specialising in distinct parts of the value chain (Rainbird and Ramirez, 2012; Tveterås and Kvaløy, 2004). This included services related to local egg production; fish health; feed development, the maintenance of nets, pens and cages; water circulation and oxygen machinery and equipment; laboratory testing; waste disposal; logistic services involving packing, crating and various forms of transport, such as well boats; and R&D and technical training (Rainbird and Ramirez, 2012).

The Chilean Government also recognised the need for regulatory reforms. In 1976, it created the Office of the Undersecretary for Fisheries (SubPesca), and in 1978, the Fisheries and Protection Division was founded under the Ministry of Agriculture to strengthen the development and regulation of fisheries (UN, 2006). The National Fisheries Service (SERNAP) was created in 1978. SubPesca played a pivotal role in establishing relevant laws and regulations specific to the industry, while SERNAP assumed responsibility for their enforcement. The Chilean salmon industry thus had established the foundation for its future growth.

Table. 1. Key features of the exploration and capability building phase 1960s–1980s

Phases	Organisational infrastructure development	Research and development
Efforts to build technical capability	First initiatives of Japan-Chile Salmon Project (JCSP) (1969). Domsea sets up its salmon project (1974). Fundacion Chile is created to explore innovative technologies and start new business activity. The Office of the Undersecretary for Fisheries (SubPesca) and the National Fisheries Service are created. Piscicultura Lago Llanquihue farms fry for first time in 1978–79. First hatcheries built and rearing juveniles from eggs.	Surveys of geography, marine environment and aquatic organisms in rivers, lakes and fjords are undertaken. Equipment and biological materials (e.g. eggs) are acquired from overseas (e.g. Norway, Japan, US) and locally adapted, supported by tech transfer and industrial personnel training in home countries and Chile. The most suitable salmon species are identified and selected for aquaculture. Salmon raise and release method is started. First R&D on feed production using fish meal produced in Chile.
Feasibility of industry is verified	Nichiro starts salmon mariculture (1979) and exports to Japan. Mytilus follows suit. Fundacion Chile buys Domsea Chile (1981). Salmones Antártica/Fundacion Chile put large-scale sea-cage farming on a commercial footing (mid-1980s). The private sector enters the industry – Fundacion Chile supports multiple projects by local companies.	Feasibility study on salmon mariculture is undertaken (1981–84) and operation of mariculture begun. Local R&D on feed crumbles suitable for fry. Feed production is increased for sea-cage farming. Expansion pellet feed is introduced from Norway. Support services expand, including maintenance of nets, pens and cages; water circulation and oxygen machinery and equipment; laboratory testing; waste disposal; logistic services and transport, and R&D and technical training.

Phase 2: Commercial expansion (capacity building for export including value add). When commercial salmon farming started, the Chilean economy had been reformed into a liberal, market-oriented, and internationally open economy. Exports evolved quickly, and economic groups diversified. The main fishing companies in Chile involved in exploitive fisheries did not immediately recognise aquaculture as a complement to their activities, opening the door for outsiders.

By 1987, 56 firms were running 117 farms, and by 1991, there were over 470 Atlantic salmon farms and 520 Pacific salmon farms (UN, 2006). The industry now faced new challenges to do with commercialisation, its position in major salmon markets and exploration of new markets, increasing the value add of products, and establishing quality standards. It was also necessary to establish the institutional infrastructure in the form of a regulatory and legal framework for many aspects of the industry (Hosono, 2016b).

The Association of Salmon and Trout Producers was established in 1986, renamed SalmonChile in 2002 to include supplier firms. SalmonChile played a key role in linking entrepreneurs and national agencies on issues of regulations and the operation of firms, requiring its members to implement certification standards from the Instituto Tecnológico del Salmón (Intesal), (Mendez and Munita, 1989; Wurmann, 2007) and helping the firms to upgrade their production, processing and waste management standards accordingly. In 1994, Salmon Chile established Intesal, one of the main dedicated training institutes for salmon industry workers, to develop and diffuse food safety and quality control technologies.

In 1991, the General Law for Fisheries and Aquaculture (LGPA), was established, which revised the existing fisheries law. In 2000, the Undersecretary for Fisheries (SubPesca) imposed an import ban on salmon eggs from countries where cases of infectious anaemia (ISA) had been suspected or detected. The ban further accelerated the development of domestic salmon egg production. Until that time. Chilean hatcheries were relying overwhelmingly on imported eggs. About 51 million units of salmon eggs were imported in 1991, rising to 114 million in 1994 (Katz, 2004). However, by 1995, about 40% of the salmon eggs used were locally produced, rising to 90% by 2002 (Bustos-Gallardo, 2013; Henoch, 2006).

The markets of importance during this phase were Japan and the US. The Japanese market captured 50–60% of exports of farmed salmon from 1989 to the mid-1990s. Nichiro had already begun commercial production, and the Japan External Trade Organization (JETRO) and the Export Promotion Bureau of the Chilean Government (ProChile) supported the export of Chilean salmon to Japan.

Nippon Suisan Kaisha, which had bought out Salmones Antártica in 1989, was familiar with the Japanese market, possessed its own research institutes, and had the capacity to conduct production and exports that met market requirements. The company started the production of high value-added processed products that became strategic goods for the Japanese market, including evenly salted and smoked salmon. Japanese processing technicians provided the necessary technical guidance. The collaboration between organisations on both sides of the Pacific enabled the exponential growth of Chile's salmon exports to Japan from 1,100 tonnes ($8.37 million) in 1988 to 32,000 tonnes ($174 million) in 1993. The company also constructed a state-of-the-art salmon processing plant in Puerto Aysén (Hosono, 2016b).

As Chilean production of Atlantic salmon grew, that species replaced coho salmon in the US market, and Atlantic salmon became established in 2000 as the main species produced (46%).

Increased salmon exports brought about further changes to physical distribution and logistics. For example, a new terminal equipped with refrigeration facilities was constructed at Santiago International Airport to deal with increasing air shipments of salmon. Refrigerated container yards were built in San Antonio, Lirquen, and other major ports (Hosono, 2016b). Production and marketing services diversified. For instance, there were 22 firms that produced net-pens, 13 provided painting and maintenance services, 18 produced and maintained cultivation tanks and 10 provided pathology services in the Los Lagos region. Additional firms emerged to handle logistics, fish processing and labour development (UN, 2006).

A shift also occurred in the exports towards value-added, easy-to-use and read-to-eat products to meet consumer needs, requiring new production processes, supported by quality assurance techniques that were made by the firms and overseas purchasing companies providing technical guidance. The proportion of value-added products to total exports increased from 23% in 1994 to 69% in 2004.

The sequencing of the genome of the bacterium causing Salmon Rickettsial Syndrome (SRS) by Chilean scientists from 11 institutions was one of the major steps towards understanding the disease and developing vaccines. SRS causes annual losses estimated at about $100 million to the salmon industry in Chile (Argandoña, 2004). By 2004, an SRS vaccine had been developed. In addition, a joint project involving the University of Concepción, CORFO and some private firms resulted in the development of a recombinant vaccine against infectious pancreatic necrosis.

Investments were also made to develop more sustainable and diversified feeds and feeds with better conversion rates. The salmon industry was able to reduce the use of fish ingredients in feed formulation from about 90% to 50%, and increase the conversion rate in Chile from 3:1 (3 kg of feed to 1 kg of salmon) to about 1.7:1 by 1995. Firms also adopted automatic feeders, computerised sensing and monitoring of the tank environment (Perlman and Juárez-Rubio, 2017).

Wellboats, used to transport live fish, had been imported from abroad but started being produced locally. Existing firms with experience in ship design and building facilitated the adaptation and assimilation of the technology. For example, ASENAV, founded in 1973, developed wellboats for the salmon industry with the capacity to hold up to 800 tonnes of fish, using its in-house designs, as well as designs licensed from Norway. The design of vessels was modified to adapt ship structures to the geography of the Chilean coasts (UN, 2006).

Table 2. Key features of commercial expansion phase 1980s to late 1990s

Phases	Organisational infrastructure development	Research and development
A new industry starts, with technological and institutional innovations	The private sectors enters the industry in earnest – Fundacion Chile supports numerous local firms. The number of firms increases substantially from 36 in 1985 to 219 in 1997 The Association of Salmon and Trout Producers is established (1986) and founds Intesal, one of the main dedicated training institutes for salmon industry workers. SERNAP promotes the establishment of a legal framework and regulations. The General Law for Fisheries and Aquaculture is established (1991) consolidating the legislation governing aquaculture. A system of authorising concessions to conduct aquaculture is created (1993). A national policy for the use of Chile's coastline is issued (1994), and rules for the disclosure of aquaculture activities are established (1995). Fundacion Chile provides quality certification services for farmed salmon.	R&D investment by the government through competitive grants kicks off in 1991. Research on eggs and genetic selection starts. Domestic egg production ramps up. Research into fish health yields first vaccines. Value-added products are developed for the Japanese and US market in response to consumer preferences. Professionals and technicians access tertiary level education through new schools of marine science and aquaculture (University of Austral 1989; Catholic University of Temucho 1992; Intesal).
Commercial sustainability and development of value chains	Foreign salmon companies enter market in force. Three types of firms emerge: Six large companies with significant foreign presence; national and medium-sized firms (based on sales and capital available); and small, mostly family owned, with insufficient capital to expand.	Advanced processing technologies are introduced along with quality standards. A state-of-the-art processing plant is constructed in Puerto Aysén. The volume of production grows exponentially from 3,000 tonnes in late 1980s to over 600,000 tonnes in 2007 before ISA.

Phase 3: Globalisation and adaptive responses. By the late 1990s, the industry's growth was being driven by global market needs. Exports topped 100 million tonnes in 1996, a milestone that defines the globalisation of production, with reported jobs around 30,000 before the ISA crisis (SERNAPESCA, 1998–2008). The National Aquaculture Policy, established in 2003, aimed to boost the industry further. The policy had a clear target: to double the value of exports of salmon in 10 years (Lzuka *et al.*, 2016).

