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# A systematic quantitative literature review of aquaculture genetic resource access and benefit sharing

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## Abstract

The Convention on Biological Diversity provides a framework for countries to implement laws regulating the access, use and exchange of genetic resources, including how users and providers share the benefits from their use. While the international community has been preoccupied with resolving the unintended effects of access and benefit sharing (ABS) on domestication in agriculture for the past 25 years, its far-reaching consequences for global aquaculture has only recently dawned on policymakers, aquaculture producers and researchers. Using a systematic quantitative literature review methodology, we analysed the trends, biases and gaps in the ABS literature. Only 5% of the ABS literature related to the use and exchange of aquaculture genetic resources. Most of this literature related to use in developing countries or global use, but its authors were predominantly from developed countries. The literature covered a narrow range of countries (7) and regions (3), a narrow range of taxonomic groups (9) and a narrow range of uses. Given that aquaculture is the fastest growing global food production sector with products primarily from developing countries using over 580 species, there are significant gaps in aquaculture-related ABS literature. We conclude that the sector needs urgent analyses on the consequences of ABS restrictions, obligations and opportunities for its early stages of domestication and product development. We recommend priority areas for attention to ensure that rapidly evolving national ABS laws take into account the special characteristics and needs of the aquaculture sector.

**Key words:** access and benefit sharing, aquaculture, aquatic genetic resources, convention on biological diversity.

## Introduction

At a time when the aquaculture sector has its greatest need for access to physical and digital genetic resources during its early stages of domestication, research and technical development, these resources are becoming subject to a complex array of international biodiversity and trade regimes that restrict their free exchange. From the time the United Nations' *Convention on Biological Diversity* (CBD) entered into force in 1993, there has been a tidal wave of analyses on laws regulating access to genetic resources and sharing the benefits from their use (ABS laws) as humans begin to unlock their potential for conservation, global food and health security (e.g. Kamau *et al.* 2015; Dedeurwaerdere *et al.* 2016). There has been a similar body of literature on the restrictive effects of patents on accessing genetic resources used for agriculture and pharmaceutical sectors (e.g. Chiarolla 2011; Lawson & Rourke 2016). Yet, it has only been in the past decade that the use and exchange of genetic resources for aquaculture have entered into the regulation debate (e.g. Tvedt 2013a; Tvedt & Fauchald 2011; Rosendal *et al.* 2016). Consequently, the body of ABS literature still lacks a comprehensive and contextual analysis about how ABS regimes relate to, and affect the use and exchange of, aquaculture genetic resources.

Access and benefit sharing is a legal concept and framework for regulating how people and other legal entities can access and use genetic resources within the jurisdiction or

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control of a provider. It also regulates how providers of the genetic resources fairly share the benefits arising from their research and commercial use. The CBD and *Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Conservation on Biological Diversity* (Nagoya Protocol) are international agreements that outline an ABS framework for genetic resources within national jurisdiction. These apply generally to 'genetic resources', which are 'genetic material' of actual or potential value, that is 'any material of plant, animal, microbial or other origin containing functional units of heredity' (CBD Article 2).

The ABS concept has two distinct components – an administrative process for obtaining a permit from a relevant authority to take and use the resource (the access side) and a contractual process for sharing the benefits of the resource's use with the provider of the resource (the benefit sharing side). The concept works by generally requiring the recipient of a genetic resource to obtain the provider country's 'prior informed consent' (usually through a permit) to access (e.g. collect or take) a genetic resource. If a recipient wants to use 'Traditional Knowledge' associated with genetic resources, she/he must obtain the consent of the provider country and/or the relevant Indigenous peoples and local community. The recipient must share the benefits from the 'utilization of the genetic resource' (or knowledge) with the provider in a fair and equitable way according to 'mutually agreed terms' (Nagoya Protocol article 5), which might be in the form of a benefit sharing agreement, a material transfer agreement or some other contract. It is up to the contracting parties to agree on benefits, but they can include monetary or nonmonetary benefits such as technology/information transfer and capacity building. The Nagoya Protocol promotes an international monitoring and compliance system, including 'checkpoints' (such as export or patent offices) that verify whether a recipient of an aquatic genetic resource has complied with national laws. Noncompliance with national laws varies in each jurisdiction but can range from imprisonment, such as under the Malaysian Access to Biological Resources and Benefit Sharing Bill 2017 clause 21 (not yet in force) to fines or an inability to commercialise a genetic resource product on the international market.

Determining the extent to which ABS applies to a given transaction will depend on the national laws where the use or transaction is taking place. Countries have wide discretion for implementing their ABS obligations to suit their national interest. Variations include the types of resources that fall within national laws such as those from *in situ* (in ecosystems) and/or *ex situ* sources (e.g. gene repositories), public and/or private collections, and wild and/or domesticated resources. The laws may apply to physical materials only and/or intangible components such as information (e.g. digital sequence information) and knowledge (e.g. traditional knowledge associated with genetic resources). The purpose of use can also vary between national laws, for example, a law may exclude the purpose of aquaculture or the collection of broodstock from their ABS obligations under certain circumstances (see e.g. Australia's *Environment Protection and Biodiversity Conservation Regulation 2000* (Cth) regulation 8A.03). However, many countries are adopting the CBD's broad definitions of 'biological resources' and 'genetic resources', which include aquatic genetic resources, and its broad concept of 'utilization of genetic resources' to determine whether or not a resource and an activity fall within the scope of an ABS law. 'Utilization of genetic resources' means 'to conduct research and development on the genetic and/or biochemical composition of genetic resources, including through the application of biotechnology' (Nagoya Protocol article 2). The development of transgenic aquaculture species, DNA vaccines and other aquaculture biotechnology applications is likely to fall within scope of an ABS law. Depending on national interpretation, it is likely to include selective breeding for food and ornamental species and farming to obtain biomass for pharmaceutical applications but not sea ranching where there is no element of genetic manipulation. The implications of variations in national laws need to be determined on a case-by-case basis for each transaction of aquaculture genetic resources within a particular jurisdiction so that researchers and breeders can legally carry out their activities.

