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A Model Innovation: Improving Disease Management for Meeting the Challenges of Bangladesh's Aquaculture Hatchery Sector

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Abstract

Reducing disease within shrimp and prawn production is a key policy aim for Bangladesh's export aquaculture. Hatcheries that supply the farms with seed — or larvae — are potential hotspots for disease and the production of antimicrobial resistance traits. Disease pathogens and antibiotic resistant bacteria or genes can easily be transferred to farms via infected larvae. Efforts to reduce disease and transmission have focused on testing all hatchery output, improving hatchery production techniques and management practices, and generating markets for pathogen-free seed. Whilst the intrinsic value of the innovations for reducing disease and improving quality appeared evident, uptake of improvements in the hatcheries has been low. Disease remains a key production challenge, and despite some evidence of reduction in antibiotic use, antibiotics remain a necessary component of disease control. To test the viability of the new technologies and management practices we have developed a sociotechnical method of analysis, inspired by Actor Network Theory. The method utilizes interessement to analyse the role different actors/actants play in determining the destiny of the hatchery production innovations. Our approach has highlighted how the multifaceted socioeconomic and biological elements of hatchery production combine to create a weak innovation and investment environment. We therefore advocate the development of models that combine social and technical analysis for the purposes of assessing the viability of an innovation and improving the prospects of successful implementation.

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Andrea Butcher is a postdoctoral researcher in Sociology at the University of Helsinki, working with a multidisciplinary, international consortium generating knowledge on antimicrobial resistance in West Africa (AMRIWA). Prior to joining the University of Helsinki, she acted as postdoctoral researcher in Human Geography at the University of Exeter for the project Production Without Medicalisation, examining the socioeconomic conditions driving antibiotic use in shrimp and prawn farmers in Bangladesh. An anthropologist by training, Dr Butcher's expertise lies broadly in ethnography and development studies, focusing upon themes of environment, climate and development. Her work is influenced by Science and Technology Studies.

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Steve Hinchliffe is a Professor of Human Geography and the Director of the Wellcome Centre for Cultures and Environments of Health at the University of Exeter. Professor Hinchliffe is an expert in public health and risk, with a focus upon livestock industries. His research draws together insights from Science and Technology Studies (particularly actor network theory) and Geography. Professor Hinchliffe is an elected Fellow of the Academy of Social Sciences and author and editor of numerous books and articles on issues ranging from risk and food, to biosecurity, human-nonhuman relations, and nature conservation.

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Introduction

Population growth and rising consumer expectations are fuelling demand for nutritious, protein-rich food from terrestrial and aqueous systems. This demand coincides with numerous production challenges, including unstable climates, ecological degradation, land constraints, economic uncertainty, and disease evolution. The threat of emerging, re-emerging and endemic diseases, as well as the potential risks posed by antimicrobial resistance (AMR), are particularly acute across the livestock-farming sector (FAO, 2018; Hinchliffe et al., 2016; Lowe, 2010). With an estimated 70% to 80% of antimicrobials used to treat and prevent infections in livestock production and aquaculture (Van Boeckel et al., 2015; Zhang et al., 2015), these sectors are being targeted for innovation in disease control and biosecurity to reduce the disease burden and prevent unnecessary antibiotic use. This includes aquaculture, the fastest growing food-producing sector globally in the wake of exhausted sea stocks and a collapsing capture industry (FAO, 2016: 149). More than 50% of the fish and shellfish consumed globally is derived from aquaculture, and almost 90% of global production is located in South and Southeast Asia (ibid.: 23). Alongside nutritional gains, aquaculture provides income and livelihood opportunities for rural populations and generates foreign currency reserves for emerging economies (ibid.). However, the emergence and evolution of production diseases in intensive farming systems has had devastating consequences across Asia, particularly for shrimp production (Stentiford et al., 2017), potentially increasing the dependence on antimicrobials to secure production (Cabello, 2006; Henriksson et al., 2017; Thornber et al., 2019). As a result, innovation in aquaculture is now directed towards increasing production, whilst simultaneously improving management practices and reducing the disease burden (Joffre et al., 2017).

In this paper, we focus on aquaculture production in Bangladesh and industry attempts to innovate in response to disease threats. Bangladesh is one of the most densely populated countries in the world, with 1,260 people per km^2 in 2018. In recent decades, rural development and food production in Bangladesh have shifted from rice to broiler poultry and aquaculture (finfish and shellfish) production (Belton et al., 2012; Hensler, 2013; *The Economist*, 2018). The latter now surpasses capture fisheries in terms of production volumes and supply of dietary protein (Belton et al., 2011; Stentiford et al., 2017). In 2016-17, Bangladesh exported 40,000 mt of high-value shrimp and prawn, generating US$450M in export earnings (DoF, 2017). In 2013-14, these figures were closer to 48,000 mt and US$550M (ibid.), indicating a decline in production and a reduction in global market prices.

The results and analysis presented in this paper form part of a wider project examining antibiotic use in Bangladesh's export-oriented shrimp sector, and to a lesser extent the prawn sector. Bangladeshi farmers currently cultivate native Black Tiger Shrimp (*Penaeus monodon*, B. *bagda*), and Giant Freshwater Prawn (*Macrobrachium rosenbergii*, B. *golda*), which are primarily exported to the European Union, the USA and Japan. Whilst a few of the farms operating in the coastal regions of the southwest are semi-intensive, approximately 90% of shrimp and prawn farms are small in scale and operate traditional or improved extensive production systems. They face several challenges, including those relating to disease (Akber et al., 2017; Paul and Vogl, 2011). The paper's focus of analysis is industry attempts to reduce disease burden and any associated reliance on antimicrobials by introducing biosecurity and seed quality innovations in the numerous hatcheries and nurseries that supply those farms with seed. Hatcheries are an under-studied area in aquaculture research which instead looks primarily at small-scale or 'traditional' farming systems and opportunities for organic production (Akber et al., 2017; Belton et al., 2012; Hensler, 2013; Paul and Vogl 2012). However, hatchery-reared seed are carriages for disease transmission onto farms, where antibiotic use in Bangladesh's export aquaculture facilities is concentrated. A key policy aim in Bangladesh has therefore been to improve hatchery management practices and seed quality, and in so doing to prevent disease outbreaks on farms, thereby increasing yields for farmers. Policy is implemented with the support of externally funded, locally delivered technical programmes.