The fall in salmon prices on the international market in the late 1980s and early 1990s had led to the exit of smaller firms and to industrial consolidation. Foreign investors in search of new production sites drove mergers and acquisitions and a move towards vertical integration, including feed and egg production, to make use of economies of scale and reduce production costs (UN, 2006; Izuka *et al.*, 2016). By 2001, 36 per cent of salmon farms in Chile were owned by foreign firms (Fazio, 2001). Vertical integration and greater control over production were driven in part by traceability and quality standards expected by retailers and consumers, and the perishable nature of the product, which demands high degrees of coordination in the production process (Tveterås and Kvaløy, 2004).

As Chile became a leading competitor in international salmon production and exports from the mid-1990s, its profile was being raised internationally. As a result, questions emerged about the industry's practices and sustainability. In the most high-profile case, filed in 1997 by the US Department of Commerce, US producers accused Chilean producers of dumping.

Concerns over the environmental impacts of salmon farming were being raised as early as 1991 (López and Buschmann, 1991; Caro, 1995). By 1999, labour conditions on salmon farms and the displacement of fishing communities had entered the discussion (Claude *et al.*, 1999). From 2002, conflicts between NGOs, unions and salmon farmers intensified, reaching a peak during the ISA crisis and fought in the public and judicial domains.

In the late 1990s international NGOs were starting to tackle problems relating to the sector. Friends of the Earth Scotland, and the Friends of Clayoquot Sound scrutinised practices overseas and were joined by Fundación Terram (established 1997) and Ecoceanos (established 1998). The Pure Salmon Campaign (an offshoot of the US National Environmental Trust), established in the mid-2000s as a coordinating body for NGO activities in different countries, consolidated local activities. It brought together common concerns about improved management of production externalities, including genetic adaptation, impacts on wild species, use of antibiotics and labour conditions.

In 2002, the Labor Minister promoted the 'Program of Social Dialogue' to address the labour and social agenda with the salmon industry, with local NGOs charged with its implementation. The first NGO was ICAL (linked to the Communist Party), which brought union leaders to engage in negotiations. After two years, El Canelo de Nos, a more centrist NGO, took over implementation, with an emphasis on building trust between stakeholders, suggesting an attempt to contain social conflicts. Unions and other civil society organisations participated in these dialogues, although remaining critical of companies, which they accused of violating agreed compromises while continuing in dialogues (Cid Aguayo and Barriga, 2016).

In the same year, Salmon Chile and the government endorsed the Salmon APL (Clean Production Agreement of Salmon) as a voluntary system of environmental certification. Challenged by civil society actors, the salmon industry engaged actively in the project. The APL implied a transformation of the regulatory agencies' roles from one of external supervision to one of partnership with the industry (Cid Aguayo and Barriga, 2016). The NGOs however challenged the legitimacy of the APL on the basis that the agreement excluded other stakeholders, specifically labour, and that the regulation's focus on individual plants did not consider their aggregated effect on the environment's carrying capacity.

In 2005, the '*Environmental Performance Review of Chile*' was published on behalf of the OECD and the Economic Commission for Latin America and the Caribbean (ECLAC). It reported that while Chile had adequate laws and detailed methodologies to monitor and protect the environment, regulatory authorities lacked adequate financial and staff resources to ensure full and effective enforcement (OECD, 2005; Leon, 2006).

In July 2006 OLACH, the labour and environment observatory of Chiloé, was created, a joint venture between Terram, Oxfam and other Chilean NGOs (CENDA and Canelo de Nos) in association with the national trade union confederation (CUT). A media campaign called *Fearless against the Current* was launched in January 2008 by Oxfam and Terram to raise awareness of the industry and its impacts among the Chilean public (Barton and Fløysand, 2010).

The *Pure Salmon* campaign brought Chilean labour unionists to the shareholder meeting of Marine Harvest in Norway in 2009 to draw attention to the plight of laid-off workers and the unsustainability of production practices. Local workers engaged in strikes at industry headquarters in Puerto Montt and at the firms Mainstream and AquaChile in 2007, and formed a new organisation, FETRASAL, to articulate their demands (Barton and Fløysand, 2010).

The rising globalisation of these NGOs, and better use of mass communications media, gave rise to a shift in scale and alliances at the same time that labour and environmental conflicts were coming to a head.

The outbreak of Infectious Salmon Anaemia (ISA) created a severe crisis between 2007 and 2010. In July, the Norwegian company Marine Harvest reported a case of ISA virus on the Chiloé coast. By the beginning of August, SERNAPESCA had detected at least nine centres affected by ISA in Chiloé, and by 2009, almost 60% of production centres had ceased production (Lizuka and Zanlungo, 2016). Almost 20,000 employees from production and processing plants were laid off and bankruptcies increased, leaving up to USD2,500 million of bank debt (Larrain, 2001; Izuka and Katz, 2015) and turning an environmental crisis into a social one.

The speed and spread of the outbreak and the absence of vaccines affected the capacity of the industry to react. Although initially slow to admit an outbreak, the salmon industry had formed a consensus within the year about its causes: overproduction and fish overcrowding, importing of contaminated eggs, spatial concentration of operations, lack of knowledge of the relationship between salmon production and the marine environment in which it takes place, and lack of oversight and enforcement mechanisms by the public sector caused by a lack of resources, personnel, infrastructure, and legal faculties (Bustos-Gallardo, 2013). The outbreak of ISA prompted a private laboratory to sequence ISA's DNA, enabling the identification of vaccines (AQUA, 2008).

International media scrutiny was harsh. The New York Times published an article in March 2008 that was highly critical of production processes, including high use of antibiotics, and the poor environmental conditions (Barrionuevo, 2008). The article effectively globalised a local production crisis, challenging the industry in its largest market, and increasing attention from consumers, competitors and NGOs on broader sustainable development strategies (Barton and Fløysand, 2010).

Shortly after the ISA incident, the government established the Mesa De Salmon (Roundtable for Salmon), with membership constituted of public-sector agencies, to resolve the crisis. The Roundtable initially had the tasks of modifying the existing sanitary norms and the rules for environmental protection, and creating new operational protocols capable of ensuring the sustainable growth of the industry, but its remit expanded to consider the social impacts and the banking crisis that had ensued.

The Roundtable played a central role in coordinating the interests of different stakeholders, which resulted in modification of the General Law of Fishing and Aquaculture (LGPA) in April 2010. The new legal framework created the Aquaculture Subdirection within the Fishing Department, and effected a change in the concession granting system, strengthening sanitary and environmental regulations and the authority of SERNAPESCA to enforce them; and creating collective management mechanisms (Lizuka and Katz, 2015). While the ISA outbreak diminished the centrality of the economic imperative, most of the regulatory changes focused on environmental issues, leaving the existing labour laws unchanged.

A key new mechanism for the management of sanitary and environmental conditions was the establishment of 'barrios', i.e. neighbourhoods of salmon producers. Barrios represented a new organisational form to encourage firms within the same barrios to collectively manage environmental and sanitary conditions through the synchronisation of the production calendar, including sowing, harvesting and fallowing, and resting periods. This coordination of production was to allow better control of high-risk transmission contamination activities such as transportation and processing. Additional measures to manage fish escapes and creating appropriate distances between the cultivation centres were also to be jointly implemented.

In September 2009, salmon producers of salmon types not affected by ISA formed their own association, the Association for Producers of Coho Salmon and Trout of Chile (ACOTRUCH) and started participation in the Roundtable, to give voice to producers who were not affected by the ISA (Izuka, Roje, and Vera, 2016).

Institutional change in Chile with regard to aquaculture is an ongoing process. In 2013, the new Fisheries Law went into effect, demonstrating the government's focus on protecting and making sustainable its marine environments and resources. The new law also incorporated new protection for workers and strengthened research capacity through the creation of a National Research Program for Fishery and Aquaculture.

Environmental issues, however, keep raising their heads. The industry was criticised for its overuse of antibiotics (over 280 tonnes in 2016, 700 times the amount used in Norway, and the highest of any country in the world), prompting US retail giant Costco to drop the bulk of its Chilean contracts in favour of Norwegian-bred salmon, citing Chile's heavy-handed use of antibiotics (2014). In 2016, Chilean production of salmon dropped by 20% due to red algal bloom, which environmentalists blamed on waste emissions from fish farms (Daily News, 2017).Table 2. Key features of commercial expansion phase 1980s to late 1990s

Phases	Organisational infrastructure development	Research and development
Production and investment is self-sustaining	Mergers and acquisitions driven by first tier firms buying up second and third tier firms and creating vertical integration. Number of firms reduces from 219 in 1997 to 79 in 2002. Goods and services firms (transport, retailing veterinary, medicines, etc.) also increase significantly from 75 in 1993 to 461 in 2003. Salmon APL (Clean Production Agreement of Salmon) is created as a voluntary system of environmental certification. The Association of Trout and Salmon Producers becomes Salmon Chile (2002) by opening up its membership to any firms within the industry and takes on the role of intermediary between public and private sector. The National Aquaculture Policy is released (2003) to promote growth sustainably. Supplier associations form, i.e. Association of Net and Net Service Industries; the Regional Ship Owners and Maritime Services Association; the Association of Diving Companies, the Association of Veterinary Laboratories; and the Association of Southern Ship Owners.	Expansion of existing production and human capacity, including: advanced processing technologies, plants and quality standards; an increase in training programmes to 1866 by 2005, driven by a policy of government subsidies of training expenses for workers; and exponential production growth from 3,000 tonnes in late 1980s to over 600,000 tonnes in 2007 before ISA.

Phases	Organisational infrastructure development	Research and development
Adaptation to globalisation and crisis	International NGOs become active, and form alliances with local NGOs. The Chilean Government creates the 'Program of Social Dialogue' to address the labour and social agenda with the salmon industry, to be implemented by local NGOs. OLACH, the labour and environment observatory of Chiloé, is created in association with the national trade union confederation. The Roundtable for Salmon is convened during the ISA crisis and results in the modification of the LGPA in 2010, reforming concession rights, strengthening environmental regulations, reorganising production through barrios and strengthening the authority of the National Fisheries Service. A new association of salmon-farming industry ACOTRUCH is established among small- and medium-sized producers. A new Fisheries Law is introduced in 2013, with an increased focus on sustainability, scientific criteria and research capacity and incorporating more social protection.	Technical missions are undertaken to salmon producers in Canada, Norway and Faroe Island to find solutions to ISA. Large private salmon firms make substantial investments in infrastructure to secure production (e.g. transfer of production sites south, developing closed systems with recycled water plants). The DNA sequence of Chilean ISA is discovered followed by the development of vaccines. An independent diagnostic laboratory is established to service SERNAPESCA enforcement activities. The laboratory is accredited with the World Organisation for Animal Health (making it the first reference laboratory in Latin America). Capacity in the form of staff and budget are strengthened in SERNAPESCA and SubPesca.