Access and benefit sharing regimes for more specific genetic resource use are also evolving, which may influence particular uses and exchanges of genetic materials and information for aquaculture purposes. For example, the *International Treaty for Plant Genetic Resources for Food and Agriculture* (Plant Treaty) is a multilateral ABS framework for plant genetic resources for use in food and agriculture that applies to a list of specific resources (article 10). The definition of plant genetic resources is broad enough to include aquatic plants (article 2). While no aquatic plants are in the list, the Plant Treaty encourages voluntary contributions of other genetic resources into the multilateral system (article 11(2) and 15). Instead of the CBD's bilateral system requiring individual benefit sharing contacts between parties, the Plant Treaty uses a Standard Material Transfer Agreement to reduce the time and cost burden on users of genetic resources for agricultural purposes. The international community is currently negotiating an Implementing Agreement to the *United Nations Convention on the Law of the Sea* (UNCLOS) that will, among other things, develop a framework for access and benefit sharing of aquatic genetic resources from areas beyond national jurisdiction (UN Doc, 2017). Trade agreements including the *Trade Related Impacts of Intellectual Property Rights*


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agreement and the national laws evolving under these frameworks have increasing relevance for ABS as researchers seek to protect their genetic resource inventions and research through patents, copyright and database protection. It is important to understand the implications of evolving ABS regimes on the use and exchange of aquaculture genetic resources so that the farming and research sectors can contribute to policy discussions.

The overall aim of this review is to assess the literature on ABS in relation to aquaculture genetic resources (AqGR) to identify gaps, trends and biases. We undertook a systematic quantitative literature review rather than a traditional narrative review to determine (a) where aquaculture fits within the ABS debate (Section 'Where does aquaculture fit within ABS analysis (resource, study area and author location)?') and (b) the focus of aquaculture ABS literature (section 'What is the focus of ABS in aquaculture (discipline, taxonomy, use, form)?'). More specifically, the review attempts to answer the following questions: (1) how well is aquaculture covered in the ABS literature? (2) where are studies on aquaculture ABS conducted? (3) what countries are the authors from? (4) what taxa are involved? (5) what habitats are covered? (6) what are aquaculture resources used for? and (7) what disciplines are the studies published in?

## Methodology

This review uses a systematic quantitative literature review (SQLR) method to assess the literature on ABS in aquaculture. This method bridges the gap between a traditional narrative review and a meta-analysis (see PRISM 2014). It systematically identifies peer-reviewed literature from a range of databases and quantifies the data, showing trends and biases for three levels of review. It is not intended to be a traditional narrative approach with an in-depth analysis of the findings and conclusions of each of the ABS publications. Rather it summarises the status of the literature so that the results are reliable, quantifiable and reproducible. It also provides a commentary on the literature gaps and reasons why more research is needed to fill them. In this SQLR, level 1 analysed all the literature on ABS. Level 2 analysed the literature on ABS of aquatic genetic resources (including those used for aquaculture and nonaquaculture purposes). Level 3 analysed only aquaculture-specific ABS literature. The data collection methodology is summarised in Figure 1.

### Steps under the preferred reporting items for systematic review recommendations

*Step 1: Articles identified from searches of online databases*

We searched four commonly used databases for this field (Scopus, Web of Science, Google Scholar and HeinOnline) for articles relating to access and benefit sharing. Our initial search used the search term 'access and benefit sharing' for articles published between 1993 and 2017. We chose 1993 as the initial search year because the CBD was adopted in 1992. We then modified our search with ('access and benefit sharing' OR 'genetic resources' OR 'genetic material' OR 'biological resources' OR 'biological materials'). We limited our search to journal articles, books, book chapters and early access papers (excluded grey literature, editorials, comments, reviews, white papers and conference proceedings) published in English. We entered the results from all four databases into a single Endnote library ($n$ = 1298). We then excluded duplicate references to produce the final Endnote library (ABS All First) for Step 1 containing 1092 articles.

*Step 2: Initial screening of Endnote library*

We manually searched the Endnote library from Step 1 (ABS All First) to exclude unrelated or irrelevant articles. Examples of exclusions are (i) articles where only title, abstract and keywords are in English; (ii) nonacademic articles, for example editorials, conference reviews and grey literature; (iii) articles where the topic used in the article does not match review topic; (iv) articles where the topic is only included in discussion as need for further research or might be applied to the review topic field; and (v) articles where the topic is only used in keywords and/or references. The final Endnote library for Step 2 (ABS All) contained 902 articles.

*Step 3: Identification of articles specifically relating to aquatic ABS*

We divided the finalised Endnote library from Step 2 (ABS All) into five main categories: aquatic, terrestrial, global perspective, traditional knowledge and digital resources ABS articles. Aquatic articles related specifically to aquatic habitats (e.g. freshwater and marine), species (e.g. fish and algae), activities (e.g. marine bioprospecting and aquatic farming) and form (e.g. physical resources or aquatic digital information). Terrestrial articles related specifically to terrestrial habitats, species, activities and resource form (e.g. plants and domestic animals). Global perspective articles were those that covered (i) both aquatic and terrestrial habitats/species/activities/form or (ii) policy, procedures and law relating to ABS generally. The traditional knowledge (TK) articles related to the role of TK in ABS or the impacts of ABS on TK. The digital resources articles related to the information-only components of genetic resources. The final Endnote library for Step 3 (Aquatic ABS) contained 124 articles.

*Step 4: Identification of articles specifically relating to aquaculture ABS*

We identified articles in the Endnote library resulting from Step 3 (Aquatic ABS) specifically relating to