This paper examines the outcomes of one such programme, Agriculture for Income and Nutrition (AIN), a

USAID-funded programme designed to improve seed quality by introducing new biosecurity technologies and genetically improved breeds, and establishing Best Management Practices (BMP) geared towards seed testing in Bangladesh's shrimp and prawn hatcheries. Despite the apparent productivity and commercial benefits for businesses of adopting these new innovations, uptake has remained low. In 2017, we conducted a study of shrimp and prawn hatcheries to assess the reasons why this is so, the results of which we report here. The study included a survey of hatchery facilities and their operations, supplemented by qualitative interviews with managers and technicians, and analysis of evidence presented in programme reports and scientific articles addressing matters for hatchery operations in Bangladesh. Our analysis of this material demonstrated how the commercial viability of the innovations was undermined by practices and interests of actors/actants and commercial players in the wider ecology of shrimp and prawn production in Bangladesh. To understand the influence that these various actors/actants have on the hatchery industry, we developed a sociotechnical method of analysis based on *interessement*, a concept deployed in Actor Network Theory (ANT) for ascertaining the roles of different actors/actants in the formation of an actor-network or sociotechnical assemblage. Our approach, developed from Akrich et al.'s 2002 analysis of innovation as a sociotechnical process, draws attention to the diverse social and material interactions, supply chain actor practices, and industry actors' risk perceptions that determine the outcomes of the technical innovations and investment in BMP compliance in Bangladesh's food production ecology.

The article proceeds as follows: the next section lays the foundation of our *interessement* method of sociotechnical analysis by reviewing social science and industry critiques of technical interventions in food production and disease management. We then lay out our methodology before sketching the history of Bangladesh's hatchery sector and the challenges encountered that led to the AIN programme. We then present the results of our sociotechnical analysis of the programme's innovations, which demonstrate how their commercial viability was undermined by unsupportive market dynamics and biological impediments. Finally, we discuss the value of combining a technical analysis of innovation with *interessement* for identifying matters to be considered and resolved in the wider ecology production practices, in this case shrimp and prawn production practices.

Towards A Sociotechnical Analysis

The high disease burden in livestock and aquaculture sectors has boosted the research and design of technical innovations to improve farm biosecurity, delivered through programmes aimed at improving compliance with best practices. For decades, ethnographic studies examining the social relations of food production systems have drawn critical attention to the unintended outcomes and failures of agricultural and food production interventions that foreground scientific and technical transfers without considering social and institutional contexts (Ferguson, 1994; Lewis, 1997; Mosse, 2001; Scoones and Thomson, 1994). Broadly taking aim at the normative model of implementing 'technical solutions' to solve socially determined problems, they focused their critique on the consequences of poor appreciation of the social or cultural dynamics and complex local conditions at the planning stage of development interventions, detailing how multifaceted social and material contingencies influenced the way technologies were received and applied.

Researchers in the social sciences and humanities have offered similar critiques in the field of global health (e.g. Biehl and Petryna 2013; Farmer et al., 2013), seeking out complementary models for understanding the social complexity of pathogenicity that go beyond contagion or contamination approaches. Leach and Scoones (2013) draw attention to the dangers of relying on a single model that may be unable to fully capture outbreak dynamics and alternative, policy-relevant management perspectives. They call instead for an approach to disease modelling that combines sociological and ecological as well as mathematical and epidemiological perspectives. Such a relational or configurational disease model (Leach et al., 2010; Rosenberg, 1992) can demonstrate how disease and its management are configured in specific socioeconomic and material contexts, risk management strategies, and mundane interactions (Brown and Kelly, 2014; Hinchliffe et al., 2016; Høg et al., 2018). Whilst the contamination model emphasises pathogen containment, surveillance and boundary maintenance, in the configurational model the presence of pathogens are but one component in a complex process involving matters of geography, sociology and risk.

Likewise, when innovating for disease management, prospects for successful implementation are reduced if innovations are developed using perspectives provided by a narrow technical analysis of a technology's intrinsic properties. Akrich et al. (2002a; 2002b) refer to this model of innovation as 'diffusion'. Similarly, in their review of innovation approaches in global aquaculture in the Global South, Joffre et al. (2017: 132) found the "linear diffusion and adoption model" of technology transfer to be the dominant approach, focused on improving productivity and financial returns through capacity building and education (ibid.: 135). They argue that aquaculture innovation research, driven by researcher-led knowledge transfer, and offering limited user feedback, "remains linked to development project interventions at farm level [that] fails to integrate institutional context and policies" (ibid.: 140). They go on to state that if these approaches are to gain purchase, more attention must be paid to social relations and institutional challenges, calling for an alternative approach that "could be integrated in […] technology-driven research to better illustrate what needs to be implemented *beyond* technology to enable innovation and co-evolution between technology and context" (ibid.: 145, emphasis added).

Responding to this critique, we suggest an approach to innovation planning inspired by ANT and Science and Technology Studies (STS): a sociotechnical method of analysis based on *interessement*. First applied by STS scholar Michel Callon (1986) in his analysis of a novel strategy for domesticating scallops off France's Brittany coast, *interessement* refers to the ongoing assembly of allies (human and nonhuman) required to stabilize a sociotechnical network or an assemblage. Akrich et al. (2002a; 2002b) further advanced that whilst the diffusion model emphasizes an innovation's intrinsic qualities that are technological in nature, it is the *interessement* model which evaluates the capacity of the innovator or research team to connect with actors, intermediaries and use environments upon whose participation the fate of the innovation rests. This proves difficult if the innovation does not fit the context. Thus, they argue, the success of an innovation rests upon being responsive to the interests and expectations of these allies, intermediaries, and use environments, and the challenges that they raise.

