Aquaculture Health Management

Design and Operation Approaches

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Animal health: the foundation for aquaculture sustainability

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Chapter outline

1.1 Introduction-the importance of animal health in the future growth of aquaculture

Aquaculture has a 4000 year history beginning prior to written history in China as a means to aggregate wild fish for easier harvest (Rabanal, 1988). This aquaculture was typically unfed, low-density (extensive) production, and may have started as fishponds for emperors and pharaohs (Beveridge & Little, 2002). Aquaculture performed at this level for millennia, and it was not until the post World War II economic boom of developed countries (Thia-Eng, 1997), along with increasing global trade as well as the advent of formulated feeds, that aquaculture intensified to its current standing and producing 50% of the freshwater and marine aquatic products consumed globally (FAO, 2016). The recent growth in aquaculture came through the increase in the fed-aquaculture sector, where species that rely on feed now

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comprise 50% of aquaculture production (FAO, 2016). Placed in context to terrestrial animal agriculture, aquaculture is the new kid on the block, and has not had the benefit of gradual intensification over the last few centuries. This new industry paradigm is critical, as many suggest that a continued increase in aquaculture production is essential given the expected significant increase in global population in the coming decades (Searchinger et al., 2019). Good management and practices lead to healthy animals, and intervention through medicating or culling is a sign in aquaculture that the system is out of balance. Aquatic and terrestrial productions mirror each other in that as production intensifies, the need for herd management increases as functional limits to production are met. In addition, increased human oversight that comes with active management also increases the ability for direct intervention to manage animal health. In aquaculture, the increased development of animal health tools and practices coincides with production by well-funded multinational companies that are selling to developed world markets. The chapters within this volume are a testament to the arduous work that has been devoted to improve aquaculture. Yet, there is also the belief that despite our extensive knowledge of animal health, veterinary medicine, and genetic improvements, disease will continue to constrain the aquaculture industry (Jennings et al., 2016; Stentiford et al., 2012). These constraints are not merely because of the recent emergence of aquaculture as a significant food provisioning system and there has not been sufficient time to develop new techniques. The constraints will occur because of the nature of the species in aquaculture, and the environment in which they are farmed. Ultimately, the greater the constraints to future aquaculture development, the slower will be the approach to sustainability.

1.2 Continued health constraints on aquatic animal production

1.2.1 Species diversity

While aquaculture's intensification arc has been delayed compared to terrestrial agriculture, its relative newness compared to terrestrial animal production cannot be reason enough for continued significant disease issues. There are a number of factors at play, primary being aquaculture is much more specious than terrestrial animal production (Henriksson et al., 2017). Terrestrial agriculture draws from a pool of 40 species, but production primarily comes from just 5 (Biodiversity International, 2017). Aquaculture draws from a pool of over 580 species (or species groups; FAO, 2016), and 22 species (or species groups) account for only 75% of animal aquaculture production (FAO, 2016). In step with the slower intensification than terrestrial animal production, aquaculture also has had less research and development paid to it, and certain sectors such as salmonids have had significantly more development than others (Stentiford et al., 2017). If we consider publications in five of the primary journals devoted to aquaculture and animal health (*Diseases of Aquatic Organisms*, *Journal of Aquatic Animal Health*, *Journal of Fish Diseases*, *Aquaculture*, and *Aquaculture Research*), less than 10% of the published papers in the health specific journals mention aquaculture in the title, abstract, keywords, or descriptors, while 10%-12.5% of journals in *Aquaculture* or *Aquaculture Research* focus on health or disease (Table 1.1). Of these papers, salmonids represent the significant effort in publishing with 35%-58% of papers focused on salmon and/or trout (Table 1.1). This is played out in practical terms where a mere 10% of all farmed fish have been selectively bred to improve production (Gjedrem, 2012) with this selection being focused on only a few key traits (growth, disease resistance, and fillet yield). These results demonstrate a general disconnect between the global production of aquaculture, and the interest paid by the developed world. Carp and oysters are the most produced animal proteins in aquaculture (FAO, 2016), and yet are only subject to a maximum of 13.8% (carp in *Aquaculture*) and 8.4% (oyster in *Diseases of Aquatic Organisms*) of the papers in these journals (Table 1.1). The diversity of species in production globally in aquaculture will limit effective steps toward better management of aquaculture as a whole given the lack of transferability of knowledge across species groups (Brudeseth et al., 2013). The top species include freshwater and marine fish, as well as mollusks, and crustaceans. Invertebrates tend to have more severe disease outbreaks than fish (Leung & Bates, 2013). Furthermore, the transfer and adoption of technology proven to be successful in one sector of the industry (e.g., fish) is often impossible to transfer to other sectors. For example, salmon aquaculture has relied heavily on vaccine development to mitigate disease (Lorenzen & LaPatra, 2005). Crustaceans do not have an adaptive immune response on par with fish or mammals, and while there is mounting evidence crustaceans may have some degree of ability for immune system priming (Rowley & Powell, 2007), the feasibility of accomplishing this on a working farm may not be cost-effective (Rowley & Pope, 2012; Stentiford et al., 2012).