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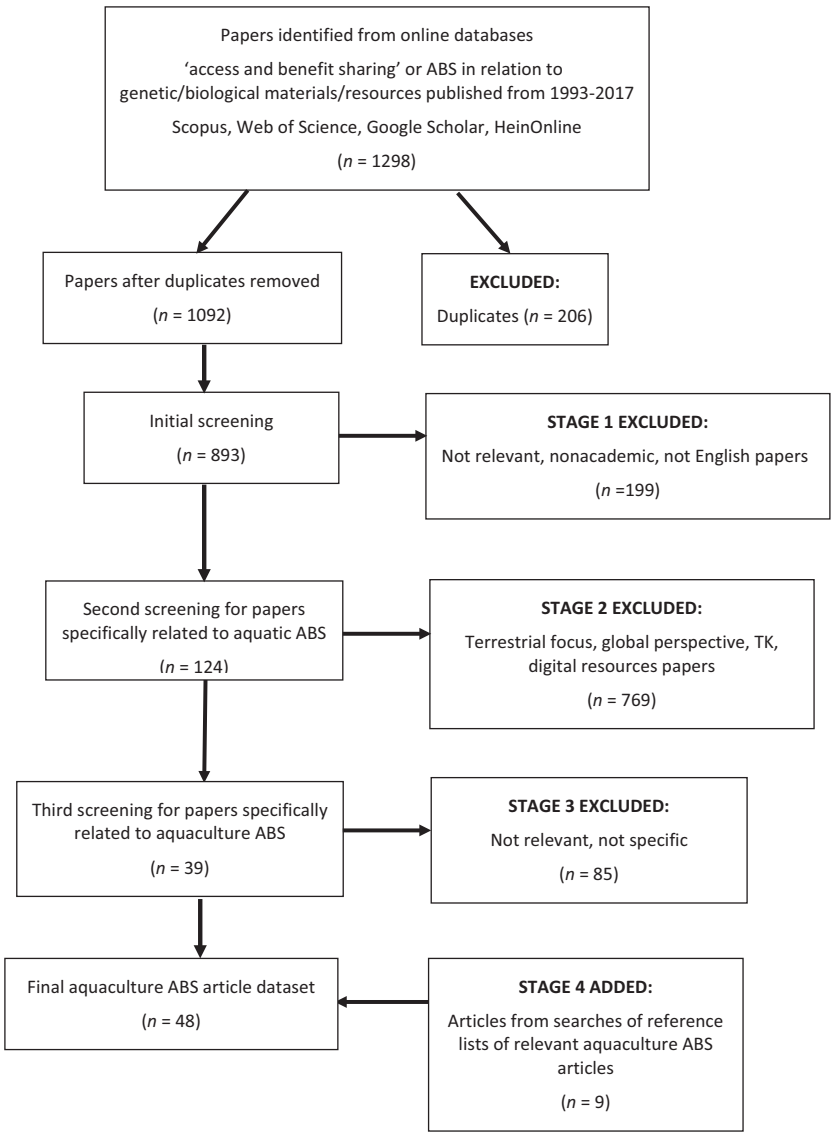



**Figure 1** Preferred Reporting Items for Systematic Review Recommendations (PRISMA) flow chart outlining the process for compiling this review (modified from Moher *et al.* 2015). *n* = number of articles.

aquaculture. We excluded articles where (i) the focus was on areas beyond national jurisdiction (ABNJ); (ii) the focus was on climate change; (iii) the focus was on traditional knowledge other than relating to aquatic genetic resources; and (iv) ABS was mentioned as relevant without further explanation.

This refinement resulted in 39 articles specifically relating to aquaculture ABS. We searched the reference lists of these 39 articles and cross-referenced with Google Scholar for any additional relevant articles that were missed by our initial searches of the databases and that met all the inclusion criteria (9 articles). The final Endnote library on aquaculture ABS consisted of 48 articles.

These 48 articles were manually entered into an Excel database for analysis of geographic, taxonomic and other thematic patterns. Key data entered included authors, article title, publication title, year of publication, discipline area, country of study, author affiliation country, habitat/medium, general taxonomic group covered, individual species covered, specific topic and whether there was specific mention of intellectual property (IP) or traditional knowledge (TK) in the article.

We identified discipline area using SCImago (http://www.scimagojr.com/index.php) classification of different journals. Author affiliation country was allocated based on (i) where the majority of authors were based; or (ii) in the



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**Table 1** Summary of level 2 aquatic ABS and level 3 aquaculture ABS categories

| Category type | Categories | Level 2 aquatic ABS ($n$ = 124) | Level 3 aquaculture ABS ($n$ = 48) |
|---|---|---|---|
| Medium | Freshwater vs marine vs all media | X | X |
| General taxa | Animal vs plant vs microbe vs all taxa | X | X |
| Specific taxa | By species or species groups, for example tilapia and paeneid shrimp | | X |
| Specific topic | Selective breeding vs biotechnology vs bioprospecting vs conservation | X | X |
| General geographical area of study | Tropical vs temperate vs global | X | X |
| Specific geographic area of study | Individual country vs areas beyond national jurisdiction (ABNJ) vs region (e.g. Africa) vs global | X | X |
| Development status of study country† | Developed vs developing vs least developed | X | X |
| Specific geographical area of author affiliation | Individual country | X | X |
| Development status of author affiliation country† | Developed vs developing vs least developed | X | X |
| By discipline | Subject area based on SCImago classifications | | X |
| Specific mention of | Traditional knowledge or intellectual property | | X |

†Based on UN Human Development Index.

cases of two authors from separate countries or equal numbers of countries for multiple authors, the country affiliation of the first author. We used this method to better capture the intellectual contributions of authors from different countries to each article and the overall database. The development regions for author affiliations and study countries were based on the UN Human Development Index (http://hdr.undp.org/en/content/human-development-index-hdi).

### Methods – analyses of patterns, trends and themes

*Level 1 analysis – complete ABS data set*

We classified the articles in the ABS All data set ($n$ = 902) into five main categories: aquatic, terrestrial, global perspectives, traditional knowledge and digital resources (see Step 3 above for details of each category). We then further split the terrestrial ($n$ = 231) and aquatic ($n$ = 124) categories into four broad taxonomic groups: plant, animal, microbe and all taxa. This allowed us to determine which taxonomic groups were best represented in the ABS literature and whether there were general taxonomic differences between the terrestrial and aquatic groups.

*Level 2 analysis – aquatic ABS analysis*

We categorised articles in the aquatic ABS database ($n$ = 124) in several ways to identify geographic and other thematic patterns. These categories are summarised in Table 1.

*Level 3 – aquaculture ABS analysis*

Using the Excel database, we categorised the 48 aquaculture ABS articles to identify common geographical, taxonomic and other thematic patterns. The categories are summarised in Table 1.

## Results

### Where does aquaculture fit within ABS analysis (resource, study area and author location)?

*Resource origin*

The systematic search identified 902 peer-reviewed articles on ABS of all genetic resources (level 1), but only 5% (48) were related to ABS of aquaculture genetic resources. Almost half the publications (430, 48%) did not specify the origin of the genetic resources. Instead, they focused on genetic resources generally ('global' origin). Of those that did specify the subject matter of ABS, the majority (231, 26%) analysed physical genetic resources from terrestrial environments, while 14% (124) analysed those from aquatic environments (aquatic and aquaculture genetic resources combined). The remaining literature focused on the information/knowledge components of genetic resources – traditional knowledge (91, 10%) and digital genetic resources (26, 2%). However, the bulk of the 'information' literature referred to terrestrial application of the knowledge or digital resources.