In terms of biosecurity innovations, this means examining the underlying models that are used to analyse and respond to the presence of pathogens, or for explaining disease outbreaks, to understand their shortcomings. For example, as stated above, whilst the contamination model favours technical solutions (promoted by diffusion), a configurational model analyses how disease and its management are configured in socioeconomic and material contexts, risk management strategies, and mundane interactions (which requires *interessement*). This was the method of analysis we applied to our survey and interview data, and associated article review. Our results highlighted the economic, institutional and environmental dynamics underpinning the operation of Bangladesh's hatchery sector, which operate beyond the scope of technical solutions alone. In the following sections, we highlight the multifaceted socioeconomic, market, and biological elements of Bangladesh's food production ecology that need to be considered if seed testing and quality improvement innovations are to gain purchase. First, we detail our methodology.

Methodology

This article draws upon data from the project *Production Without Medicalization*, designed to assess the socioeconomic and risk-related drivers of antibiotic use in Bangladesh's shrimp and prawn aquaculture sector. The data were collected primarily during a fieldtrip undertaken in March 2017, and a survey of hatchery characteristics conducted in June 2017. We augment the results of the hatchery study with interviews and discussions with farmers, seed traders, and AIN officials during a further fieldtrip in October 2017, as well as results presented in reports and articles associated with AIN and Bangladesh's shrimp and prawn hatchery sector and grow-out farms.

During the initial trip, the research team conducted semi-structured interviews with eight hatchery technicians and five hatchery supply shop owners in Cox's Bazar and around Khulna City in southwest Bangladesh (see Figure 1). Interviews lasted between 30 and 45 minutes and were used to gain a working sense of the key issues for the sector, including production challenges, processes, treatments, and any recent changes. A member of the research team familiar with the sector facilitated interviews, which were conducted in both Bangla (Bengali) and English. Given the mix of language and often simultaneous translation in the field, the interviews were not recorded and transcribed. Instead, researchers kept detailed notes and checked these with participants to ensure an accurate account of the issues discussed.

Figure 1: Map of Bangladesh, showing Cox's Bazar in the southeast where the shrimp hatcheries are located; and Khulna Division in the southwest where the farms and prawn hatcheries are located.

The team used the interview data to design a survey questionnaire that included questions on hatchery characteristics, productivity, threats to production, and economic performance. After piloting with two hatchery technicians, the questionnaire survey was implemented face-to-face in May 2017 with 15 shrimp hatcheries in Cox's Bazar (approximately half of all operational hatcheries), seven shrimp larval rearing and nursery centres in the southwest, and four prawn hatcheries (all those attempting production in 2017) also in the southwest. Given the limited size of the survey and our method of sociotechnical analysis, the compiled results were analysed qualitatively, though where appropriate we present summary descriptive results in numerical form.

Our sociotechnical method of analysis, based on *interessement*, was developed through an iterative process of close reading of survey results, field notes, interviews, and the programme reports. Codes were compiled according to key themes of market and investment challenges, biological complications, and compatibility with grow-out farming systems. We structure our results accordingly before returning to the research questions and our suggested approach towards a resolution, in the discussion section.

Bangladesh's Shrimp and Prawn Hatchery Production

Hatcheries are cultured systems of aerated tanks and water filtration that recreate aquatic habitats for hatching and nursing fish and crustacean seed or postlarvae (PL). They operate by taking either wild-caught or specifically bred broodstock and inducing them to reproduce. Suboptimal culture environments are a primary source of broodstock and PL stress, rendering them highly susceptible to production diseases. Therefore, avoiding disease requires technicians to manage stress and monitor culture environments. Probiotics, biocides and, at times, antibiotics are utilized to this end.

Bangladesh's shrimp hatchery sector began expanding in the 1980s. There are currently around 35 operational facilities (60 if we include non-operational facilities), mainly located in the southeast of the country close to Cox's Bazaar. They aim to supply seed to over 200,000 shrimp and prawn aquaculture ponds, located mainly in Khulna Division, in the southwest of the country (see Figure 1).

The hatcheries were originally established with financial support from Asian development banks to supply 21 intensive shrimp farms operating in the Cox's Bazar region during the 1980s (Debnath et al., 2015: 3). In the early 1990s, an outbreak of a lethal and highly contagious disease called White Spot (associated with the

White Spot Syndrome Virus, WSSV, a viral infection lethal to paneaid shrimp) devastated shrimp farming in Bangladesh. Exposed to the greatest risk, the intensive farms collapsed, leaving the hatcheries to re-orient their market to the largely extensive shrimp farms in Khulna Division. Unlike the intensive, industrialised production of PL, these farms are heterogeneous in terms of size and feeding regimes, and often incorporate integrated or alternated rice production, polyculture and multiple cropping as methods for distributing economic risk (Hinchliffe et al., 2018). The farms initially relied on wild seed collected from rivers and mangrove wetlands. Indiscriminate collection of wild PL was however linked to ecological degradation of riverine habitats (Akber et al., 2017; Paul & Vogl 2011). In 1999 the Government of Bangladesh's Department of Fisheries (DoF) therefore banned their collection in order to protect riverine ecologies, prevent disease cycling from estuaries to ponds, and possibly also as a means to increase the commercial viability of the domestic hatcheries.

The prawn hatchery sector developed later in the 1990s when the Bangladeshi NGO, BRAC, opened its first facilities. Despite the high commercial value of prawn on the global market, prawn hatcheries did not receive overseas financial investment or technical backing, and relied instead on financial support from private enterprises and regional NGOs. Compared to shrimp, juvenile and mature prawn are more disease resilient in grow-out phases. However, hatchery-reared prawn PL are highly susceptible to disease, resulting in considerable production difficulties in the hatcheries (Hossain et al., 2016).