Table 1.1 The number of papers present on the Web of Science November 10, 2018, for three prominent aquaculture health journals, as well as two prominent aquaculture journals.

	Diseases of aquatic organisms	Journal of aquatic animal health	Journal of fish diseases	Aquaculture	Aquaculture research
Years	1985-2018	1997-2018	1978-2018	1978-2018	1997-2018
Total papers	3,806	796	3,500	15,606	5,007
Aquaculture/ health or disease (%)[a]	321 (8.4%)	57 (7.2%)	337 (9.6%)	1,946 (12.5%)[a]	527 (10.5%)[a]
Species					
Finfish					
Salmonids	114	25	197	852	236
Salmon and trout	32	9	59	317	77
Salmon	46	3	75	221	39
Trout	36	13	63	314	120
Catfish	26	2	33	168	61
Carp	24	3	35	146	73
Tilapia	20	7	18	191	100
Bass	19	5	25	148	49
Seriola	7	0	8	26	2
Eel	5	0	5	35	3
Rohu	1	5	0	15	5
Invertebrates					
Shrimp	44	2	0	411	120
Oyster	27	4	1	127	20
Mussel	12	1	0	37	4
Crab	12	1	0	60	13
Crayfish	8	0	0	45	8
Scallop	3	1	1	21	4

The papers are parsed by total in journals, those that reference aquaculture (or health or disease) in the title, keywords, or descriptors and then those within this subset that refer to species. Salmonids are separated out into salmon, trout, or both, given their prevalence in all of the journals

[a] Indicates parsing is only on health or disease.

1.2.2 Environment

There are inherent difficulties to farming in water compared to farming on land (Oidtmann et al., 2013). Disease ecology is categorically more of a challenge, as more than half of the parasites on earth rely on aquatic ecosystems (Shields, 2017). But more fundamental than that is the ability to control large volumes of water that have other users and natural processes affecting its quality. At times, water quality is so poor that it can kill animals. In a terrestrial setting, this would be equivalent to trying to farm pigs or chickens in a location where nothing can breathe. Control in aquaculture is tied to culture system, and increased control requires a greater degree of infrastructure and investment. Cage culture will by default be a less controlled system, as a number of water quality factors are outside the control of the aquaculture operator. Low oxygen pulses and anoxic events routinely occur with examples including events that occur in Chile around Chiloe Island (Pérez-Santos et al., 2018; Silva & Vargas, 2014), or the dead zone in the Gulf of Mexico. Other large-scale water quality issues untied to operator performance include harmful algal (Anderson, 2009) and jellyfish blooms (Baxter et al., 2011).

With coastal areas becoming limited for a variety of reasons (Duarte et al., 2009), offshore production remains an option (Klinger & Naylor, 2012) provided it can be spatially colocated with other oceanic uses (Tlusty et al., 2018). Space is abundant to meet future production needs to provision food for an expanding global population (Gentry, Froehlich, et al., 2017), and offers resilience in the face of climate change (Klinger, Levin, & Watson, 2017). Experience and relevant data are accumulating indicating that siting that maintains environmental integrity can be achieved (Benetti et al., 2010; Gentry, Lester, et al., 2017). Larger cages offer a benefit to maintain economically relevant biomass while preventing overcrowding. Yet, stock health will need to be closely watched, as there are a limited number of studies investigating health benefits of offshore production (Kirchhoff, Rough, & Nowak, 2011).

As the aquaculture operator increases control of their water through moving to a flow through system (pond), they trade-off being less subject to outside environmental variables for increasing cost, but are more subject to user error. Pond producers are still subject to low oxygen events, but in this case it can occur at warm temperatures when oxygen demand during feeding can denude the water of oxygen. Yet, even ponds are subject to outside farm influence through influx of water or poor biosecurity as demonstrated by the significant disease issues in shrimp ponds throughout Thailand (Stentiford et al., 2012). The ultimate in control for aquaculture is recirculation systems (RAS), and while not subject to the same environmental perturbations as net pen culture, there are environmental influences and impacts that do need to be considered (Pelletier et al., 2009). The increased cost places this option outside of the realm for many producers, and primarily favors high-value species. This increased control also does not eliminate the possibility of disease, and poor biosecurity (Delabbio et al., 2005) can lead to disease incidence (Good et al., 2015; Rurangwa & Verdegem, 2015).