IMPACT EVIDENCE

The Chilean salmon industry has created significant economic benefits. The industry provides upwards of 30,000 jobs directly and 30,000 indirectly. Salmon currently represents 58% of all fishing exports of the country, and its contribution to national exports is close to 4% (Salmon Chile, 2013). Infrastructure (roads, bridges) in the production regions has improved, especially in the Los Lagos region. Supporting services have grown and R&D and training facilities have emerged (UN, 2006).

However, questions remain over the industry's environmental and labour practices. Despite the creation of employment, labor unions question the treatment of workers, hiring contracts lacking adequate social security protection, and there is a lack of social services and on-the-job training. Local communities question corporate social responsibilities and lack of company involvement in community and municipal affairs (Katz, 2016). Thus, the establishment of minimum labor standards and the enforcement of labor legislation are ongoing grounds for contestation (Cid Aguayo and Barriga, 2016). Concerns also remain over the overall degradation of water ecosystems, and the effect this has on fishing communities' livelihoods.

CONSEQUENCES

The case of the development and growth of the salmon industry provides general lessons about creating a non-traditional export industry based on natural resources in a developing country, where lack of traditional institutions and local knowledge must be overcome and increasing economic activity alone does not ensure sustainability. Chile built the capacity to manage and sustain a major export industry and is evolving the institutions required to do this in a socially and environmentally friendly way.

Market liberalisation created the opportunity to establish a dynamic export sector that revitalised the regional economy and generated profits for domestic and international firms, and income for the local government. A parallel process of socio-ecological globalisation has also 'opened up', bringing different actors to the table, including international buyers, retailers, consumers, researcher institutions, politicians, international media and NGOs.

The future growth of the salmon industry will depend on the fulfilment of the principles and objectives committed to in the National Aquaculture Policy of 2003, which promotes maximum possible economic growth, within a framework of environmental sustainability and equality in access. Public and private capacities are available to do this (FAO, 2017). The industry is starting to participate in Clean Production Agreements and the norms of environmental standardisation ISO 14000 and certification initiatives such as WWF, Global Gap and GAA (Salmon Chile, 2013). It can be argued that Chile's market position is not only due to its capacity to produce volume and efficient integration into a global market, but by the incorporation of high standards in the development of the business. Lessons from the salmon industry are likely to prove relevant in future attempts to develop or expand other industries in a socially equitable and sustainable way.

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SEEDS OF LIFE IN TIMOR LESTE

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SUMMARY

Seeds of Life was a 15 year programme of work that combined technical innovation in crop varieties with institutional innovation in seed production, dissemination and national policy. The programme was embedded within the Timor-Leste Ministry of Agriculture and Fisheries (MAF) and emphasised institutional capacity building within MAF as part of its overall development agenda. Although the approach taken was incremental or step-wise, over time it may have contributed to a degree of systems change, though it is yet unclear if this will be sustained without project support and funding.

Table. Patterns of Innovation and Impact processes Summary table

Initiator	Aid responses to post-conflict reconstruction. Research project to improve the germplasm of major food crops.
Critical features	Coupled research on varietal improvement with institutional development of seed system and strengthened capacity and governance in the Ministry of Agriculture, and Fisheries (MAF).
Role of research	Central at first, but later as a component of a wider capacity building approach.
Operational alliances	Evolved from CGIAR centres early on, to alliances with farmers, community-based seed groups, NGO programmes and private seed companies.
Strategic alignment of stakeholders at sector or national level	Close alliance with the MAF.
Solution, product, or system innovation	Local production and value-chain innovation evolving to system innovation to deliver product and service innovation.
Scope of impact (and metrics)	At the national level, incremental staple food production is estimated to increase from 14,980 Mt to 19,220 Mt over a period of 10 years.

CHALLENGE/OPPORTUNITY

Timor-Leste voted for independence from Indonesia in 1999. The ensuing violence and conflict destroyed most of the infrastructure and displaced a significant proportion of the population. Growth was driven by revenue from petroleum sales and infrastructure, while the community faced high levels of poverty, malnutrition and several months each year of food shortages (Boon, 2015).

A key goal of the young government was to improve food security. Agricultural productivity was low, but there was significant potential to improve through the provision of rural infrastructure and improvements in farming practices. Food shortages were common and households would often have to consume seed stock saved for planting next year's crop (Borges *et al.*, 2009). The government was dependent on imports of food, and also of seed stock (Boon, 2015). Imported seed was often held up, exposed to too much heat and, if delivered in time, had low germination rates (Boon, 2015).

The country was in the process of defining and rebuilding itself – creating institutions for governance and to provide for the basic needs of a diverse and often remote rural population.

INNOVATION

This case demonstrates technical innovation, in the form of improved seed varieties, and the institutional innovations and adjustments required to support and sustain the use of new technology.

Germplasm for the major food crops were imported in partnership with a range of CGIAR centres and tested on research stations for the range of agro-ecological systems in Timor-Leste. Promising varieties were used in participatory varietal selection processes on-farm and evaluated for yield, eating quality and other characteristics. By 2015, the project had released three maize varieties; two rice varieties; one peanut variety; three cassava varieties; five sweet potato varieties; two kidney bean varieties; and two mung bean varieties.

In conjunction with the introduction and testing of varieties, significant effort was invested in the establishment of a National Seed System, which included (Boon, 2015; Nesbit and Spyckerelle, 2016):

- Capacity building within the Ministry of Agriculture and Fisheries (MAF)
- Establishment of a regional network of research stations
- Development of a National Seed Policy and supporting institutional architecture
- Development of a regulated system to breed, reproduce and disseminate improve planting material through a network of MAF, commercial producers and community groups.

INNOVATION PATHWAY

This case uses multiple reinforcing pathways to support innovation. Technical science of crop development is realised through participatory approaches and informally scaled out, leveraging the social capital of farmers. Multiple institutional innovations guiding community-level seed access through to national policy decisions are carried out in order to foster the continued, sustainable use of technical outputs.

Seeds of Life (SoL) started as a focused ACIAR project that focused on improving germplasm of major food crops, and evolved into a research and development programme (Nesbitt and Spyckerelle, 2016). Each phase had co-funding from the Timor-Leste government and there was strong support and ownership of the programme within the Ministry of Agriculture and Fisheries. Each phase was progressive, building directly on the progress and findings of the previous phase. Young (2016) describes this as essential to building long-term sustainability of the programme in MAF.

Phase 1: Introduction and evaluation of germplasm, ACIAR-funded, AUD1.2 million (2000–2005). Facing major food shortages and low agricultural productivity, the introduction of germplasm and development of locally appropriate improved varieties was considered the most cost-effective strategy for addressing key constraints (Lacoste *et al.*, 2012). The project was led by the University of Western Australia, who designed the project with the transitional administration and National Council of Timorese Resistance (no government had yet been established) (Boon, 2015).

Crop centres from the CG system contributed expertise, breeding material and supported evaluations of crops. Research station trials were established and managed in conjunction with a range of NGOs, including World Vision, Catholic Relief Services and Australian Volunteers International. The project had the long-term goal of improving farmer access to a range of high-yielding crop varieties that were locally adapted, and building the capacity of MAF to evaluate, produce and distribute seed stock (Boon, 2015). Identification of appropriate crop varieties would continue throughout the three phases, expanding to consider issues of climate variability, integrated water resource management, post-harvest management and nutrition (Boon, 2015).

Phase 2: Participatory varietal selection and capacity building, joint AusAID and ACIAR funding, AUD10.4 million (2005–2011). Phase 2 expanded to include participatory on-farm testing of promising varieties with farming households to evaluate varieties in terms of suitability in different conditions, and household preferences. Popular lines from these trials were first released in 2007, and it was expected that some dissemination of new varieties would occur through farmer networks, though formal distribution also occurred in collaboration with NGOs, international donors and through MAF (Lacoste *et al.*, 2012). Although initial adoption rates were promising, with each successive year re-planting rates declined, primarily due to a lack of planting material (Lacoste *et al.*, 2012). Although availability of local varieties was sustained through social networks and could be maintained to some degree even after poor seasons, the improved varieties had not yet been integrated in this way (Lacoste *et al.*, 2012).

Phase 2 took an expanded approach to capacity building, setting the foundations for the National Seed System that would be embedded under phase 3. Capacity building encompassed research and release of varieties, but also infrastructure improvements and training in policy development (Boon, 2015).

Phase 3: National seed system, multiplication and distribution of seeds, joint AusAID and ACIAR funding, AUD28 million (2011–2016). This final phase sought to achieve the programme goal of at least 50 per cent of farming households with access to, or using, improved varieties of staple crops, and ensuring sustainability of the programme through continued capacity building in MAF.

Crop identification and development work continued in this phase, however the main focus was on activities relating to the National Seed System, and the establishment of seed production and distribution networks (addressing a key constraint to adoption identified in the previous phase).

Under Phase 2, a resource-intensive formal seed system was designed which aimed to produce large quantities of high-quality seed each year. Under Phase 3, it became clear this system would be too resource-intensive for MAF to continue by itself without project support. The Phase 3 seed production was designed to produce enough seed stock for research needs, to provide planter seed to community groups, and to hold some stock in reserve in case of natural disasters (Nesbit and Spyckerelle, 2016). Breeder and foundation seed was grown by MAF staff on research stations under strict quality control provisions. Foundation seed was then provided to contracted seed growers, who produced certified seed under close supervision and quality control by MAF. Certified seed was distributed to a) MAF to meet research needs; b) commercial seed producers to produce seed for commercial sale; and c) to Community Seed Production Groups who would multiply it for use by members. Community Seed Production Groups were based on a modified version of a model previously used by CARE. While CARE established their own seed production groups, Seeds of Life observed challenges in handover and sustainability of groups after the CARE project finished. Rather than establishing new groups (which would create unsustainable burdens for MAF in trying to meet group support needs post project), Seeds of Life fostered Community Seed Production Groups from existing farmer groups (that were already supported by MAF) (Nesbit and Spyckerelle, 2016). Commercial seed producers emerged from highly successful community groups which produced more than enough seed to meet member needs, and identified the opportunity of producing seed for sale. These groups were formalised, registering with MAF and undergoing quality control checks and standards. In some cases, commercial groups started savings and loans operationswith income from seed sales.