A particularly critical point in seed production is the introduction of broodstock to the hatchery. The shrimp hatcheries rely principally on shallow water wild-caught broodstock from the Bay of Bengal. The presence of WSSV tends to be high in these warmer shallow waters, with 65% of landed stock testing positive for the virus during May and June when sea temperatures rise (Debnath et al., 2014; Iqbal et al., 2011). White Spot and other diseases not only affect hatchery performance, they also pose significant risks to farmers as pathogens can be vertically transmitted to their spawn, and passed to grow-out ponds via infected PL (Debnath et al., 2014). All prawn broodstock are wild-caught from nearby rivers, with similar issues for production success and disease transmission to ponds (Ahmed, 2008).

Improvements and Innovations

The threat of hatchery disease and pathogen transferral prompted a number of responses and joint policy initiatives involving the DoF, international aid organizations, and private investors. These included investment in improved biosecurity innovations, broodstock genetic enhancement, and schemes for the testing and accreditation of seed. This led to the 2011 Department of Fisheries Hatchery Act, which stipulated that all hatcheries must ensure the quality and safety of their larvae by maintaining proper feed and input regimes, regulating the use of antimicrobials, and certifying all seed to be free from specific viral and bacterial pathogens before onward distribution (Keus et al., 2017: 20).[1]

The USAID-funded AIN programme, delivered by regional NGO WorldFish from 2011 to 2016, offered technical support for the Act's implementation. AIN aimed to increase aquaculture output by building technical and compliance capacities in hatcheries for improved seed quality, and enhancing the farm management skills of smallholder farmers (ibid.: 5). By improving hatchery compliance and seed quality, the Hatchery Act and AIN aimed to establish a shrimp PL market oriented towards competition based on quality as well as price, to support an export product market responding to importer safety regulations (Callon et al., 2002; Islam, 2008).

By establishing BMP in the hatcheries, AIN steered production protocols towards the testing of broodstock and PL as a key biosecurity measure. As part of AIN, the DoF and WorldFish partnered to re-open laboratory facilities located in Cox's Bazar and train laboratory staff (ibid.: 9).[2] The laboratory enabled Polymerase Chain Reaction (PCR) testing of both broodstock and PL for key production diseases of shrimp ahead of stocking

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[1] This includes finfish hatcheries, although they do not form part of this discussion.

[2] Originally established in 2003 by USAID's Agrobased Industries and Technology Development Project (ATDP), the facilities had lain dormant since 2011.

and before onward sale. Hatcheries were encouraged to follow a 'one mother, one tank' (OMOT) process, that is, the solitary stocking of tested pathogen-free broodstock in individual tanks. The resulting PL would, given good levels of additional biosecurity, be low-risk in terms of tested diseases. Further PCR testing of seed prior to onward sale would, in theory, provide a guarantee for farmers that they were stocking with seed free from White Spot or other problematic diseases. Branding and traceability techniques would allow hatcheries to recoup production and testing costs, thus incentivizing businesses to invest in BMP compliance technologies.

As well as OMOT, AIN introduced a further quality seed initiative: the establishment of Specific Pathogen Free (SPF) shrimp PL production facilities in Bangladesh (Keus et al., 2017: 10). SPF ventures are domestication programmes offering genetic improvement of broodstock in a captive breeding programme (Barman et al., 2012). Broodstock 'lines' are repeatedly bred in special facilities under controlled, disease-free conditions that allow them to maintain their SPF designation, with their resulting PL 'guaranteed' to be free from specified viral and bacterial pathogens. In 2017, Bangladesh had one facility for producing SPF shrimp PL, located in Cox's Bazar, although there were plans to upgrade more facilities with this technology.[3]

The hatchery's managers partnered with a Hawaiian marine biotechnical company collaborating with USAID's 'Feed the Future Partnering for Innovation' programme to introduce SPF broodstock and PL, with AIN and the DoF providing funds to purchase the necessary hatchery equipment (Keus et al., 2017: 20). They operated a unique procedure with rigorous biosecurity measures, a diet of certified organic artemia and algae, maintained their own indoor algae laboratory to ensure organic status and biosecurity, and had a strict policy of no antibiotic use.

In comparison, the prawn hatchery sector was characterised by much lower levels of investment, and thus was left behind by programmes that concentrated on the more globally developed shrimp sector. Since 2010, prawn hatcheries have experienced severe mortalities, in part a reflection of a lack of investment in water filtration and other biosecurity measures (Briggs, 2013). By 2017, only four facilities were able to produce — with total production of PL down from 200M to 15M over the previous five years (according to respondents). Macrobrachium Rosenbergii Noda Virus (MrNV) was identified as the underlying cause (Keus et al., 2017: 16), although Hossain et al. (2016) reported that samples taken in 2012 contained bacterial agents that had developed resistance to multiple drugs, potentially a result of indiscriminate antibiotic use in this sector.

The opportunities the innovations provided for improving the quality of shrimp seed appeared promising, nevertheless, and a study concluded that farmers producing with disease-free seed had experienced better production success, particularly when combined with the adoption of improved management practices on their farms (Rahman et al., 2018). Despite these positive findings, our review of the literature and AIN report suggested that securing the intended policy outcomes and improvements that BMP compliance aimed to achieve would require the following socioeconomic challenges to be addressed. Firstly, given the initial investment requirement and higher production costs, the extent to which hatcheries would find a commercial opportunity in the quality seed market or continue to compete on price alone became a key question for policy success. Secondly, if the capacity for hatcheries to source enough pathogen-free broodstock to meet industry needs was uncertain, the extent to which broodstock health limited investment would need to be assessed. Thirdly, the uncertainties created by the multi-factorial nature of hatchery and grow-out farm problems, many of which would not be addressed by testing or SPF seed alone, raised the question of whether the focus on BMP compliance would be sufficient to reduce the burden of disease across Bangladesh's aquaculture production. We therefore developed our method of sociotechnical analysis to test the viability of the AIN programme's innovations for addressing these specific challenges.