A solid approach to maintain good animal health in any farming system is to prevent, detect, and diagnose (National Research Council, 2005). Each of these will be a challenge in aquaculture production as the large number of both the farmed species and the aquatic pathogens make for an unwieldy number of combinations. It will take a concerted effort by global experts in aquaculture with pathologists, epidemiologists, ecologists, pharmaceutical companies, and food security policy specialists (Stentiford et al., 2012) to ensure aquaculture remains a viable industry.

1.3 Adding animal health into the aquaculture sustainability discussion

1.3.1 Sustainability

The discussion of sustainability began in earnest with the Brundtland Commission in 1987 (Brundtland, 1987). This report solidified the idea of sustainable development being that which "meets the needs of the present without compromising the ability of future generations to meet their own needs." Originally, sustainability was developed as two complimentary ideas. First, the idea the Brundtland Commission put forth was that sustainability was framed as the dichotomy of betterment of the human condition while managing limiting resources. This places the balance between the socioeconomic needs versus those of the environment with each considered to have half of the value in this discussion (Fig. 1.1A). Over time, this discussion transitioned into the discussion of sustainability being the people-planet-profit triad where social, economic, and environmental values each garner a third of the discussion (Kuhlman & Farrington, 2010). This discussion will use the approach that the socioeconomic dimension needs to be meshed with the environmental discussion.

The second idea advanced by the Brundtland Commission was that the approach is a journey of improvement toward a more sustainable state rather than merely declaring a final sustainable state (Curran, 2009; Stefanovic, 2000). This is the difference