While work at the municipal and suco/village level on seed multiplication was occurring, work at the national level was confronting the development of a national seed law, which had been started in Phase 2. With limited progress, the project sought out the experiences and advice of Nepali experts, who had been through a similar process of establishing a seed law and system. On the advice of the Nepali experts, who warned against prematurely locking in conditions in law, MAF instead pursued a National Seed Policy, which would allow flexibility in trialling and revising the process, with formalised legislation enacted once this had been improved (Nesbitt and Spyckerelle, 2016). The National Seed System was developed with input from municipalities, national working groups and other interests. It was endorsed in 2013 by the Minister, and implemented soon after.

Several features of this case have supported the various pathways that have led to innovation. First, the programme was literally embedded within a nascent government agency. In the crowded space of agricultural development, such close and unfettered access to government staff and such influence over the establishment of the architecture of government is rare. Embedding the office within MAF enabled capacity building or 'institutional strengthening' within MAF as well as engendering a strong sense of local ownership of the programme (Boon, 2015).

Second, the project was adaptive and collaborative – taking advantage of initiatives that emerged locally, such as commercial seed producers, and linking with other NGO programmes to leverage off the programmes of others. For example, partnering with IFAD who were distributing drums for seed storage, and distributing seed through the IFAD programme; or working with Mercy Corp to link seed producers and local stores.

Third, the adaptation of different activities with consideration of the ability of MAF to continue activities post project without support is laudable. The pathways pursued by Seeds of Life can therefore be considered to emphasise the local system, its existing capabilities and limitations – embedding the innovation within the system rather than developing parallel or competing systems.

IMPACT EVIDENCE

The programme formally finished in June 2016. Impact assessments and evaluations therefore occur within the visible shadow of intense programme support and funding.

At the household level, there is evidence that the programme improved food production and household income. Young (2016) found adoption of improved crop varieties 'has, and will have in the future, reasonable potential to increase farm incomes.' Income calculations vary depending on the crop, and the agro-ecological area of the household. An end of project survey found an overall reduction in the number of households experiencing hunger in the 12 months prior to the survey, reduced from 82 percent to 65 percent in the general population, and for those growing improved varieties, from 77 percent to 54 percent (Nesbitt and Spyckerelle, 2016).

Nationally, Young (2016, p.10) found the project 'has and will have a major impact on staple food production in Timor-Leste … at the national level, incremental staple food production is estimated to increase from 14,980 Mt to 19,220 Mt over a period of 10 years.'

Alongside food production, a key aim of the programme was to build capacity within Timor-Leste to address critical shortages of technical skill. Capacity building programmes included agricultural professionals in MAF (researchers, extension practitioners, administrators, seed production staff), NGO staff, staff working for Seeds of Life and farmer groups involved in seed production (Raab, 2016). Between 2006 and 2015, Seeds of Life provided 10,363 training opportunities to 2,653 individuals. Training covered a wide range of topics, but most participation was in seed production, followed by English and statistics (Raab, 2016). The training programmes and infrastructure development resulted in the establishment of six agricultural research stations, seed warehouses and storage capacity, three seed laboratories, one soil laboratory, 65 community seed houses, and 1,200 community seed production groups, from which emerged 69 commercial seed producers (Nesbitt and Spyckerelle, 2016).

Qualitative interviews showed that training recipients felt the training had a positive individual impact, and evaluation concluded there were broader benefits: "*changes in individual capacity engendered by [Seeds of Life] have rippled out to bring positive changes at wider levels, have laid the foundation for future improvements in Timor-Leste's food security situation and that the contributions of its capacity building efforts are largely sustainable*". (Raab, 2016, p.15).

CONSEQUENCES

The project has demonstrated significant potential for long-term impact through the strong capacity built at a range of levels. The National Seed System has ministerial endorsement and has been operationalised. Community and private-sector networks for seed production and distribution are linked to formalised MAF programmes to ensure supply and quality. The introduction of new varieties has sought to complement local varieties and add to biodiversity rather than create mono-cropping. The key question to be asked is how sustainable the system will be without project support? Young (2016, p.7) in a financial and economic analysis of Seeds of Life highlights the "critical need for ongoing expenditure to support: (i) continued variety importation and testing; (ii) seed multiplication; and (iii) seed purchase and distribution". Though MAF have the responsibility to sustain the National Seed System, they have a modest annual budget.

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SUNDROP FARMS IN AUSTRALIA

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SUMMARY

This case study examines the development of a technology for environmentally sustainable, intensive horticulture. Global population growth and the effects of climate change are increasingly challenging the world's food, energy and fresh water security. Sundrop Farms, a UK-based agri-business with operations in Australia, Portugal and the US, has developed and patented a system of effective greenhouse crop production that doesn't depend on fossil fuels, arable land and fresh water resources. Having successfully tested the technology in a pilot facility in Australia, Sundrop Farms worked with a number of commercial partners to expand the Australian facilities and bring the first consumer product to market. On the back of this success, the company set up trial farms internationally, opening up opportunities to build capacity in arid climate food production technologies elsewhere.

Table. Patterns of Innovation and Impact processes Summary table

Initiator	Integration of established technologies in a novel form from across the world (solar thermal systems, greenhouse design, hydroponic systems, vertical farming, desalination technology, etc.), to create a large-scale agriculture system that does not rely on traditional inputs.
Critical features	Assembling the necessary elements to produce crops at scale and building supply arrangements and relationships to service retailers and consumers.
Role of research	Proof of concept through testing and optimising the Sundrop Farms technology.
Operational alliances	Agreements with major value-chain actors, financial providers and research organisations overseas to execute a joint programme for testing and optimising the Sundrop Farms technology.
Strategic alignment of stakeholders at sector or national level	Partnership with the second largest supermarket in Australia provided confidence for investors to help commercialise the technology and scale-up production.
Solution, product, or system innovation	An alternative farming method and organisational network capacity to allow commercial crop production in Australia, and trialling of the technology in other countries.
Scope of impact (and metrics)	Sundrop Farms created an agricultural system that can be profitable as well as environmentally sustainable. The company estimates a 5–15% cost saving over fossil-fuel powered glasshouses.

CHALLENGE/OPPORTUNITY

Today, the world faces significant challenges to food security and fresh water and energy resources. The agriculture sector consumes about 69% of fresh water globally (WWF, 2017), contributes to over 20% global anthropogenic greenhouse gas emissions (IPCC, 2014) and consumes nearly 40% of the planet's land area (Ramankutty *et al.*, 2008). By the middle of the century, the world's population is estimated to rise to over nine billion people, increasing the demand for food by 50% (Alexandratos and Bruinsma, 2012). Sustainable intensification of agriculture is suggested as a key tool to addressing this need (Chartres and Noble, 2015).

This requires new ways of thinking about and applying technology and science to agricultural practice. The specific challenge in this case was to turn a sustainable greenhouse production system into a profitable business.

INNOVATION

The innovations in this case concern the development of an alternative farming method and building organisational networks and capacity to allow commercial crop production in Australia, and trialing the technology in other countries. An exclusive retail arrangement provided access to the Australian market and attracted government funding and venture capital for commercialisation and expansion. R&D is ongoing to enable adaptation of the technology to local conditions in the target countries and the expansion of production to include different crops.

The Sundrop Farms System™ integrates established technologies from across the world (solar thermal systems, greenhouse design, hydroponic systems, vertical farming, desalination technology, etc.), which are put together in a novel form. The system is the first large-scale agriculture system of its kind and does not rely on the traditional inputs – soil, pesticides, fossil fuels and groundwater. Instead, energy generation through solar technology, fresh water production and sophisticated hydroponic greenhouses enable the growing of food.

The first Sundrop pilot, a 0.2 ha greenhouse, generated its energy using curved, parabolic mirrors that concentrated solar heat onto pipes filled with oil, which was transported superheated to 160°C to storage tanks for use in heating and cooling the greenhouse and water desalination. During winter, diesel oil was used for 10 to 20% of energy required to operate the plant. The crop produced was hand-delivered weekly to local greengrocers (Sundrop Farms, 2012).

The current setup has improved the system. Four glasshouse modules spread over 20 ha, located about 15 km south-east of Port Augusta, produce up to 15,000 t of tomatoes annually. The 'engine' of the farm is the almost 24,000 flat mirrors that reflect sunlight towards a 127 metre high receiver and solar boiler, creating steam to drive a turbine and generate electricity. Unused heat is transferred to a thermal energy storage tank and then used to desalinate seawater. The solar tower generates up to 39 megawatts of power, enough to run the greenhouses and desalination plant and provide enough water to irrigate 180,000 plants. The facility relies on the grid for only 10–15% of its power needs, primarily in winter.

The seawater is piped for 5 km from the Spencer Gulf to the farm. It is kept in storage tanks before being condensed into fresh water using heat from the thermal storage tanks. Waste heat is pumped into the four greenhouses for heating. To cool the greenhouses, seawater provides cooling through evaporation from wet cardboard that lines the glasshouse walls, while at the same time sterilising the air, making chemical pesticides unnecessary. Pests that survive this treatment are bio-controlled. The freshwater is kept in a 25 million litre storage pond. On average, one million litres of fresh water are pumped in daily and the same amount is removed for use in the greenhouses (Sundrop Farms, 2016).

The climate and irrigation inside the greenhouses are computer-controlled to ensure the crops (a single variety of truss tomatoes for Coles) receive the right levels of nutrients, light, water, temperature and carbon dioxide. Although perennial in nature, the tomato plants are replaced annually to maintain maximum productivity. Planting to harvest takes about 10–12 weeks (Sundrop Farms, 2016).