Results: The Outcomes of Implementation

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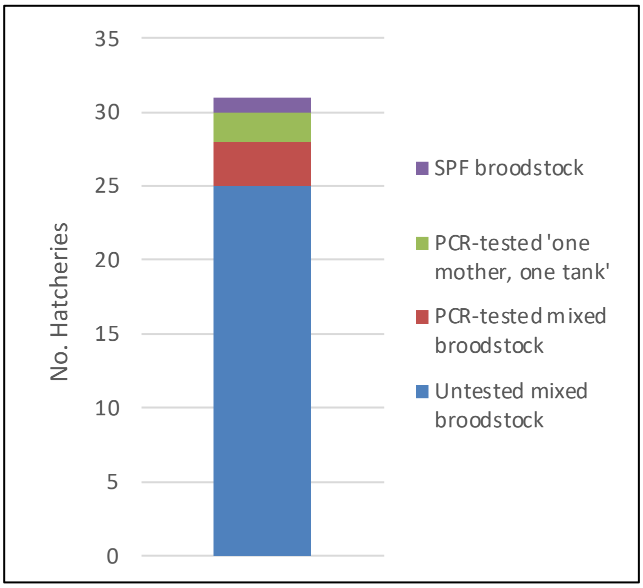
[3] According to an unpublished report, a new facility was to be trialled in 2018 in the Satkhira district of Khulna Division, and there are anecdotal reports of as many as four SPF facilities now in operation.

We present the results of our sociotechnical analysis under the following headings: market and investment challenges; biological complications; and compatibility with grow-out farming systems.

Market and Investment Challenges

Testing and securing healthy broodstock and PL requires laboratory and production capacity, both of which rely on significant human, technical and financial resources (Keus et al., 2017: 28). Likewise, secure production using OMOT requires an increase in production cost per unit and may reduce throughput from the hatchery. Thus, hatcheries would have to see an effective mark-up in terms of the price they could charge for tested seed if they were to implement BMP compliance. PCR-tested and SPF shrimp PL producing hatcheries did report higher and more stable selling prices; in 2017, the average price for accredited seed was $12.50/1000 pl, compared to the lower and fluctuating prices for untested PL ($2.50-9.50/1000 pl, depending on supply and demand dynamics). Industry specialists assumed that the higher selling price would incentivise hatcheries to upgrade their management practice and expand tested/accredited production. However, according to our survey, in addition to the single SPF producer, only five of the 22 shrimp hatcheries surveyed reported PCR-testing their broodstock ahead of stocking (see Figure 2). Just two of these five had adopted OMOT for a proportion of their output. The considerable majority of shrimp and prawn hatcheries reported continuing to utilize untested broodstock.

Figure 2: Hatchery broodstock management practices



Our study found that barriers to uptake of BMP compliance related to price competition, weak diagnostic capacity, and the absence of compensation should a hatchery cycle fail. Hatchery respondents claimed that the market for quality seed was limited, which they attributed to weak farmer purchasing power and competition from non-tested sources. PL can be a farmer's most significant production cost, and on small, open system farms, the productivity premium for 'higher quality' seed may be less obvious to the farmers (see *compatibility with farming systems* section below). Furthermore, technicians complained of markets oversupplied with cheap PL from low-quality operations, the illegal collection of wild PL sources, and illegal imports smuggled across the border from India. Few hatcheries sold their PL directly to farmers; the majority sold their product wholesale to seed traders at the wet markets in Khulna Division. Quality was not the primary driver for these traders, who also dealt in illegal PL sources, and thus they were able exercise bargaining power that forced hatchery gate prices downward (see also Høg et al., 2018). Accredited hatcheries reported finding an alternative market by supplying directly to farms (primarily the few semi-intensive farms in operation) or providing NGO-run programmes with the quality seed required for their farming improvement schemes. This may explain the relative price stability, but this market was nonetheless limited.

Low selling prices were exacerbated by rising production costs, with businesses reporting increased costs for live feed, inputs, medicines, labour, energy, and transportation. Shrimp hatcheries in Cox's Bazar were particularly exposed to transport costs, as they had no option but to ship their PL 700km via one of the two daily flights to Jessore and then via jeep to the wet markets in Khulna Division, with seed traders and farmers reporting PL weakened by the long journey.[4] Rising costs tightened the economic margins of many businesses, meaning few possessed investment potential to upgrade their facilities. Furthermore, whilst the SPF facilities received financial support as part of AIN, there was little in the way of government investment to support facil-

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[4] The problem has been partially alleviated by the establishment of nurseries in the southwest, which has allowed hatcheries to transport Nauplii to the nurseries in greater numbers, at lower cost and with less risk to their health than in later stages of development.

ity upgrades; nor was there any kind of business protection, with the economic burden for production collapse being borne by the producers themselves. The majority of hatchery operations were financed by bank loans with little or no access to insurance or compensation in the event of production collapse.

A further barrier to uptake cited by hatchery respondents was the shortage of laboratory capacity and access to diagnostic technologies, with a single independent laboratory for testing broodstock and PL in Cox's Bazar, and the absence of any equivalent in southwest Bangladesh close to the prawn hatcheries. Without the ability to test, there was no incentive to invest in BMP compliance. The relative scarcity of accredited PL presumably contributed to their higher price.[5]

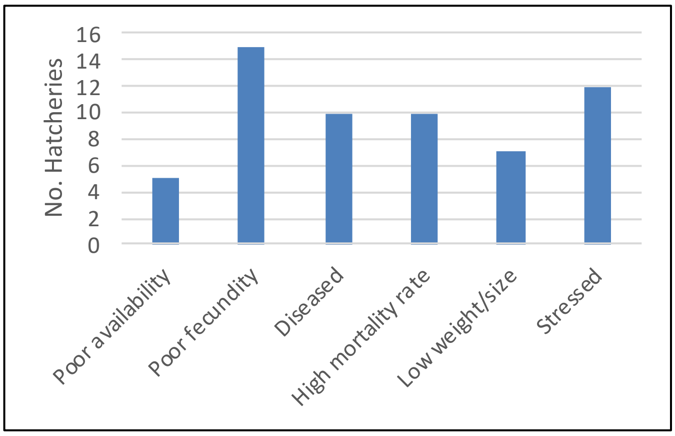
Low farmer demand, an unfavourable market, lack of investment potential, and insufficient laboratory capacity meant shrimp hatcheries found little commercial viability in the premium quality PL market. As a result, most had little choice but to continue competing on price rather than quality. For the prawn hatcheries, the margins were arguably biological rather than economic, with mass mortalities being the significant barrier to production (although, as stated above, the absence of laboratory facilities in the southwest foreclosed any opportunities for implementing seed-testing and BMP compliance). Prawn PL prices for 2017 started at US$18/1000 pl and reached as high as US$27/1000 pl, reflecting the limited supply with farmers almost wholly relying on illegal wild caught PL.