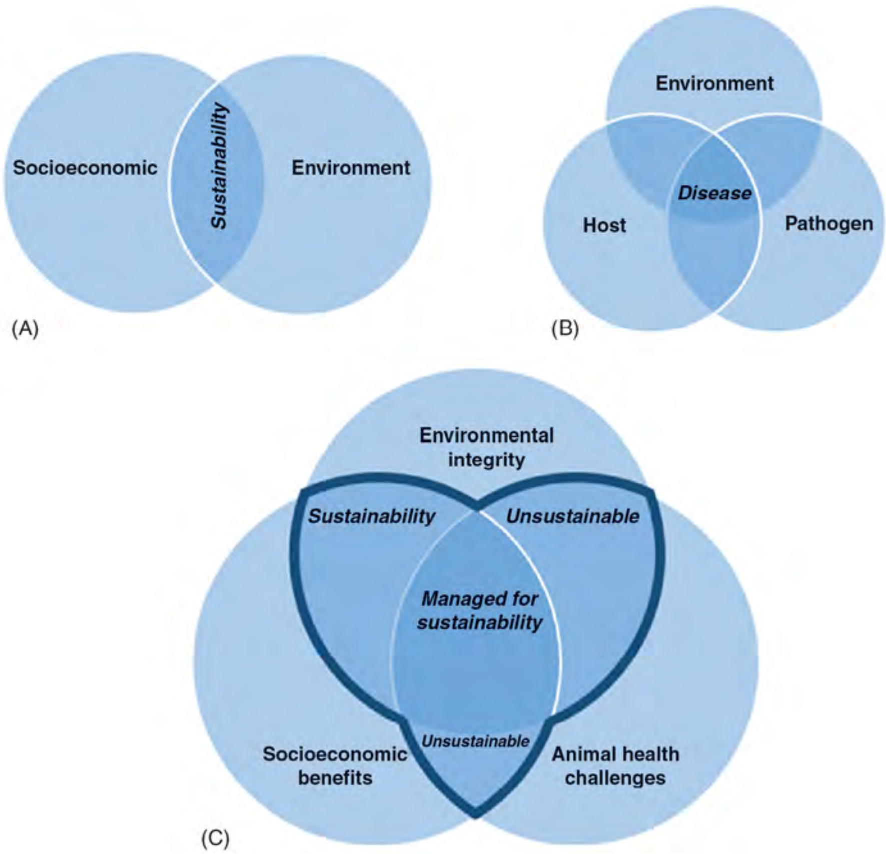

Figure 1.1. The melding of sustainability and animal health in aquaculture. (A) Sustainability is achieved by fulfilling both socioeconomic needs while maintaining environmental function. (B) Poor animal health and disease is realized when the animal (host) and pathogen overlap in an appropriate environment (Snieszko, 1973). Melding these two ideas, and overlapping the diagrams on the environment (and acknowledging the animal will always be present), presents the outcome space for aquaculture (C, area encapsulated by the *dark line*). Sustainability can be achieved when benefits to the socioeconomic and the environment are maintained for the long term, when animal health is not an issue. When the socioeconomic and environment aspects are maintained, but animal health is not maintained, management is required to ameliorate the impacts of the disease to achieve sustainability. In this case, if aquaculture is practiced so that the socioeconomic benefits or the environment are degraded, there would be a shift to unsustainable states.

between sustainable-a state, and sustainability-a process or journey of continual improvement (Tlusty et al., 2012). The difficulty with declaring any food production system as a single sustainable state is that improvement stalls, which is unfortunate as there are a myriad of ways to continue to improve any food system (Tlusty & Thorsen, 2017). Even though the seafood sustainability movement works toward continual improvement, there have been multiple claims that aquaculture (as well as fisheries) has achieved a sustainable state (Sampson et al., 2015). For further discussion in this chapter, the focus is on how to reach conditions for sustainability. The practices and tactics to improve and increase the level of sustainability (Tlusty, 2012) are beyond the scope of this chapter.

Disease in fish has long been conceptualized as a balance between the host, pathogen, and the environment, where disease occurs when the host and pathogen are present in an environment that is conducive to infection (Fig. 1.1B; Snieszko, 1973). As discussed earlier, the large number of species being produced in aquaculture (hosts), along with the diversity of aquatic pathogens, (Shields, 2018) increases the overlap and hence the potential for disease. To integrate fish health into the sustainability discussion, the Venn diagrams for sustainability (Fig. 1.1A) and disease (Fig. 1.1B) can be overlapped. To accomplish this, the disease diagram (Fig. 1.1B) needs to reduce the frame of reference to animal health challenges by functionally condensing the host and pathogen factors to a single dimension (Fig. 1.1C). This now provides the opportunity to join the two diagrams with the environment being the dimension that anchors and joins animal health to sustainability.

The resultant animal health-sustainability diagram (Fig. 1.1C)-shows sustainability is achievable when both the integrity of the environment and the socioeconomic benefits are maintained in the absence of animal health issues. The operational space for this discussion of aquaculture is the overlap of these three dimensions. When there are animal health issues, sustainability is not a given, but may be maintained under appropriate management as identified by best practices, or verified under certification schemes. As animal health issues become more prevalent, there may be concomitant socioeconomic or environmental challenges that can push the designation of the aquaculture system into one of the unsustainable spaces.

1.3.2 Environment and its integrity

Environment and its integrity is a main driver of disease in aquaculture (Kautsky et al., 2000; Mahmud, Bradley, & MacColl, 2017; Páez-Osuna, 2001). As the quality of the environment degrades, animals will exhibit stress responses, and those that do will then be more susceptible to disease (the host susceptibility hypothesis; Tlusty et al., 2007). However, there is a feedback loop where disease can impact the environment. Antibiotic usage continues to be significant in aquaculture (Henriksson et al., 2017), and those released in effluent to the environment can bioaccumulate and are toxic to local aquatic organisms including the microbiota (Holmström et al., 2003). As the animals in culture become ill, their feeding patterns utilization and metabolism can change (Boerlage et al., 2017). In extreme cases, the animals will even cease to feed, and their feces may change, altering the nature and extent of their impacts on the environment (Tlusty et al., 2000). Without a behavioral adjustment by the operator, feed can be wasted and this is one of the main causes of benthic impacts below net pen farming.

Integrating animal health into the environmental dimension for sustainability will help because maintaining animal health is a means to make farmers more profitable, while at the same time better maintaining the environment. This in effect gets farmers to care for the environment through a direct cost, as opposed to merely letting the negative externalities, in this case environmental degradation and loss of ecosystem services that have long-term effects and are paid for by future generations, be subsumed by outside entities (Lafferty et al., 2015).