The tomatoes are harvested by hand, after which the process becomes automated. Robotic carts move the crop and feed it through a state-of-the-art packing facility. From there, trucks deliver the produce daily to Coles distribution centres across Australia. During peak production in summer, between 15,000 and 20,000, 5 kg cases are shipped out every day (Wagstaff, 2017).

A training facility for staff was set up at the original pilot site to simulate the activities at the commercial greenhouse (Neindorf, 2015). Sundrop obtained a grant from the South Australian Government for a pilot skills development project with around 30 job seekers, providing a potential pathway to gaining employment with the company. The training requirements included accredited units from Certificate II in Horticulture and Certificate III in Agriculture and general skills development to assist participants transitioning into the workplace (Syndigate Media, 2015).

INNOVATION PATHWAY

Sundrop Farms started as a Seawater Greenhouse, using technology invented by Charlie Paton in the 1990s. In 2010, Seawater Greenhouse Ltd built an Australian project facility, its first with a commercial focus, after earlier proof of concept and trials in Tenerife, the UAE and Oman (Bjelkeman, 2009; Seawater Greenhouse, 2017). It operated as Seawater Greenhouse Australia Pty Ltd as a joint venture between Seawater Greenhouse Ltd and private investor Saumweber Holdings Ltd, a firm with a focus on international agricultural investments (Seawater Greenhouse, 2010). The project team comprised Charlie Paton, his son Adam Paton, and Philipp Saumweber and Reinier Wolterbeek, who would go on to establish Sundrop Farms.

The goal was to test integrating solar power electricity generation, fresh water production and hydroponics to grow crops in non-traditional conditions. The pilot comprised just 0.2 ha of greenhouse, growing tomatoes, capsicums and eggplants. The venture partners fell out over disagreements about technologies and strategy. Charlie Paton had developed the earlier technologies to be simple and low-cost. He accused his partners of 'abandoning sustainability in the interests of commercial greed', and dismissed the installation of expensive, high-tech kit and a gas boiler for back-up power. His partners, in turn, considered the Seawater Greenhouse technology to be 'commercially hopeless' (Margolis, 2012) and turned their focus on desalination using concentrated solar power (Pearce, 2013).

After paying out an undisclosed sum to the former partner, Greenhouse Australia became a subsidiary of Saumweber Holdings Ltd, trading as Sundrop Farms Pty Ltd (Sundrop Farms Australia). Saumweber Holdings Ltd and privately owned Alternative Energy Investment (AIE) Ltd co-founded Sundrop Farms Holdings Limited (20%/80% share) in 2012, which holds a number of the Sundrop Farms subsidiaries, including the Australian company.

Philipp Saumweber, who had been the venture partner and Managing Director of Seawater Greenhouse Ltd, was now Sundrop's owner and CEO. A Harvard MBA and former investment banker and hedge fund manager with Goldman Sachs and King Street Capital, he had led investments across the agricultural value chain globally. Joining him was Reinier Wolterbeek, the Seawater Greenhouse engineer and water specialist, who became Sundrop's Chief Technology Officer. In 2012, they applied for a patent for the integrated Sundrop Farms system, which was granted in 2015. The registration of Sundrop Farms as a trademark in the US and Australia occurred in 2013 and 2015.

Once the system had been proven to work, the project became about assembling the necessary elements to producing crops at scale and building supply arrangements and relationships for the service to retailers and consumers.

Sundrop entered discussions with Coles, Australia's second-biggest supermarket chain with over 30% market share in national food retailing (Roy Morgan, 2016). Coles was keen to secure a reliable supply of tomatoes year-round and to address growing consumer demand, which was outstripping supply on particular varieties of tomatoes. Coles had production goals of 15,000 tonnes of tomatoes a year, including during the traditional winter supply gap, requiring Sundrop Farms to design the production and resources to match (Wagstaff, 2017; Sampson, 2016). In 2014, Coles signed an unprecedented 10-year deal with Sundrop Farms to supply 100% of its tomato crop to Coles, allowing for plans to be finalised and expansion of the existing facility to begin.

This deal provided confidence to strategic investors to help commercialise the technology and scale-up production. The South Australia Regional Development Fund provided $6 million towards the project (MENA, 2015; PIRSA, 2015). In 2013, Australia's Clean Energy Finance Corporation provided debt financing for up to $40 million of the investment (WMIN, 2015; CEFC, 2014). These public-sector investments provided a cornerstone to attracting private capital.

In December 2014, the US private equity firm Kohlberg Kravis Roberts (KKR) invested $100 million in Sundrop Farms Holdings to expand the Australian glasshouse facility and support the company's international development. KKR also acquired the AEI Ltd 20% shareholding in Sundrop Farms Holdings (AEI, 2017). KKR had been looking for agribusiness investments in Australia as part of a green initiative championing environmental innovations and funding businesses with a focus on eco-efficiency globally (Burroughs and Liu, 2014; KKR and Co. L.P., 2016). The Commonwealth Bank of Australia provided additional funding in the form of $75 m of non-recourse debt funding (Burroughs and Liu, 2014; Takahashi, 2016).

Sundrop obtained planning approval for the expansion from the Port Augusta town council in August 2014. In December, John Holland Group Pty Ltd (a Leighton company) was awarded a USD126 million (AUD200 million) design-build contract to expand the facilities to 20 ha (WMIN, 2014; WMIN, 2015).

The glasshouse expansion was undertaken in 2015 and 2016. Construction contractor John Holland Group; Aalborg CSP, a Danish renewable energy specialist; and Van der Hoeven, a Dutch company specialising in horticultural products and services, managed the construction. The Adelaide-based firm Cold Logic developed the refrigeration system for the plant (Mena, 2016). The expanded facility opened in stages, with the first tomatoes planted in March 2016 and full production ramped up in June 2017.

Meanwhile, Sundrop Farms was extending its international reach. In 2012, Sundrop Farms Holdings appointed BMG Financial Group as its financial adviser in Saudi Arabia in preparation to enter markets there (Arab News, 2012). That year Sundrop Farms Australia and the Sahara Forest Project AS signed a cooperation agreement to execute a joint programme for testing and optimisation of the Sundrop Farms technology in Qatar, aiming at large-scale commercialisation. An R&D facility and farm was built (FDI, 2013). The cooperation focused on knowledge sharing and exploring the potential for integrating the parties' technologies (Lowe, 2012).

In 2014, Sundrop opened a regional headquarters in Dubai, UAE (TradeArabia, 2014), registered as Sundrop Middle East Limited. The following year, the Ministry of Environment and Water and Sundrop Middle East Limited signed a technical cooperation contract to conduct R&D in models of protected agriculture and aquaculture in the UAE and to investigate alternative desalination systems and different cooling technologies more suited to the local climate (Government of UAE, 2015). Sundrop Middle East Limited was dissolved in 2016 (DIFC, 2017).

Sundrop Farms also built trial farms in Odemira, Portugal and Tennessee in the US, and is experimenting with growing different crops using similar technologies to those at the Australian site. Another Australian site is planned, but its development will depend on first establishing a partnership with a retailer to assess the client's requirements and then design the infrastructure around them. What crops will be grown depends on retail and consumer needs.

IMPACT EVIDENCE

The environmental, social and economic impacts of the technology currently occur at farm scale. Sundrop Farms created an agricultural system that can be profitable as well as environmentally sustainable. The company estimates 5 to 15% cost savings over fossil-fuel powered glasshouses. The operation is also not exposed to fluctuating energy costs in the market.

Sundrop has estimated its energy and pollution savings compared to traditional methods as follows (Sundrop Farms, 2016):

- Approximately 26,000 tonnes of carbon dioxide per year – equivalent to removing 500 cars from roads
- More than 450 million litres of freshwater per year – equivalent to 180 Olympic sized swimming pools
- More than 2 million litres of diesel per year – equivalent to driving a car around the equator 500 times.

Questions, however, remain about the potential of such projects to operate at a global scale. The exorbitant upfront capital costs means the system must achieve economies of scale to be viable, and production must focus on high-value crops (like tomatoes or cucumbers), which poor countries might find cheaper to import while putting the same resources to better use (Bacchi, 2017).

CONSEQUENCES

Sundrop Farms successfully proved a sustainable horticulture production system was possible in an arid climate using renewable resources, but medium to longer-term consequences of its development and spread are not yet clear. The system is said to be adaptable to be less technology intensive to suit developing countries; however, for successful implementation, a well-developed supply and retail chain is necessary to enable production to occur at sufficient economies of scale. Environmental and climate conditions also need to be appropriate. Proximity to the sea or easy access to seawater, low humidity (uncommon close to the sea), and abundant and steady sunshine are required to make the system work as currently designed.

The technology is unlikely to replace broadacre farming, however, it is already being considered for adaptation to other crops and aquaculture. The strategic partnerships and initial public investments were essential to providing confidence for large private investors to join. These investments, in turn, were essential to the growth of the company. KKR's investments extend all over the world, which provides Sundrop with opportunities to enter new markets and establish local financing, retailer, and operating arrangements much more easily. Sundrop is already exploring potential partnerships with other companies in the KKR portfolio.

Sundrop's expansion into a fully commercial operation demonstrates a high-tech, integrated solution to difficult global problems. Its partnerships to build new skills and knowledge and to trial new approaches in other parts of the world provide an example for pioneering new paradigms in agricultural production systems

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THAI POULTRY EXPORTS

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SUMMARY

In the space of two decades, the 1970s and 1980s, Thailand went from backyard poultry production to become the world's number one exporter of value-added poultry and fourth overall producer of broiler meat, with Japan and the EU as its major markets.

One Thai company, Charoen Pokphand Company, was largely responsible for introducing highly productive breeds and other advanced technologies from the US, and also modern ways of organising production, especially contract rearing and vertical integration, that were subsequently also adopted by other companies. The combination of these technological and organisational advances with rapidly increasing demand in Thailand and the Asian region, driven by strong economic growth, created the environment that enabled the very rapid growth of the poultry sector, especially export-oriented broilers, but also of layers and ducks. Exports of raw, frozen poultry started in 1973, while exports of cooked products began in 1994.