Of the publications that focused on genetic resources from aquatic environments (for aquaculture and other


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uses such as pharmaceuticals), there was a strong bias towards genetic resources from marine environments (70%, Table 2) (e.g. Guo 2009; Humphries 2017a). These were mainly from Areas beyond National Jurisdiction (the high seas and the deep seabed) and the Antarctic Treaty Area where biotechnology, not aquaculture, is the focus of resource collection (e.g. Tvedt & Jørem 2013). Most aquaculture-specific literature related to a range of species in both freshwater and marine environments (73%, Table 2) (e.g. Adarsha *et al.* 2011). Only 10% related to marine-only environments, while 17% related to freshwater-only environments.

*Study area and author location*

The majority of the aquaculture literature (67%) did not specify a country (Table 2, e.g. Bartley *et al.* 2009a; Olesen *et al.* 2008; Nguyen *et al.* 2009). The only countries specifically analysed were Bangladesh, China, Ghana, India, Norway, Philippines and Vietnam while regions specified were Asia, Africa and the Pacific (e.g. Lind *et al.* 2012; Olesen *et al.* 2007; Rosendal *et al.* 2012; Ramanna-Pathak 2015). Of those studies that did specify a location, 25% examined AqGR access/use in developing and least developed country locations (Table 2) with only 8% studying aquaculture in developed countries. In contrast, authors in developed countries wrote most of the literature (58%) with only 2% coming from least developed countries (Table 2).

**Table 2** Summary of aquatic ($n$ = 124) and aquaculture ($n$ = 48) ABS literature, rounded to the nearest integer value

| Category | Specific category | Aquatic ($n$, %) | Aquaculture ($n$, %) |
|---|---|---|---|
| Medium | Marine | 87 (70%) | 5 (10%) |
| | Freshwater | 10 (8%) | 8 (17%) |
| | All | 27 (22%) | 35 (73%) |
| General taxonomy | Plant | 3 (2%) | 3 (6%) |
| | Animal | 25 (20%) | 20 (42%) |
| | Microbe | 4 (3%) | 0 |
| | All taxa (not specified) | 92 (75%) | 25 (52%) |
| Study region | Tropical | 18 (15%) | 9 (19%) |
| | Temperate | 15 (12%) | 5 (10%) |
| | Global | 91 (73%) | 34 (71%) |
| Resource use | Selective breeding | 36 (29%) | 40 (84%) |
| | Biotechnology | 17 (14%) | 5 (10%) |
| | Bioprospecting | 64 (52%) | 2 (4%) |
| | Conservation | 7 (5%) | 1 (2%) |
| General study locations | Developed | 11 (9%) | 4 (8%) |
| | Developing | 18 (15%) | 11 (23%) |
| | Least developed | 1 (0.1%) | 1 (2%) |
| | Global | 69 (56%) | 31 (65%) |
| | ABNJ† | 13 (10%) | 1 (2%) |
| | Regional | 12 (9.9%) | 0 |
| General author affiliation | Developed | 95 (76%) | 28 (58%) |
| | Developing | 29 (23.9%) | 19 (40%) |
| | Least developed | 1 (0.1%) | 1 (2%) |

†Areas beyond national jurisdiction.

Author location and study location were often not connected (Fig. 2). Most aquaculture authors came from Norway (23%) and Australia (17%) and yet only 8% of the literature related to Norway aquaculture. Norway, China and India were the main country locations specified in the literature, yet only 10% of authors were located in China and 12% came from India. Other authors came from Bangladesh, Canada, Chile, France, Germany, India, Ireland, Italy, Malaysia, Philippines, Spain, Thailand and United States. This indicates that most authors were writing about aquaculture generally (globally) or in countries other than their own.

## What is the focus of ABS in aquaculture (discipline, taxonomy, use, form)?

*Discipline*

While the aquaculture ABS literature was published in a range of journals and disciplines, most of the literature (75%) was published in scientific journals (Fig. 3). The remaining articles were from the primarily from the fields of policy, law and governance.

*Taxonomy*

There was a distinct bias towards analysis of plant genetic resources (194 articles, 84%) in the 231 terrestrial ABS articles, with 10% (23) on animal genetic resources, 1% (2) on microbes and 5% (12) with unspecified genetic resources. In contrast, 42% of the aquaculture literature focused on animal genetic resources (Table 2), 52% on unspecified resources and only 6% on plant genetic resources. Less than 3% of aquatic ABS literature focused on microbial genetic resources (Mazarrasa 2013), although a large component of the unspecified literature raised issues that were relevant for this classification.

Almost half of the literature on ABS in aquaculture did not specify a species or had a mix of species (Fig. 4). Of the articles that identified species or taxonomic groups, the majority related to tilapia (17%), salmon (10%), crustaceans (10%), carp (8%) and catfish (8%) (e.g. Eknath & Hulata 2009; Jeney & Jian 2009; Na-Nakorn & Brummett 2009; Nguyen 2009; Andriantahina *et al.* 2013). Only 4% related to seaweed (e.g. Mantri *et al.* 2017).

*Use of genetic resources*

The literature explored four major uses of aquatic genetic resources – selective breeding, bioprospecting, biotechnology and conservation. Over 50% of the aquatic literature focused on accessing the resources for bioprospecting (searching for species from which commercially valuable compounds can be obtained), primarily for lucrative uses



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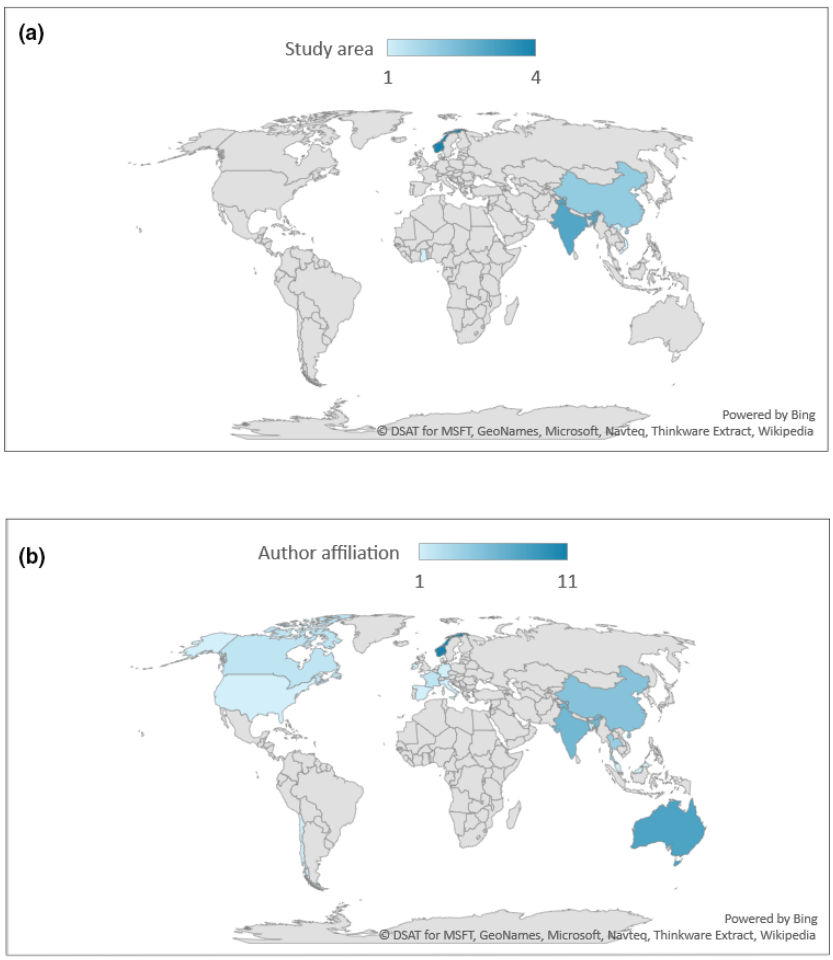