Biological Complications

Respondents reported multiple biological production challenges that reduced the viability of seed testing, such as deteriorating broodstock health, poor culture environments, and frequent disease outbreaks. As stated above, with the exception of the SPF facilities, the sector relied on wild-caught broodstock, which were increasingly likely to harbour production diseases. For shrimp, broodstock trawlers and wholesalers sold their catch at a single undifferentiated price, set daily depending on the size of the catch with a price variation ranging from BDT 2,500 (US$ 30) to BDT 12,000 (US$ 140) (Debnath et al., 2014: 76; unpublished report). The single market price meant that trawler crews had no commercial incentive to journey to deeper waters, where broodstock are less likely to harbour production diseases (Debnath et al., 2014: 76). Furthermore, none of the hatcheries — including the SPF hatchery — had quarantine facilities (unpublished report).

Poor broodstock quality was a common complaint in both shrimp and prawn hatcheries (see Figure 3). Shrimp technicians complained of broodstock arriving at the hatchery gate smaller in size, in poor physical condition, and frequently suffering high levels of stress (most likely a result of poor nursing practices onboard trawlers; see Debnath et al., 2015). They reported an increase in bay-caught mothers already displaying visible signs of disease, particularly from April onwards when ocean temperatures begin rising. Furthermore, technicians reported reduced reproductive success, and failures in tried and tested (if contentious) techniques for inducing reproduction using eyestalk ablation. Therefore, low numbers of healthy broodstock further reduced the commercial viability of OMOT.[6]

Figure 3: reported broodstock complications



Similarly, prawn technicians attributed reduced reproductive capacity to the smaller size and poor physical condition of broodstock. Despite policy stipulation, difficulties sourcing healthy broodstock (along with the lack of laboratory access discussed above) meant

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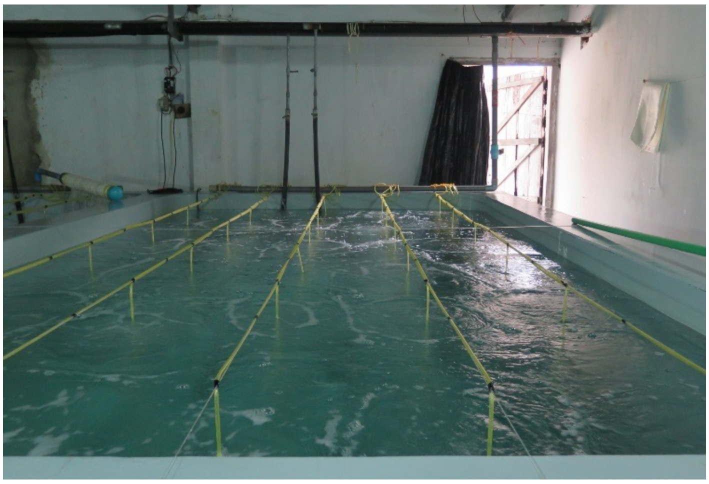
[5] Although not explicitly stated by our respondents, one can speculate that fears of oversupplying the market with quality seed, thus reducing the selling price, also acted as a barrier to uptake.

[6] Losses resulting from the destruction of disease-positive PL may also act as a barrier to uptake; see Rahman et al., 2018.

that 85% of PL from surveyed hatcheries were sold untested, with a high risk of transferring bacterial infections, viral infections, and pathogenic micro-organisms to grow-out ponds.

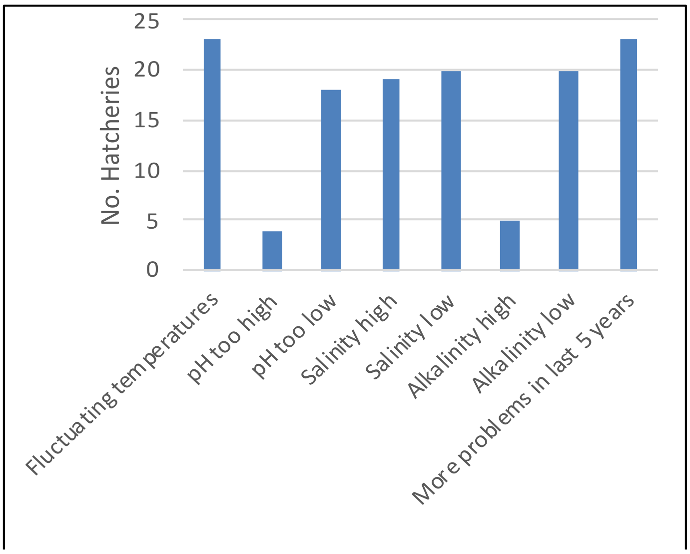
Figure 4: Broodstock Tank



Poor broodstock condition was further exacerbated by difficulties maintaining good culture environments (see Figure 5). This was particularly acute for the prawn hatchery sector, with respondents blaming poor water quality for the widespread PL mortality they experienced. They reported a significant decline in water quality from local rivers, requiring them to transport clean water across longer distances in order to produce. Despite installing seawater filtration systems and other technologies for maintaining good culture environments (e.g. temperature controls and oxygenation), maintaining the optimal water parameters was difficult across the board. Respondents attributed deteriorating water quality to an increasing frequency in extreme weather events (such as droughts and flooding), pollution from industrial and agricultural wastes, inadequate sewerage and wastewater treatment infrastructure, and (for shrimp hatcheries) the high number of hotels in Cox's Bazar.[7]