More than three decades of impressive year-on-year growth came to an abrupt end in early 2004, however, when an outbreak of Highly Pathogenic Avian Influenza (HPAI) was officially confirmed in the country. In response to the outbreak, all importing countries banned imports of raw poultry meat. At that time, 65% of poultry exports by weight was raw, frozen meat and 35% cooked products. Japan, Thailand's largest market, also temporarily banned cooked products, although later it accepted these from facilities its officials had inspected and approved.

The HPAI outbreaks between 2004 and 2008 acted as a catalyst to wide-ranging structural changes across Thailand's poultry industry driven by the large-scale export industry, importers, and the Thai government. More stringent biosecurity, food hygiene and animal welfare regulations and standards were imposed and enforced by the Thai government and importing countries. The industry underwent significant consolidation with fewer, larger integrated poultry companies emerging to dominate the export trade. These included indigenous and multinational companies. The predominant business model shifted from contract rearing to fully vertically integrated businesses that encompassed breeding farms, feed mills, rearing units, slaughterhouses and processing facilities, and domestic retail outlets and fast-food restaurants.

Responding to the ban on raw meat exports, the large integrated companies were able to access finance and very rapidly expanded their existing processing capacity; most have

already implemented the now stringently enforced enhanced biosecurity systems, which had been introduced by the Thai Government's Department of Livestock Development (DLD) in the early 2000s. Thai government policy ensures that the food industry can access cheap credit[20] through the Industrial Finance Corporation of Thailand (IFCT) and the Small Industry Finance Corporation, and farm credit from the Bank for Agriculture and Agricultural Cooperatives (BAAC). Small- and medium-sized poultry businesses struggled to adapt to the new order. Many independent farms, former contract rearers and smaller-scale processors went out of business or switched to other less regulatory demanding sectors, such as pigs and aquaculture. Free-range duck farmers had to switch to mandatory housed systems, which not all could achieve.

In 2003, the total value of poultry exports from Thailand was USD939 million.[21] Following the HPAI outbreak, in 2004 the value of exports decreased by more than 38%. Recovery in the following years was steady but the 2003 value (before the outbreak) was not exceeded until 2008. By 2016, the total value of poultry exports was more than two-and-a-half-times the 2003 figure.

In 2003, just 39% of exports by value (US$ equivalents) were cooked products; between 2004 and 2013 this proportion was over 90% and by 2016, after exports of raw, frozen poultry had resumed to the EU, Japan and other markets, it was 80%. Even before the outbreak the trend was towards a steadily increasing proportion of total broiler exports being accounted for by cooked products. Factors driving this trend include growing demand for these products in the major importing countries and rising labour costs[22] in Thailand making the shift to higher value-added products more attractive.

Although Thailand recovered well from the HPAI shock, exports of raw/frozen chicken meat did not resume to the EU until 2012 and to Japan until 2014, almost a decade later. Despite the Thai government's intense efforts to get the importing countries to accept Thailand's compartmentalisation approach (i.e. maintaining a sub-population with a different health status within the country), as allowed under OIE guidelines, the importing countries were not convinced. This was also despite OIE selecting Thailand as one of two countries to pilot the compartmentalisation approach, which included significant technical support from OIE. Thailand's compartmentalisation system is still not recognised by the EU and Japan; some commentators view this as a non-tariff barrier rather than a genuine public health concern.

One result of the strict biosecurity arrangements now in place in the Thai poultry industry is that the country is well positioned to avoid HPAI outbreaks – there has been no outbreak since 2008, despite outbreaks in nearby countries. The shift to predominantly cooked products also means that, in the event of an outbreak, Thailand will be able to continue exporting, avoiding a severe dip in exports as experienced in 2004.[23]

[20] http://www.eria.org/Chapter%209%20Thailand.pdf

[21] Based on Thai Ministry of Commerce website, www.ops3.moc.go.th/infor/MenuComen/default.asp converted into USD at rates for 1 January each year. Historic exchange rates obtained from http://fxtop.com/en/currency-converter-past.php

[22] http://www.eria.org/Chapter%209%20Thailand.pdf

[23] http://www.efeedlink.com/contents/06-08-2012/a37725a8-6c3f-4859-be8c-78ab01faa5db-a622.html

Table. Patterns of Innovation and Impact processes Summary table

Initiator	Thai poultry exporters, Thai government, governments of importing countries all responding to HPAI outbreak.
Critical features	Rapid switch from 65% raw/frozen and 35% cooked exports (by volume) to 100% cooked products. New and more rigorous enforcement of existing biosecurity, food safety and animal welfare standards and regulations. Switch from contract rearing to fully integrated vertical model. Trend towards fewer, larger-scale fully integrated poultry enterprises dominated by handful of Thai and multinational companies.
Role of research	Evidence that heat treatment destroyed HPAI viruses in poultry products. Ongoing surveillance for HPAI by DLD. Recognition that spread of HPAI to chickens correlated with presence of free-ranging ducks. Compartmentalisation approach tried but failed to gain support from major importing countries despite support from OIE.
Operational alliances	Thai poultry exporters and Thai government. Thai government and governments of importing countries. Thai poultry exporters and foreign and domestic financiers. Thai poultry exporters and Japanese and UK companies. OIE and Thai government.
Strategic alignment of stakeholders at sector or national level	Large Thai and multinational poultry exporters closely aligned to Thai government.
Solution, product, or system innovation	Switch from export of 65% raw/frozen and 35% cooked poultry products to close to 100% cooked products for duration of ban (c. 10 years).
Scope of impact (and metrics)	Thailand export broiler industry recovered from HPAI outbreak to again become 4th in the world for total chicken exports by value and the largest exporter of prepared chicken. By 2008, total value of exports had exceeded 2003 figure and by 2016 it was over 2.5 times the 2003 value. Proportion of exports accounted for by cooked products shifted from 39% in 2003, to more than 90% from 2004 to 2013, and was 80% in 2016.

CHALLENGE/OPPORTUNITY

In 2003, Thailand was the world's fourth largest exporter of broiler meat with Japan (50% of all exports) and the European Union (EU; 38%) as its major customers. Around 65% of exports by weight were uncooked frozen poultry meat and 35% were cooked products. Exports of broilers represented 40% of total production. Total exports in 2003 were worth a little under USD1 billion (USD939 million). Thailand's poultry industry had recently increased capacity from farm to processing, and was anticipating a 6% increase in broiler meat exports and a 10 to 12% increase in domestic consumption for 2004.

That situation changed dramatically with the official confirmation by the Thai government of an HPAI outbreak in January 2004. Between January 2004 and November 2008, four separate epidemic waves occurred with a total of 1,929 HPAI outbreaks officially registered in Thailand. Most outbreaks occurred between July 2004 and April 2005. An estimated 63 million birds were culled or died due to the HPAI outbreaks. The Thai Broiler Exporters Association, which represents the major exporters, estimated the total cost to the poultry industry in Thailand to be USD3.1 billion in 2004 alone

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When the HPAI outbreak was confirmed, the EU, Singapore and South Korea banned imports of Thai frozen raw poultry products while others, including Japan, Malaysia, Hong Kong and China, also banned the import of cooked products. The EU, Singapore and South Korea continued to allow imports of cooked products subject to these meeting country-specified heat treatments to kill the HPAI virus. At the time of the initial outbreak many poultry product shipments, already in transit, were returned to Thailand having been denied entry by the importing countries. Also, domestic consumption decreased abruptly, by up to 80% in the immediate aftermath of the outbreak, due to loss of consumer confidence in the safety of poultry meat.

According to Thai Ministry of Commerce data[24], the value of raw frozen poultry exports (61% of total exports) from Thailand decreased by 92% between 2003 (USD574 million) and 2004 (USD44 million), dropping even lower in 2005 to under USD14 million, less than 2.5% of the 2003 value. In early 2004, the immediate challenge facing Thailand's export poultry industry was therefore to switch from an export model based mainly on frozen poultry meat, to one based exclusively on cooked products, at least for the duration of the ban, and to convince all countries that its cooked products were safe. In the longer term, the challenge was to take the necessary measures to enable the export of raw frozen poultry to resume and to reduce the risk of further outbreaks.

In 2003, the year before the outbreak, Thailand had exported about 500,000 tonnes of poultry meat, of which 325,000 tonnes was raw frozen. At the 2003 level of production, another challenge in 2004 therefore was to process and find a market for around an additional 165 million birds a year converted into cooked products.

INNOVATION

The Thai poultry sector developed very rapidly. From small-scale, backyard production for meat, eggs and fighting birds prior to the 1970s, it became the fourth largest poultry meat exporter in the world with a 7.5% share of the export broiler market and the world's top exporter of value-added poultry by 1991.

The transformation came about as a result of the introduction of improved poultry genetics, other new technologies and contractual arrangements for rearing broilers based on US models, the impetus for which was provided by rapidly growing domestic and Asian regional demand for poultry, which in turn was fuelled by rapid economic growth. Greatly improved efficiencies of production led to sharply reduced prices relative to pork and freshwater fish, key features of Thai diets. As a result, domestic per capita consumption of chicken nearly doubled between the early 1980s and 2001. Further vertical integration followed, with large poultry integrators increasingly controlling all aspects from breeding, feed production, rearing, slaughter, processing, exporting, and retailing and fast-food restaurants for the domestic market.

Exports of frozen chicken meat from Thailand started in 1973. The industry grew fast, gaining a reputation as low-cost but technically efficient. In addition to raw frozen poultry cuts and added-value products, such as deboned thighs and breasts and skewered meat targeted mainly at the Japanese market, the Thai poultry industry started experimenting with cooked poultry products for export in the 1970s, although the first exports of pre-cooked chicken meat did not occur until 1994. The HPAI outbreaks acted as a catalyst to additional wide-ranging structural changes across Thailand's poultry industry driven by its large-scale export industry, the importers, and the Thai government.

By 2003, Thailand had been exporting pre-cooked poultry products for around 10 years. Cooked prod-

[24] Data for volumes and value of Thai poultry exports varies between sources. In this case study, values quoted come from the Thai Ministry of Commerce website, www.ops3.moc.go.th/infor/MenuComen/default.asp converted into USD at rates for 1 January each year. Historic exchange rates obtained from http://fxtop.com/en/currency-converter-past.php

ucts accounted for about 35% of exports by weight. The relative importance of cooked products had grown steadily since the first exports in 1994, mirroring growing demand in the major importing countries for ready-meals and other pre-prepared products. Also, as labour costs in Thailand grew, production of higher added-value products, such as ready-meals, became more attractive. The country therefore already had experienced and trained personnel, expertise, an understanding of the demands of its major customers, and a reputation for the quality of its existing production facilities.