**Figure 2** National geographic location of aquaculture ABS (a) study sites and (b) author affiliations. Note that the study site locations are only provided for those studies located in a single country (excludes global- and regional-based articles).

such as pharmaceuticals (e.g. Leary *et al.* 2009) (Table 2). Fourteen per cent of aquatic literature focused on the next stage of research – using those resources for biotechnology purposes (e.g. Ninawe & Indulkar 2017). Most of the remaining literature concerned selective breeding in aquaculture (e.g. Rosendal *et al.* 2006).

Of those aquatic publications relating to aquaculture, 84% focused on selective breeding, while only 14% concerned biotechnology and bioprospecting (Table 2). A similar proportion of both aquatic and aquaculture categories focused on conservation of the genetic resources (5% and 2%, respectively).

*Form of genetic resources – tangible and intangible*

Most aquaculture-specific literature touched on the information or knowledge aspects of resource use and exchange, with intellectual property issues featuring heavily (22 articles, 46%) (e.g. Tvedt 2013b; Humphries 2016a,b). Most of these articles explored the effects of patents on accessing genetic resources for product development. While 19% (9) examined issues relating to both intellectual property and traditional knowledge, only one publication explored traditional knowledge associated with aquaculture genetic resources as an issue in its own right (e.g. Rosendal *et al.* 2013b). A third of the literature (16 articles) did not mention either.

## Discussion

### Research on ABS aquaculture is geographically limited

*Resource origin*

The results reveal a strong bias in the literature towards analysing ABS in relation to terrestrial genetic resources and associated information, rather than resources from aquatic environments, particularly those that relate to


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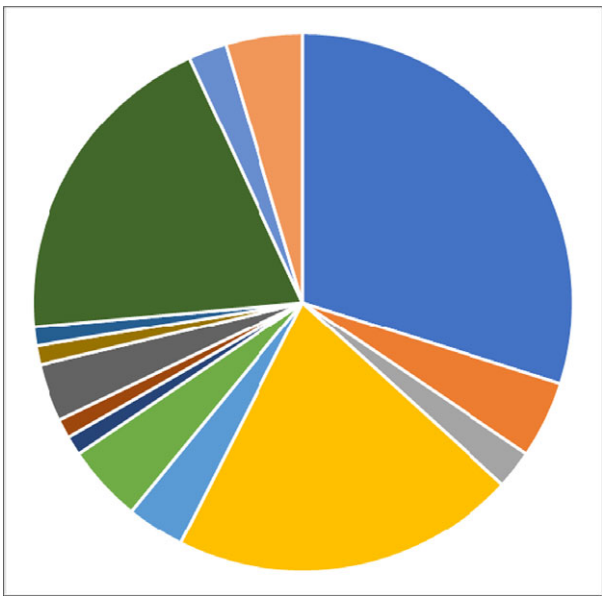


**Figure 3** Summary of key discipline areas publishing studies on aquaculture ABS. Journal discipline area identified using SCImago (http://www.scimagojr.com/index.php) classification. Note categories are not exclusive. (■) Aquatic Science; (■) Biotechnology; (■) Conservation; (■) Ecology; (■) Economics and Econometrics; (■) Environmental Science; (■) Governance; (■) Medicine; (■) Microbiology; (■) Oceanography; (■) Plant Science; (■) Policy and Law; (■) Political Science; (■) Social Science.

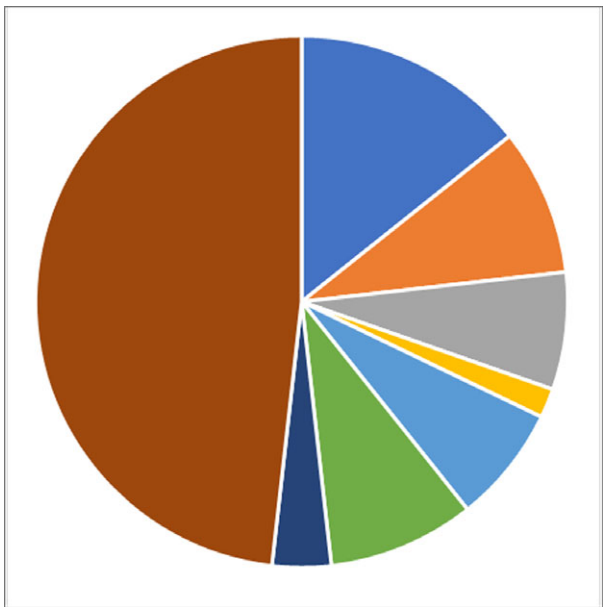


**Figure 4** Breakdown of aquaculture ABS species or species groups. (■) Tilapia; (■) Salmon; (■) Carp; (■) Cod; (■) Catfish; (■) Crustacean; (■) Red Seaweed; (■) Other/non specified.

aquaculture. The terrestrial bias of the ABS literature reflects the history of conflict that led to negotiation and agreement on the CBD's bilateral ABS regime. As a generalisation, the conflict arose in the context of using territorial (particularly plant) genetic resources. 'South' (developing) biodiverse-rich countries, where the majority of genetic resources for global crops originated, objected to 'North' (developed) countries freely taking the resources and profiting from the products and technologies arising from their use and restricting other countries' access to them (Frison *et al.* 2011). The compromises under the CBD for recognising state sovereignty over its resources and developing the ABS framework was an attempt to create fairness and economic incentives for conserving and sustainably using biological resources by requiring users of genetic resources to compensate those who bear the cost of conserving and providing the resources (Lawson 2012). In contrast to the terrestrial pattern of exchange, resource sharing for commercially important aquaculture species generally flows from South to South or North to South (Bartley *et al.* 2009b). Structural developments of the aquaculture sector are leading to fewer and larger companies so conflicts are more likely between small- and large-scale private actors rather than between countries (Rosendal *et al.* 2013a). The vastly different patterns of exchange and potential conflict for terrestrial, as opposed to aquatic, genetic resources raise the question about whether the global ABS regime can accommodate aquaculture's unique characteristics. Given that only 5% of the literature analysed ABS in relation to aquaculture, there is not enough research to answer this question.