Hatcheries relied instead on more cost-effective strategies for managing disease outbreaks that included treatment with chemical inputs, probiotics and, when necessary, antibiotics. Chemical treatments and biocides functioned to disinfect the broodstock and their eggs ahead of stocking or to prevent fungal and protozoan infections, while probiotic remedies improved the culture environment and the digestive systems of the broodstock and PL. Probiotics were a key component of shrimp operating procedures, with technicians reporting improved PL growth and healthier culture conditions. Farm supply shops reported a significant increase in probiotic sales over recent years, with a corresponding reduction in antibiotic sales. Nevertheless, with the exception of the SPF facilities, all respondents — including those from BMP compliant hatchery facilities — reported resorting to antibiotics to rescue a cycle from collapse due to a suspected bacterial infection, sometimes in relatively large quantities. Whilst the most common antibiotic in use was Oxytetracycline (approved for use in aquaculture), respondents also reported using antibiotic classes that were either prohibited or classed as being critically important for human health by the World Health Organization (for example Furazolidones, Nitrofurans, and Chloramphenicols).

Figure 5: Reported difficulties with water quality



Respondents claimed that decisions to use antibiotics were taken as a last resort, when all other attempts at treatment had been exhausted, and the risk of cycle collapse was immediate. However, the combined effects of tight economic margins and frequent biological complications meant that — for now — antibiotics remained a necessary component of disease control, with the potential dissemination of resistance-conferring microbes

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[7] The survey was undertaken ahead of the current refugee crisis in Bangladesh's southeast. Almost one million Rohingya Muslims fleeing violence and persecution in Myanmar are currently sheltering in camps near Cox's Bazar, with frequent disease outbreaks being reported.

and their genes to the tens of thousands of ponds that stock PL from these hatcheries.

Figure 6: Water filtration and ingress

Compatibility with Farming Systems

A further question for policy was whether requirements for farming with domesticated seed were compatible with extensively managed smallholder aquaculture ponds. During interviews, farmers expressed concern regarding the ability of hatchery-reared seed to tolerate the open, low-input pond conditions. Many reported a preference for stocking with wild PL sources, which they claimed were better able to tolerate the culture environment compared with domesticated seed raised in the artificially recreated and relatively sterile hatchery tank environments. This was particularly the case in coastal regions supplied by highly saline tidal rivers. Farmers here reported a decline in production when using SPF PL, which they attributed to the poor tolerance of hatchery-reared seed to the saline environment. Technicians, on the other hand, claimed that *the farmers* were responsible for the poor productivity of premium quality seed, complaining that they were not making the necessary pond modifications or adjusting their farming methods to support domesticated PL health and growth. However, the situation on the farms themselves was more complex.

Switching to premium quality seed requires farmers to modify their farms, their farming practices, and their cropping patterns in ways that are not compatible with extensive farming systems and technologies, or with the commercial risk management strategies that they currently practice (Hazan et al., 2020; Hinchliffe et al., 2018; Rahman et al., 2018; Hinchliffe et al., 2021). For example, to farm with domesticated seed, farmers were expected to practise single stocking with disinfecting and drying of ponds between production cycles. However, farmers of extensively managed ponds practised polyculture (stocking of multiple species of crustacean and finfish) and multi-stocking (the continuous stocking at regular intervals across the season). In biosecurity terms, multi-stocking increases the risk of disease outbreaks, but it also allowed farmers to manage the financial risks, offering them a certain amount of security by spreading the costs and income throughout the season (Hinchliffe et al., 2018). The modifications also required farmers to deepen pond depths to a minimum of one metre (see also Rahman et al., 2018). Again though, the majority of small-scale farmers practised integrated agriculture, supplementing their incomes by cultivating rice paddy in their ponds either concurrently, or alternating between shrimp and rice according to seasonal salinity levels. Whilst those practising concurrent rice/shrimp and prawn production were able to dig a deeper ditch around their paddy field to accommodate their aquaculture, seasonal rice growers had to maintain a pond depth suitable for rice paddy cultivation (between 50 and 100cm). Furthermore, in situations where farmers were leasing their ponds, landowners could refuse permission to make the necessary modifications (Joffre et al., 2017).

Figure 7: Chemical inputs for managing tank environments and shrimp health, including a tub of Oxytetracycline

Finally, farmers were required to acclimatise hatchery-reared PL to the new conditions before stocking. A lack of nursing facilities meant farmers were expected to create homemade nurseries by netting off a corner of the pond. Farmers with limited pond space reported finding it difficult to section off their ponds for this purpose.

Figure 8: Integrated rice aquaculture. The pond on the left produces rice and prawn concurrently. The pond on the right practices alternative shrimp and rice production. In this photograph, the shrimp season has ended, and the farmer has shifted to rice cultivation.

Along with the intermediary interests and transportation issues discussed above, our results determine that many of the challenges posed by professional practices and culture environments in the wider production ecology will not be addressed by testing or SPF seed alone. Altogether, several factors coalesced to produce a weak environment for innovation in Bangladesh's shrimp and prawn hatchery industry: the combined and interrelated consequences of unsupportive markets; the absence of insurance or compensation; inadequate laboratory capacity; high frequency of diseased broodstock; polluted and fluctuating aquatic environments; incompatibility with extensively managed farming systems; and the unlikeliness of BMP costs being recouped in hatchery gate prices.