Export was already dominated by a relatively small number of large-scale producers and these big businesses were able to very rapidly scale-up their production of pre-cooked poultry products. An important factor in enabling this rapid switch was that they could access new financing to invest in production lines and facilities for cooked products. The HPAI shock was, however, too much for some: before the HPAI outbreak, 22 chicken exporters were operating but by early 2005 only nine were still in business. The scale of production at the surviving integrators increased.

Prior to the outbreak, the predominant business model was contract rearing: the large integrated poultry companies supplied independently owned broiler farms with day-old-chicks, feed and medicines. At the end of the production cycle, the birds were bought back at a guaranteed price. This model had played a critical role in the industry's rapid growth, reducing risk to the poultry producers and ensuring continuity of supply to the processors. After the outbreak, with increased emphasis on biosecurity, food safety and animal welfare and handling, it became increasingly important to be able to control the entire production process. The major poultry companies therefore increasingly switched to fully vertically integrated operations. This also enabled them to implement the now mandatory traceability systems throughout production and processing and to enforce the biosecurity, food safety and animal welfare standards deM&Ed by the Thai government and the major importers, especially the EU and Japan. The integrated model also delivered productivity improvements.

INNOVATION PATHWAY

One local Thai company was at the centre of the transformation of the Thai poultry industry, Charoen Pokphand Company (CP). CP was established in 1921 in Bangkok by two Chinese immigrant brothers selling seeds and vegetables. Later, in the late 1950s, the company diversified into animal feed production before undertaking forward integration to include poultry production. Today, the CP group is one of the world's largest multinationals with over 500,000 employees worldwide in three main sectors: food, retail and telecommunications. The food division had total sales worth almost USD14 billion in 2016, accounting for about one-third of the group's total revenue.[25]

In the early 1970s, CP established a modern chicken breeding business in a joint venture with the US poultry giant Arbor Acres. As demand continued to increase, the company introduced other modern production technologies and approaches based on US production models, including contract rearing.

Perhaps in part to avoid conflict with Thailand's small-scale poultry traders in the domestic market, CP successfully lobbied the government for permission to build an export-oriented slaughterhouse, which was opened in 1973. The government also created tax incentives to encourage the sector's development as part of a broader package of supportive regulation and trade liberalisation.

Other companies followed CP's lead and adopted similar approaches, often with capital supplied by foreign investors, especially from Japan. With strong regional demand in Asia, especially during the period of rapid economic growth between 1985 and 1995, and increasing demand from Europe during the 1990s, production and exports increased rapidly.

[25] https://www.thailand-business-news.com/corporate/54158-charoen-pokphand-group-thai-empire-chinese-roots-global-vision.html

Following confirmation of the HPAI outbreak in Thailand, all importing countries imposed bans on raw and frozen poultry and some, including the major market of Japan, also banned cooked products. Building on existing capacity, knowledge and skilled labour, the large export poultry companies were able to quickly organise financing to facilitate expansion of their poultry processing plants. It was also reported that creditors were flexible to assist financially troubled enterprises and in some cases refinancing was successfully negotiated to enable them to cover cash flow needs.

An important factor that gave CP an advantage in the switch to cooked products was its relationships with major companies in Japan and the UK.[26] The company's partnerships with Japanese importers meant that CP had access to information on the types of cooked products and the food safety standards that were deM&Ed. Meanwhile, CP's partnership at that time with the UK supermarket giant Tesco, through the Tesco-Lotus supermarkets in Thailand, facilitated access to the ready-to-eat chicken product market in the UK and also helped increase its capacity to meet demanding UK animal welfare standards.

The demand for cooked poultry products followed on from a series of technological advances and social changes between the 1940s and 1980s which influenced the way people live and eat, first in the West and increasingly throughout the more prosperous parts of the world: increasingly they deM&Ed more convenience, higher quality and more choice. In relation to ready-made poultry products, the 'invention' of the chicken nugget in the 1950s, and its popularising by MacDonald's from 1979 onwards, was a game-changing event. In the UK, another game changer was the launch of chilled rather than frozen ready-meals, the first of which is considered to be Marks and Spencer's chicken Kiev, introduced in 1979 and meeting a new demand for fresher, higher-quality convenience products. The UK market for chilled ready-meals is now worth GBP2.6 billion a year.

Thailand's focus on added-value poultry products differentiated it from its major competitor in the global poultry export market, Brazil, which focused on export of whole frozen birds and cuts. The rapid expansion and differentiation of Thailand's poultry industry was enabled by a number of advantages the country enjoyed, including low-cost and high-skilled labour, which was critical to production of deboned meat and other added-value products, ample supply of domestically produced feed grains and fishmeal, close proximity and therefore low transport costs to the key market of Japan, streamlined vertical integration and strong involvement of Japanese companies, especially in processing and overseas distribution. Later, as Thai labour costs increased, the shift to higher value-added products, such as cooked products, became an increasingly attractive option.

After the HPAI outbreak, Japan initially banned all poultry imports from Thailand. However, an agreement was soon reached between Thailand and Japan which entailed permits issued by Japan on a plant-by-plant basis. As a result, from February 2004, 22 plants received permits, allowing them to resume exports of cooked poultry products to Japan. It was reported that many of these plants were joint venture operations with Japanese investors.

The Thai government played a key role in the recovery from the HPAI outbreaks and its policies helped shape the way the country's poultry industry developed in its aftermath. Greater emphasis was placed on strict biosecurity, traceability of products and certification. Although the Thai DLD had introduced new standards for export poultry farms in 2000, these were more rigorously enforced after the 2004 outbreak. Among new measures introduced after the outbreak were screening of birds for disease before and after they were caught prior to slaughter and a certification process for processing plants. With increased emphasis on biosecurity, and also to meet the requirements of major importers for poultry produced without the use of antibiotics, there was also a shift from treating disease to

[26] http://www.eria.org/Chapter%209%20Thailand.pdf

preventive approaches. Another regulatory change imposed in that respect by the Thai DLD was that farms were not allowed to restock with day-old-chicks unless they had closed rearing sheds: previously open-sided poultry houses were allowed which enabled natural ventilation but exposed poultry to the risk of contact with potential sources of infection, especially migratory wild birds. This necessitated a shift to climate-controlled housing which was achieved with evaporative cooling systems consisting of large fans and water sprinklers that can maintain temperatures below 30 °C.

The regulations and policies introduced by the Thai government are widely regarded as being in favour of the large-scale integrated companies. Many of these companies already largely complied with the more stringent requirements whereas the smaller producers were faced with the need to invest to meet the new standards. In the case of the remaining contract rearers, they either had to upgrade to meet the new standards or lose their contracts.

Thai government policy measures introduced in 1995[27] to support agri-food businesses included tariff exemptions for imported raw materials, improved procedures for claiming tax rebates, tariff reforms, promotional and assistance measures for export goods, registration of foreign migrant workers, and trade negotiation for market access with important trading partners. Thai government policy also ensures that the food industry can access cheap credit through the Industrial Finance Corporation of Thailand (IFCT) and the Small Industry Finance Corporation, and farm credit from the Bank for Agriculture and Agricultural Cooperatives (BAAC). This is part of the government's broader policy aim to promote Thailand as the 'Kitchen of the World', including promotion of Thai cuisine abroad, and to be among the top five exporters of food products with emphasis on safety, health and hygiene.

The Thai export poultry industry is well organised and politically sophisticated with close personal and business links with policy makers. This means the industry is well placed to influence government policy, especially in the interest of the large-scale integrated producers. For example, the industry was vehemently opposed to vaccination against HPAI in any sector. It also lobbied successfully to maintain domestic consumption through a campaign to convince Thai consumers that poultry products were safe. At the time of the outbreak, domestic consumption accounted for 60% of total production by weight. During 2004 and 2005, in an attempt to win back domestic chicken meat and egg consumers in Thailand, many of whom had switched to pork and fish, the government and private sector mounted an intensive campaign consisting of giveaways, aggressive public relations and price discounting. Following decreases in domestic consumption in 2003 and 2004, consumption started to grow again from 2005, although the 2002 figure was not exceeded until 2008, since which growth has again been strong.

Another example of the influence of the export poultry industry concerned a problem they faced importing day-old-chick breeding stock. The DLD's policy from 2000 was to audit individual farms and slaughterhouses in exporting countries before they could export breeding chicks to Thailand, although this requirement was only implemented in September 2005. In response to lobbying from the Thai Broiler Processing Export Association, the DLD unofficially waived this requirement soon after it was implemented, which overcame the shortage of grandparent and parent stock and allowed local production of day-old chicks to keep pace with growing demand.

One invention that did not succeed in Thailand was the then new concept of compartmentalisation. Recognising that it would be difficult in some cases to maintain disease-free status for a whole country, in 2005 the OIE introduced the idea that a sub-population of birds within a country could have a different health status. OIE define a compartment as: *'one or more establishments (premises in which animals are kept) under a clearly defined common biosecurity management system containing an an-*

[27] http://www.eria.org/Chapter%209%20Thailand.pdf

imal sub-population with a distinct health status with respect to a specific disease or diseases for which required surveillance, control and biosecurity measures have been applied for the purposes of disease control and/or international trade'.[28] In 2008, the DLD introduced a compartmentalisation system whereby large-scale poultry farms or clusters of such farms could be treated as a compartment. Specific disease surveillance and prevention measures are carried out within a buffer zone of 1 kilometre around the farms in these compartments. These include routine clinical surveillance and sampling of birds through cloacal swabs.

The Thai government lobbied the EU and Japan to allow the resumption of exports of frozen raw poultry meat from compartments that could demonstrate freedom from disease and the requisite biosecurity and other measures. This approach was, however, not successful. The EU only lifted their nationwide ban on frozen raw poultry in July 2012, with Japan following suit in December 2014, close to 10 years after the ban first came into effect. The situation was not helped by the widely held view that the Thai government initially suppressed information about the outbreak of HPAI; although officially reported in January 2004, it is believed to have begun in November 2003. It has been speculated that the government was influenced by the poultry exporters to suppress announcing that HPAI had been detected. The eventual announcement of the HPAI outbreak in Thailand coincided with the announcement of the first human cases.