When aquatic genetic resources were analysed in the context of ABS, the strong bias in the literature towards those from marine environments in areas beyond national jurisdiction and in the Antarctic Treaty Area reflects the economic (as opposed to conservation) drivers for ABS analysis. These areas contain genetic resources predominantly collected for their potential value in the pharmaceutical and nutraceutical biotechnology sectors (Leary *et al.* 2009). Despite the more extensive use (by volume) of aquatic genetic resources in aquaculture than biotechnology, the assessment of advantages and disadvantages of ABS for aquatic genetic resources is biased towards the needs and characteristics of its high-value sectors. The aquaculture-specific ABS literature referred to both marine and freshwater environments, with slightly more emphasis on freshwater. This reflects the patterns of habitat preference in aquaculture where both marine and freshwater production are rising, but inland finfish culture is currently the most common type of aquaculture production in the world (FAO 2016).

The low representation of aquaculture genetic resources (AqGR) in ABS analyses (only 5%) is disproportionate to the importance of fair resource use and exchange in the



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aquaculture sector. Modern aquaculture was virtually unknown 40 years ago, but since 2013, aquaculture has become the main global source of fish for human consumption (OECD-FAO, 2017). Even with its rapid increase in production, the sector still needs exponential growth to fulfil its expected role for global food security. Estimates of future production increases necessary for feeding global populations range between 350 and 1000% (FAO 2010; Dunham 2011).

Fish are susceptible to reduced viability if inbreeding occurs and genetic improvement programmes generally aim at maintaining as much genetic variation as possible within the population (Rosendal *et al.* 2013a). The requirement for genetic diversity for farmed aquatic animals is possibly greater than for livestock, because the high fecundity of aquatic animals makes it too easy for farmers to obtain all their germplasm from one or two individuals (Greer & Harvey 2004). Global aquaculture is heavily dependent on wild stocks as the penetration of genetically improved material is still limited in production systems – and much of the use of improved material in production systems is limited to a few species such as white shrimp, salmon and tilapia (Gjedrem 2012; Nguyen 2016). The CBD envisages both wild and domesticated aquatic genetic resources falling within scope of national ABS laws. This heavy dependence on wild inputs for genetic viability means that restrictions on the use and exchange of AqGR will have a profound effect on aquaculture's early stages of domestication. The agricultural sector was not similarly restricted in its early stages of domestication that spanned thousands of years (Koo *et al.* 2004). Given the world's hopes for aquaculture to fill the growing hole in global food security, it is surprising how little research there is about how ABS affects the aquaculture sector with its unique resource use and exchange characteristics.

*Study area and author location*

The global nature of most aquaculture-specific ABS literature reflects a similar trend in the overall ABS literature, where authors discuss how transactions of biological resources fall within the international regimes generally, rather than analysing how particular national ABS laws affect genetic resource use and exchange more specifically. This global approach does not effectively highlight an important challenge for aquatic genetic resource access, use and benefit sharing—pinpointing the origin of free-flowing migratory resources between jurisdictional areas. Determining whether ABS and technology transfer obligations under the various instruments apply to a given genetic resource depends on where the physical sample originated. In other words, geographical origin is emerging as the approach for determining whether a given resource falls within a particular regime. This geographical origin benchmark might be relatively clear for terrestrial resources confined to national jurisdictions. However, aquatic genetic resources are located within national jurisdictions, in areas beyond national jurisdiction and in the Antarctic Treaty Area, which causes complexities for overlapping regimes in the three jurisdictional areas (see Humphries 2017b). The free movement of aquatic species between jurisdictional areas and the lack of information about the particular accession's origin challenges whether the geographical approach is appropriate for the exchange and use of aquatic genetic resources. More research is needed to explore whether this bilateral and geographical approach to ABS can effectively regulate highly migratory and highly fecund AqGRs. This gap is particularly urgent in the light of the current negotiations for an Implementing Agreement under UNCLOS that is likely to manage ABS in areas beyond national jurisdiction (United Nations General Assembly 2017).

Where the literature did specify countries, the relatively large numbers of studies about aquaculture ABS in developed countries is disproportionate to the importance of aquaculture to developing countries. Developing countries: (i) supply 90% of global aquaculture products (FAO 2016); (ii) depend on farmed fish as a primary source of protein (World Bank 2007); (iii) depend on the sector for sustainable livelihoods (in 2012, 96% of fish farmers were in Asia, FAO 2014); and (iv) depend on aquaculture products for their economies and trade (accounting for half of all traded commodities in some developing countries, FAO 2014).

According to the FAO, the biggest producers of farmed product are China, India, Indonesia, Vietnam, the Philippines and Bangladesh, which account for more than 83% of the world's aquaculture production (FAO 2016). Yet the primary country included in the aquaculture ABS literature was Norway, followed by (in order) India, China, Bangladesh, Vietnam, Ghana and the Philippines. The absence of ABS literature about Egypt (a top 10 producer) is a significant gap for gaining an accurate picture of the effects of ABS in aquaculture, given that Nile tilapia accounts for 90% of all tilapia cultured outside their native Africa (Tran *et al.* 2011).

It is questionable whether the body of literature offers an accurate picture of ABS in aquaculture as most authors were writing about aquaculture globally or in countries other than their own. The analyses in the literature were generally in the form of generic or abstract, desk-top studies which suggests an absence of empirical research about the actual practices of farmer and researcher use and exchange of AqGR. This review revealed a distinct trend of authors in developed countries writing about aquaculture practised in developing countries, importing their own cultural biases and perspectives. In addition, the literature reviewed was only in English and it is highly likely that there are other authors from developing countries writing


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about ABS in their own countries and languages. However, the body of English literature that has the capacity to influence international bodies and policymakers lacks the perspectives of developing country authors – to the detriment of accurate and contextual ABS analysis.