Concluding Discussion: Rethinking Innovation Models

A key aim of the Hatchery Act was to improve hatchery management practices, establish seed testing, and prevent the transmission of pathogens onto the farms (and by extension reduce antibiotic use). The DoF partnered with AIN to achieve these objectives. It made clear business sense to intervene in broodstock management, given their crucial role at the very beginning of production. It also made sense to target technical interventions at the relatively small number of hatcheries, rather than some 200,000 shrimp and prawn ponds. A partnership has been established with the Hawaiian-based biotechnical company and USAID collaborator that developed and marketed the SPF technology (Keus et al., 2017). A study has confirmed the relative success of the technologies for containing pathogen transmission and reducing or preventing disease outbreaks on farms when combined with the adoption of improved management practices (Rahman et al., 2018). The intrinsic qualities of the technologies and procedural innovations were evident, and the arguments for adding value were persuasive. However, as our results demonstrate, multiple challenges and factors relating to markets and investment, biological challenges, and on-farm practices that could not be resolved by seed testing alone prevented users from finding an investment opportunity. The innovation environment remains focused on improving seed quality, more specifically investment in SPF technology, which industry specialists argue is the only viable solution for reducing the disease burden, improving biosecurity, eradicating disease, and producing sufficient quantities of certified disease-free PL (Debnath et al., 2015; Keus et al., 2017). Introducing imported domesticated broodstock removes the reliance on disease burdened wild broodstock sources, and the only hatchery not to report antibiotic use was the SPF facility. This was a result (the technicians argued) of developing a high-quality system for the breeding and nurturing of domesticated broodstock that comprises effective use of probiotics and imported, certified organic live feed. Nevertheless, questions remain over SPF technology's capacity to reduce the disease burden and improve grow-out production. One key question is technical and relates to the contamination model of disease. As both PCR testing and SPF facilities target known pathogens, they cannot guarantee freedom from diseases arising from newly emerging or mutating pathogens, or from adverse pond conditions (Barman et al., 2017: 67). However, our sociotechnical analysis of the use environment suggests that the implementation of SPF technologies will likely face similar obstacles to OMOT's implementation as outlined above. Given their own tight margins, it is likely that farmers will struggle to pay the higher cost per 1000 PL for SPF, especially if grow-out results are uncertain.

Within diffusion-based technology models, examination of the social and use environment tends to be shallow, and limited to cost-benefit analysis, improved productivity output, or quality that can be optimally achieved with the right technical modifications. As our study has demonstrated, this can lead to unintended outcomes and a limited diffusion of the technology. Nevertheless, our study has also demonstrated the possibilities offered by a social science-influenced innovation model for improving awareness of the social conditions and key relations a technology will encounter and become embedded within, thus enhancing the prospects of success. Just as models have been developed to improve awareness of how disease and pathogenicity are configured by microbial, environmental and socioeconomic drivers and interactions (Leach and Scoones, 2013; Rosenberg, 1992), similar models can be applied to improve awareness of how the fate of an innovation will be shaped by the drivers and interactions occurring in the intended use environment. Following Akrich et al. (2002), we therefore advocate the combination of a model of diffusion with interessement for the purposes of assessing the viability of technologies and management practices for improved seed quality. Such an approach can take the form of ethnographic studies or participatory modelling workshops with key actors, with the aim of providing a space for all those involved to reflect and interact, test assumptions, and identify uncertainties to be investigated and challenges to be resolved.[8] Here, the goal of interessement is to bring innovators and policy makers into contact with multiple sources of additional expert knowledge produced by those who engage with different elements of the use environment daily, and who have a sound appreciation of the complexities not easily captured by technical analysis alone.

By positioning itself "at the exact place where innovation is situated, in this hard-to-grasp middle-ground where technology and the social environment which adopts it simultaneously shape each other" (Akrich et al., 2002: 205), the interessement method of sociotechnical analysis has demonstrated how innovation is shaped by socioeconomic and material contexts, risk management strategies, and mundane interactions in an ecology of production practices. Taking Bangladesh's shrimp and prawn hatchery sector as our case study, we have examined the capacity of an innovation programme — designed to enhance seed quality, improve disease and production management practices, and by extension reduce reliance on antibiotics — to adapt to established breeder practices and the wider ecology of shrimp and prawn production. Our results and sociotechnical analysis have demonstrated how, when implanted into Bangladesh's export aquaculture production ecology, the relationships established and interactions encountered modified the technological innovations and defined their value: trawlers decided on which quality broodstocks were commercially available; market intermediaries decided on pricing and competition; farmers decided the value of PL sources according to their financial and adaptive capacities. The multi-factorial nature of shrimp and prawn production in Bangladesh placed limits on investment capacity and the capacity to implement BMP compliance, further driving risky disease control measures and limiting the successes of technical interventions for improving the seed quality.

When a novel technology becomes available, there is a risk that providers will assertively promote its diffusion without considering the suitability of the use ecology. Innovation requires supportive institutional, physical and market environments, which were missing in our case study. We suggest considering at planning stage whether the technology's diffusion can be sustained and what it would take to sustain it. This offers opportunities to include complementary social science perspectives that provide greater contextualization of the situation on the ground. This kind of validation improves knowledge and understanding of the innovation

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[8] The authors of this article held participatory workshops with farmers, technicians, and other industry specialists, where we collaborated to produce a digital model that generated information on potential pathways and drivers of antibiotic use and AMR in the sector for the project (Hinchliffe et al. 2018).

environment, particularly when designing programmes that aim to deliver capital intensive and technically complex innovations in a farming context where preventing disease outbreaks requires more than the implementation of technological innovations for broodstock domestication and seed testing. Diffusion defines the intrinsic qualities that users will be receptive to (in this case the opportunities for reducing disease and antibiotic use in the hatcheries, and preventing pathogen transfer onto farms), but interessement generates information about the use ecology that the innovation will be implanted in: the relationships established and interactions encountered that modify the innovation and decide its value. To move beyond the normative practice of applying technical solutions to problems that are both social and technical, we recommend developing complementary models that can combine technical analysis with an analysis of the diversity of commercial and production practices, risk perceptions, and social and environmental relations in a production ecology. Applying a sociotechnical model of interessement can provide policy makers, producers, and other industry actors with multiple perspectives for understanding the often complex and multifaceted nature of disease outbreaks and their management in food producing sectors. These can either complement and enhance the outcomes of innovation programmes, or can indicate that a more socially and institutionally sustainable course of action is required.

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