1.3.3 Socioeconomic solvency

Socioeconomic solvency is directly tied to disease within the aquaculture operations. Aquaculture has been a driver to advance sustainable livelihoods by reducing poverty and vulnerability in developing communities (Ahmed, Allison, & Muir, 2008). Across the shrimp sector, infectious diseases cause devastating economic and social impacts with yearly losses exceeding 40% of global capacity (Israngkura & Sae-Hae, 2002). This is especially true where the farmers tend to be small holders, such as India, with 80% of shrimp farmers in this category (Mohan & Bhatta, 2002). Within these communities, disease was listed as a main constraint, and a prime reason debt could not be repaid (Ahmed et al., 2008). But shrimp is not the only species with these challenges. In Chile, the 2007 Infectious Salmon Anemia outbreak resulted in the loss of 25,000 (50%) of direct and indirect jobs (Alvial et al., 2012). Yet, there is a limit to return on investment for eradicating diseases in aquaculture, and this means that some diseases are invested in heavily, while others, though devastating, will not be addressed (Peeler & Otte, 2016). The focus of animal health in aquaculture is biased toward “listed” diseases that affect trade (Lightner, 2012; Peeler & Otte, 2016), and not the pervasive ones that can limit production in Low-Income Food-Deficit Countries where most aquaculture production occurs (Stentiford et al., 2017). This differential investment was exemplified in the early discussion of published research focusing on key species of importance to developed world markets.

The social solvency of aquaculture is not merely tied to the impacts to the farmer. Aquaculture is often operated with the use of public resources, and, as such, the greater society has an influence on the success or failure of the industry. Where there is much opposition to aquaculture, it will not be able to proceed, and disease may influence how society views aquatic animal production (Páez-Osuna, 2001). Recently, salmon disease has been used in Scotland as a way to erode the social license of aquaculture. The Scottish Government developed the Farmed Fish Health Framework that is a range of short-, medium-, and long-term actions to enable the salmon industry to adapt to changes and ultimately enable the sector to grow sustainably (The Scottish Government, 2018). As part of this, they collected images of diseased fish for future training. A freedom of information request was made for the images by investigative journalists, and the public release of these images has been used by animal welfare groups to call for a boycott of the industry (Edwards, 2018).

1.3.4 Regulatory factors

Regulatory factors exist in a myriad of forms regarding animal disease, yet in the absence of effective regulations, significant and devastating disease outbreaks can occur such as the ISA crisis in Chile (Adam & Gunn, 2017). In order to limit the negative impacts of disease, the World Organisation for Animal Health (OIE) focuses on aquaculture animal health standards and recommendations increase, along with creating awareness of disease problems associated live animal trade, and to conduct research on diseases important to aquaculture (Murray & Peeler, 2005). As mentioned earlier, OIE is focused on diseases that affect global trade (Lightner, 2012; Peeler & Otte, 2016). These OIE standards are filtered down through nations and states to be implemented at a local level. In the United States as example, there is a call for a standardized approach to the implementation of state, national, and international regulations (see the Aquatic Animal Health and Disease Regulations website, www.avma.org/KB/Policies/Pages/Aquatic-Animal-Health-and-Disease-Regulations.aspx).

However, where there is distrust of local regulation, voluntary third party certification can be added as an overlay to provide a market signal that product achieves an (ideally) higher degree of production rigor (Tlusty, 2012). This idea was formalized by the

FAO (2011) in their "Technical guidelines on aquaculture certification" where they state:

> *Animal Health and Welfare*
>
> *20. Aquaculture activities should be conducted in a manner that assures the health and welfare of farmed aquatic animals, by optimizing health, minimizing stress, reducing aquatic animal disease risks and maintaining a healthy culture environment at all phases of the production cycle.*

and then provide 10 minimum substantive criteria to ensure that aquatic animal health and welfare are adequately addressed by aquaculture certification schemes. Recently, the Global Sustainable Seafood Initiative (ourgssi.org) used these FAO guidelines to create a Global Benchmark Tool for certification schemes. By the end of 2018, the Global Aquaculture Alliance Best Aquaculture Practices, Global GAP Aquaculture Certification System, and Aquaculture Stewardship Council Certification have all been benchmarked, and similarly overlap greatly in their standards (Tlusty, Thompson, & Tausig, 2015).