**The focus of ABS in aquaculture is limited in scope**

*Discipline*

Despite ABS being a legal framework, scientific disciplines dominate the discourse about ABS in aquaculture with only 25% of the literature originating from policy and law journals. This indicates that scientific practicalities are driving the debate about the relationship between ABS and aquaculture, rather than legal, economic, human rights or political drivers. The trend may be the result of the scientific community's concerns that unnecessary red tape (see Lawson 2011) and restrictive access requirements may discourage basic research (Grajal 1999). Aquatic science generally lags behind terrestrial sciences in basic data such as the status and trends of aquatic genetic material (FAO, 2013), identifying species, understanding ecosystem relationships and assessing potential uses for genetic resources (UN Doc 2013a). Communities of life on the ocean floor are among the least-understood systems on the planet (Schoenberg 2009). Research on aquatic genetic material faces additional complications associated with the complexity of aquatic ecosystem interactions and their relative inaccessibility (Greer & Harvey 2004). Greer and Harvey (2004) argue that, unlike in aquatic sciences, much of the basic research on plant genetic material was carried out before access requirements became an international issue. They caution that the 'lag in aquatics-related knowledge means that access to aquatic genetic resources for basic research may be even more crucial than in plant research, and impediments are likely to delay advances in uses of aquatic genetic resources, especially in aquaculture' (Greer & Harvey 2004, p. 79).

Aquatic sciences are following the trends in terrestrial sciences towards corporate sponsored research (including government partnerships) with its focus on practical, profitable applications (Rosendal *et al.* 2013a). This economic focus of applied science may explain why one of the discipline categories with the least amount of ABS literature was 'conservation'. Across all journals, only 2% of the literature related to conservation of aquaculture genetic resources. This indicates that authors are more concerned with the effect of ABS on scientific applications of AqGRs and commercialisation than they are with the original conservation purpose of ABS. Given that most aquaculture relies on the conservation of wild stocks, analyses about whether the predominant model of ABS achieves its conservation objectives is a crucial area for research. This may also imply that the potential impact of ABS legislation on trade and innovation was not understood in framing the legislation and the need to better understand those impacts to achieve a practical implementation of the process.

*Taxonomy*

The FAO lists 580 species with production data from aquaculture (FAO 2016). Yet, the aquaculture-specific ABS literature mentioned only seven taxonomic groups – tilapia, salmon, carp, cod, catfish, shrimp and seaweed (e.g. Benzie 2009; Solar 2009; Andriantahina *et al.* 2013). This list generally correlates to the top species for global production. Top species include carp, tilapia, catfish, salmon and shrimp (FAO 2018). However, focusing the aquaculture ABS literature on a handful of species means that the effects of ABS regimes for the overwhelming majority of aquaculture species are unknown.

Most aquaculture ABS literature related to aquatic animals while the terrestrial ABS literature overwhelmingly analysed plants. Only three aquaculture papers referred to aquatic plants (e.g. Jacob & Reddy 2015; Mazarrasa 2013). Yet, according to the FAO, farmed aquatic plants (seaweed and microalgae) account for 25% of total aquaculture production by volume (FAO 2016). It is unclear why there is such little attention on ABS of aquatic plants. Perhaps, it is because their share in total aquaculture value is disproportionately low at less than 5% (FAO 2016). The lack of analysis is a concern because the sector is growing exponentially. For example, Indonesia's share of global farmed seaweed production increased dramatically from 6.7% in 2005 to 36.9% in 2014 (FAO 2016), but the aquaculture ABS literature does not mention Indonesia. FAO's statistics significantly understate microalgae culture (e.g. spirulina) despite large-scale production in Australia, India, Israel, Japan, Malaysia and Myanmar (FAO 2016). The lack of ABS literature about aquatic plants is a significant gap in legal analysis.

*Use of genetic resources and benefit sharing agreements*

The results show a strong bias in the general aquatic literature towards the effect of ABS rules on taking genetic resources from areas beyond national jurisdiction for biotechnology purposes in the pharmaceutical sector. In contrast, the focus on selective breeding rather than biotechnology in the aquaculture-specific literature reflects the aquaculture sector's early stages of domestication and biotechnology product development. In contrast to the agriculture sector, aquaculture has a high percentage of production from wild-derived seed, or closely related to wild stocks, and a much smaller proportion of genetically improved material (Gjedrem 2012; Chavanne *et al.* 2015). Most of the genetically improved stocks in aquaculture are derived from selective breeding programmes rather than


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biotechnology interventions (Gjedrem 2012). These percentages are likely to change in coming years, particularly as the first genetically modified fish (salmon) was approved for commercialisation in 2017, opening the gate for other transgenic species under development including tilapia (e.g. Caelers *et al.* 2005). The bulk of the literature examined ABS in relation to selective breeding while a relatively small proportion (10%) focused on ABS for aquaculture biotechnology applications. Only two papers mentioned bioprospecting for aquaculture species or aquaculture product development. It is unclear whether the lack of aquaculture bioprospecting literature indicates that the sector is not looking for new aquaculture species for this purpose or whether there is a significant underanalysis of bioprospecting activities that would trigger ABS obligations.

The small percentage of aquaculture ABS literature (5%) reflects the limited current awareness of ABS laws and limited use of benefit sharing agreements or material transfer agreements in the aquaculture sector. Most genetic resources and technologies for breeding in aquaculture are freely exchanged or sold without further conditions attached (Louafi & Schloen 2008). The exception is high-value species or aquaculture technologies subject to intellectual property, particularly those produced in developed countries with strong ABS frameworks. This could explain the high proportion of ABS literature from Norway, despite salmon having less production by volume than species in developing countries. However, it is likely that ABS agreements for sharing genetic resources for breeding in the aquaculture sector will increase as (i) countries clarify and implement their ABS obligations under the relevant instruments; (ii) farmers become aware of their obligations under national ABS laws; and (iii) the aquaculture sector relies more heavily on biotechnologies.

For some of the major species, there is a trend to develop local strains of farmed animals to counteract the spread of disease, which may limit the exchange of biological material but increase the need to exchange technology and information (Bartley *et al.* 2009b). However, analysis of information obligations and the use of digital genetic resources are a significant gap in the aquaculture ABS literature. Unlike the extensive system for the exchange of terrestrial plant germplasm collections, there is 'no coordination between aquatic gene banks', nor accepted protocols or regulations governing access and use of the materials and information (Greer & Harvey 2004, p. 33; Bartley *et al.* 2009b, p. 24). The sector needs more research on how to manage information sharing between aquatic gene banks and other users and providers of AqGRs.