To date, Thailand's compartmentalisation approach has not been recognised by the EU or Japan, although some Middle Eastern countries [29]have allowed imports of frozen, raw chicken from Thailand under its compartmentalisation arrangements. More broadly, there are very few examples globally where an exporting country's compartmentalisation system has been recognised by importing countries.

Timeline.

1921	CP established in Bangkok selling seed.
1954	CP diversify into animal feeds, opening its first feed mill in 1954, and later livestock production.
1970s	Modern broiler technologies introduced in Thailand by CP through joint venture with Arbor Acres.
1973	First export slaughterhouse opened in Thailand; first batch of frozen/raw chickens exported to Japan.
1990s	Evaporated cooling houses for broilers introduced.
1994	First cooked poultry products exported from Thailand.
2003	Thailand is number four in the world for total chicken exports by value and the largest exporter of cooked poultry products.
December 2003/January 2004	H5N1 virus identified in tigers and leopards that died in Thai zoo and had been fed on fresh chicken carcasses.
January 2004	After initial denials, HPAI outbreak confirmed by government in Thailand. Bans imposed on import of raw but not cooked poultry by EU and, initially, of all poultry by Japan.
2003–2008	HPAI outbreaks occur in Thailand with peak in 2005.
July 2012	EU lifts ban on raw chicken imports from Thailand.

[28] http://www.oie.int/fileadmin/Home/eng/Publications_%26_Documentation/docs/pdf/TT/2014_AME2_Kahn_A.pdf
[29] http://discovery.ucl.ac.uk/1348547/1/1348547.pdf

2012	Thailand is again number four in the world for total chicken exports by value and the largest exporter of prepared chicken.
January 2014	Japan lifts ban on raw chicken imports from Thailand.
December 2016	South Korea lifts ban on raw chicken imports from Thailand.

IMPACT EVIDENCE

The average broiler farm size increased gradually from the 1970s but then increased rapidly in the 1990s. This was partly because new technologies, such as evaporative cooling for poultry houses, were more suited to larger production units. Small-scale poultry farmers found it increasingly hard to compete with the larger and more efficient producers. They also found it harder to sell their birds as the traders preferred to deal with the larger producers to enjoy economies of scale.

The overall impact of the response to the HPAI outbreak in Thailand has been that the country has recovered from the initial shock and, after an initial dip in exports, is continuing to experience dynamic growth.

In 2003, according to data obtained from the Thai Ministry of Commerce website, exports of prepared (heat treated) chicken accounted for 39% of poultry meat exports by value. In 2004, this increased to 92%, at the same time as the total value of poultry meat exported decreased by 38%. Between 2004 and 2013, exports of prepared poultry made up more than 90% of total value of exports; by 2016, this proportion was 80%, by which time the value of chilled and frozen cuts was still less (29% less) than the 2003 figure (Table 1).

The value of poultry meat exports, chilled/frozen and prepared, stayed below the 2003 value (c. USD939 million) until 2008. By 2016 it had grown significantly and was 263% of the 2003 value (just under USD2.5 billion). By 2012, production of broilers exceeded the 2003 level. In the same year, Thailand was again number four in the world for total chicken exports by value and the largest exporter of prepared chicken.

Table 1. Value of poultry exports from Thailand, 2003–2016 (millions)

Year	Chilled or frozen poultry cuts, value THB	Prepared poultry, value TBH	Total exports, value TBH	Total exports, value USD million	Prepared poultry as % total value	% of 2003 value USD
2003	24,767	15,704	40,471	939	39	100
2004	1,749	20, 821	22,875	578	92	62
2005	536	27,339	27,875	716	98	76
2006	595	28,706	29,301	713	98	76
2007	1047	31,983	33,030	930	97	99
2008	1335	50,275	51,610	1,734	97	185
2009	1582	47,264	48,846	1,408	97	150
2010	1876	50,346	52,222	1,568	96	167
2011	3248	56,981	60,229	2,003	95	213
2012	5880	61,871	67,751	2,139	91	228
2013	6330	60,470	66,800	2,184	91	233

Year	Chilled or frozen poultry cuts, value THB	Prepared poultry, value TBH	Total exports, value TBH	Total exports, value USD million	Prepared poultry as % total value	% of 2003 value USD
2014	12,650	61,315	73,965	2,258	83	240
2015	14,334	66,856	81,190	2,470	82	263
2016	17,581	71, 532	89,113	2,472	80	263

Source: Ministry of Commerce, Thailand website, accessed 5 July 2017[30]
Conversion from Thai baht to USD based on rates for 1st January each year obtained from
http://fxtop.com/en/currency-converter-past.php

Measures introduced in response to the HPAI outbreak led to further concentration of poultry production. A telephone survey carried out in 2007, in which farmers known to have produced broilers in 2003 were asked whether they were still in the business, found that 29 percent of the farmers that could still be contacted (49%), had given up broiler production. A similar survey among farmers that had kept layers in 2003 revealed that 44 percent had switched to other activities (NaRanong, 2007).

Domestic consumption of chicken in Thailand increased steadily from 1990 (8 kg per capita) to 2003 (14 kg per capita). In response to the HPAI outbreak consumption dropped in 2004 (10 kg per capita), but recovered to near pre-outbreak levels by 2005, suggesting the government's campaign to support domestic consumption had succeeded.

CONSEQUENCES

In the immediate aftermath of the HPAI outbreaks and the ban on export of raw frozen poultry, high stocks of chicken meat built up. However, by 2006 the stocks had been absorbed as capacity to process chicken meat into cooked products for export was rapidly scaled up. In 2006 there was around 30% unused capacity on broiler production farms. This capacity, however, was soon brought back into production enabling the broiler integrators to meet growing domestic and international demand.

At the time of the HPAI outbreak, some large integrated poultry companies had only recently completed full integration of their farm and processing capacity, and had borrowed heavily to finance this. Most small and medium scale export-oriented businesses focused mainly on raw frozen products prior to the outbreak; they had to either switch to production of cooked products or go out of business. The more demanding regulations and standards introduced after the outbreak, which were costly to implement, the shift from contract rearing to fully integrated poultry enterprises, and the shift to cooked products resulted in further consolidation of the sector. Prior to the HPAI outbreak, 22 chicken exporters were operating but by early 2005, only nine exporters were still in business, all of them large-scale integrators. Currently, just five companies, some local Thai and some international, dominate the export market – together they account for 70 to 75% of exports, with one company alone, CP, accounting for 29% of total production.

One consequence of consolidation of the market, the shift towards integrated production and the adoption of new technologies and practices, such as climate-controlled housing and enhanced biosecurity, is that productivity has improved. Comparing 2017 with the year 2000, average slaughter weights have increased from 2.0–2.1 kg to 2.3–2.4 kg, days to slaughter have decreased from 49 days to 40–42 days and the feed conversion ratio has improved from 1.9–2.0 to 1.6–1.7, all of which contribute to increased profitability. However, installing the climate-controlled systems and instigating strict biosecurity, food safety and animal welfare

[30] http://www.ops3.moc.go.th/infor/MenuComen/default.asp

standards was costly – the cost of constructing a closed housing system for 10,000 birds has been estimated at around USD32,000 and installing an evaporative cooling system over USD8,000. Small and medium independent producers were especially hard hit; those who previously reared under contracts from the large integrators found it hard to get loans needed to make the necessary improvements without the security provided by contracts. Some switched to pig production or aquaculture while others exited the livestock sector altogether.

The shift to greater reliance on cooked versus raw/frozen poultry exports means that Thailand is now less vulnerable to loss of export markets in the event of another disease outbreak compared to countries that export only or mainly raw poultry. With its current HPAI-free status and no outbreak since 2008, higher standards of biosecurity and a compartmentalisation model now being implemented, Thailand also stands to benefit when other exporting countries are closed down due to disease outbreaks.

Most HPAI outbreaks occurred in native chickens, ducks and laying quail and chickens. The Thai government's response to outbreaks consisted of a stamping-out policy: affected and potentially exposed birds were culled and their owners compensated. Compulsory registration was introduced for free-ranging poultry, including ducks; owners of fighting cocks and the stadia where the fights were staged also had to register. In early 2004 there were an estimated 10 to 11 million free-ranging ducks in Thailand. Free-ranging ducks were herded in rice paddies and moved by truck between sites when the food supply was depleted. Health investigators in Thailand realised that there was a high correlation between the presence of free-ranging ducks and the spread of HPAI to chickens. In closed systems with high biosecurity standards, no infections were detected in ducks but HPAI virus was prevalent in the free-ranging birds. Often the infected ducks showed no signs of disease: the transporting of these 'silent carriers' around the country was therefore a high-risk means of spreading the disease widely. In response, the government made housing ducks compulsory. To facilitate this, the government ordered the Thai Bank of Agriculture and Agricultural Cooperatives to make cheap loans available to finance barn construction.

According to FAOSTAT data, duck production was already declining before the outbreak: production peaked at 112,500 tonnes in 1998, declined to 93,077 by 2002, fell further to 69,824 in 2003, and by 2013 was 89,897 tonnes, less than 80% of the peak figure. Most production is for domestic consumption. In 2000, 8832 tonnes of fresh and frozen duck meat were exported, steadily reducing to just 2225 tonnes in 2012 (around 2% of total production). This goes against the global trend, which saw total duck production increase by about one-third between 2000 and 2013. Given that the trend was downwards before the outbreak, it is difficult to assess the impact of the introduction of compulsory housing on the duck sub-sector.

The perceived lack of transparency by the Thai government in confirming the HPAI outbreak damaged its reputation and resulted in a lack of trust. Officials from the EU and Japan carry out annual audits of the Thai poultry production system. The DLD, as the competent authority, supervises and controls the whole production system to ensure safety and compliance with importing country requirements. Individual poultry exporters also have to comply with private standards imposed by specific customers; these cover aspects including animal and worker welfare.

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