1.4 Conclusion

Production practices that are determined only by short-term market forces lead to unintended consequences (Olesen, Myhr, & Rosendal, 2011). This is particularly true for sustainability initiatives, where our current decisions will need to be judged by future generations (Tlusty & Thorsen, 2017). This chapter places animal health as a foundational component to ensure the journey to sustainability remains on focus. It also demonstrates how poor animal management, and resulting poor health, can lead to economic, social, and even environmental ruin. In the future, animal health needs to expand to include welfare too. In 2005, FAO implicated animal welfare would be important in future scenario planning, but did not address it at that time (FAO, 2005). Jennings et al. (2016) stated "if and when fish welfare becomes more of a societal issue and impacts purchasing decisions," echoing the pervasive belief that welfare issues have been identified, but are not part of the greater sustainability discussion (Olesen et al., 2011). From a national perspective, limiting the deleterious effects of disease in aquaculture will increase yield and hence profit. This will help to alleviate poverty and provide for food security for producer nations. Maintaining animal health is the foundation for sustainability in aquaculture.

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AQUACULTURE HEALTH MANAGEMENT

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Design and Operation Approaches

Edited by

FREDERICK S. B. KIBENGE

MARK D. POWELL

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Preface

The concept of health management in veterinary sciences is not a new one. However, in aquatic animal medicine the idea of managing health is largely confused with managing the disease. That is, for many veterinarians and fish health biologists, the term fish health refers to the absence of disease. The tide is turning, fish and invertebrates in aquaculture are now looked upon as production animals; the degree of domestication is substantial. Those animals that we are growing in staggering numbers, are currently representing more than half of the total amount of aquatic biomass consumed, exceeding that provided by capture fisheries. At its very conceptualization, this book was intended to provide a guide to those interested in the management of aquatic animal health in aquaculture. It was to provide a guide to veterinarians, fish health biologists, aquaculturists, and researchers alike. We have intended to reach as broad an audience as possible and provide a volume that will provide insight but also ignite discussion about how we might further improve our practices and tackle the ongoing challenges that lay before us to produce ethically farmed fish and shellfish. This book represents the first comprehensive approach to understanding overall aquatic animal health management, examining chapters relating to the challenges of health management in aquaculture including biosecurity, the management of diseases (as opposed to health), the science of vaccinology and immunological principles, as well as examining the effects of the environment. Included in the ten chapters are specific topics tackling new approaches such as the use of cleaner fish—themselves used for biological control of parasites, particularly in salmon, but also that they pose their own health management challenges, as a non-food purpose aquaculture species. We have also included discussion of new production technologies, such as Recirculating Aquaculture Systems (RASs). The field of RAS technology is developing rapidly with facilities involving staggering numbers of fish and a scale of technology many of us could only dream of a couple of decades ago. However, raising fish in RASs has challenges. In many cases, we understand the basic principles of nitrification and gas transfer. Still, we are only beginning to understand the intricacies of water chemistry, environmental conditions, and the requirements of fish to be produced on land.

We owe an enormous debt of gratitude to the numerous authors and co-authors of the chapters that have contributed to this book.

Behind each chapter are many hours of work and discussion. For bringing their expertise to bear, imparting their knowledge, and diligently formulating chapters, we are eternally grateful. We cannot even begin to thank all of the people involved in this project at Elsevier Inc. Still, our special thanks go to Patricia Osborne, Senior Acquisitions Editor, Elsevier Books Division, without whom the book project would not have happened, and to Karen Miller, Laura Okidi, and Billie Jean Fernandez of the production team for their patience, support, and for giving us an ever-so-gentle kick to keep up our end. Without any doubt, we owe thanks to our families for their support, where professional activities inevitably spill over into personal time.

Prof. Frederick S. B. Kibenge and Prof. Mark D. Powell

Aquaculture Health Management

Design and Operation Approaches

Edited by
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Mark D. Powell, University of Bergen, Norway; Marineholmen RASLab AS

Aquaculture Health Management: Design and Operation Approaches is an essential reference for the diverse aquaculture community. With the steadily increasing importance of healthy fish production and the expansion of the animal aquaculture industry to new geographic areas, new microbial and parasitic species with pathogenic potential continue to emerge. The book covers the broad spectrum of fish and shellfish health, the functional roles of pathogen emergence, and the impacts of nutrition and preventative medicine such as pre- and probiotics, as well as chemical treatments, relevant legislation, and more.

This reference takes a comprehensive approach to understand overall fish health management, making it valuable to aquaculturists, practitioners in aquatic animal health, veterinarians, and all those in industry, government, or academia who are interested in aquaculture and fisheries and their sustainable futures.

KEY FEATURES

- Presents biosecurity measures used to prevent the spread of disease
- Discusses fish immunology to understand preventive medicine for a healthy fish production
- Examines the latest scientific methods and technologies to maximize efficiencies for healthy fish production for farming
- Includes the most commonly researched fish, crustaceans, and molluscs in aquaculture

ABOUT THE EDITORS

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