*Form of genetic resources – intangible aspects, traditional knowledge and intellectual property*

The domination of scientific perspectives on ABS in aquaculture and its effect on changing physical materials may overshadow perspectives from other knowledge bases, such as traditional knowledge from Indigenous peoples and local communities. Where the literature did mention traditional knowledge, it was mostly associated with intellectual property aspects, rather than ABS regimes. There are very few examples in the literature of how ABS regimes relate to traditional knowledge associated with aquaculture genetic resources (Demunshi & Chugh 2010), despite the broadening category of what constitutes local community traditional knowledge, which might include 'long term established rice and fish farmers in Asia' (UN Doc 2013b, p. 4). Given that the majority of aquaculture takes place in Local Communities in developing countries, this is an important gap to address.

Much of the aquaculture literature in law and policy journals touched on the effect of intellectual property on aquaculture ABS (e.g. Humphries 2015). This may be the result of the bias towards the developed country perspectives of the majority of authors. This trend mirrors the abundance of nonaquaculture literature about the relationship between patents and ABS obligations under the CBD and Protocol (e.g. Morgera *et al.* 2013), particularly in relation to plant genetic resources (e.g. Halewood *et al.* 2013). There is comparatively little research in the general and aquaculture-specific literature about the relationship between copyright (or other forms of intellectual property) and ABS information obligations under these instruments (Reichmann *et al.* 2016). Considering the growing importance of digital sequence information and associated information to aquaculture research and ABS, this is an important gap in the literature.

**What important research gaps remain?**

The literature review revealed some significant gaps in aquaculture ABS analyses. There needs to be more research about how ABS regimes can adapt to aquaculture's unique characteristics and patterns of exchange if law and policy are to strive towards fair and equitable outcomes in this sector. The characteristics include aquaculture's heavy reliance on wild materials for its early stages of domestication; the difficulties for determining geographical origin of highly migratory and highly fecund aquatic resources; and the relatively uncoordinated networks of information and material exchanges in *ex situ* facilities and developing countries where the majority of aquaculture projects come from.

Consequently, the aquaculture sector would benefit from more comprehensive analyses of (i) the implications of ABS international frameworks and national laws for aquaculture in developing countries, which are authored or co-authored by local researchers; (ii) the impacts of ABS on a broader range of species, including low value species that are important to aquaculture in developing


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countries, as well as aquatic plants; (iii) the impacts of permitting, contracting, reporting and tracking obligations in a sector whose users are predominantly poor farmers that freely exchange genetic materials; (iv) the role of ABS for conservation of AqGR, including whether the predominant bilateral ABS model achieves its conservation objectives for aquatic biological resources; (v) the extent to which Indigenous peoples and local communities' traditional knowledge associated with aquatic genetic resources relates to aquaculture species and practices; and (vi) the implications on product development if national laws impose ABS restrictions on the use and exchange of digital sequencing information and other nonphysical aspects of genetic resources.

## Conclusion

Despite the CBD being in force for nearly 25 years, almost all the literature about ABS in aquaculture is less than a decade old (from 2009). Even then, it only accounts for a tiny 5% of all ABS analyses. This indicates that while researchers have been preoccupied with the unintended effects of global ABS regimes on the agriculture and health sectors since the CBD entered into force, ABS's far-reaching consequences for global aquaculture have only recently dawned on policymakers, aquaculture producers and researchers. The research and attention on the effect of ABS on agriculture culminated in the Plant Treaty, which came into effect in 2007. The multilateral Plant Treaty attempted to accommodate the unique considerations of the agriculture sector after it became apparent that resource use in the sector did not suit the geographical and bilateral nature of the CBD's ABS regime. With the immediate pressure off the agriculture sector, the literature started to reveal similar challenges for the aquaculture sector. However, the literature has not achieved a critical mass sufficient to mobilise the international community to think about an ABS regime better suited to aquaculture's use and exchange of genetic resources. One of the major reasons is that developing countries, where most of global aquaculture occurs, do not have the capacity to research the effects of ABS in aquaculture. Waiting until developed countries feel the adverse effects of aquaculture ABS in their markets (as it did for agriculture) may be too late for aquaculture in its crucial early stage of domestication.

So users, providers and intermediaries of AqGR may ask themselves, where does aquaculture fit within ABS analysis? The short answer is that it does not fit because policy and lawmakers are trying to retrofit a system designed for terrestrial agriculture and high-value biotechnology sectors to the aquaculture sector with different patterns of resource exchange and conflict. There is not enough research on the consequences of ABS restrictions, obligations and opportunities for the sector in its early stages of domestication and biotechnology product development. Where there is aquaculture analysis, it focuses on a narrow group of species, uses and forms of genetic resources and poses hypothetical questions about what could happen if ABS laws apply. These laws, which vary significantly between countries, are already rapidly coming into effect worldwide. Aquaculture farmers and researchers need specific examples or guidance about whether they apply to their own biological or genetic resource use. For example, does it apply to some or all aquaculture biotechnology applications, selective breeding, multiplication or sea ranching activities? How do benefit sharing agreements work in practice for the aquaculture sector? What are the consequences of noncompliance with 'prior informed consent' and benefit sharing agreement obligations? Research or case studies on the actual (as opposed to hypothetical) application of ABS on aquaculture is the first step for offering farmers and researchers more certainty for their breeding and biotechnology activities.

The first *State of the World's Aquatic Genetic Resources for Food and Agriculture* report is due for publication by the Food and Agriculture Organisation's Commission on Genetic Resources for Food and Agriculture in 2018. The scope of the report will include global information on farmed aquatic species and their wild relatives within national jurisdiction (FAO 2015, appendix II paragraph 1). The report will include inventories of aquatic genetic resources for food and agriculture, drivers impacting them, *in situ* and *ex situ* conservation, institutional capacities, research and international collaboration and relevant legislation and policies. It is hoped that this report will spark a flurry of literature on aquaculture ABS as policy and lawmakers begin to see the challenges that the sector faces in complying with national laws arising from an international regime designed to address conflict over resource use and exchange in other sectors.

In the meantime, this review found that research on ABS aquaculture is geographically limited and that the focus of species, use and nature of ABS in aquaculture is restricted in scope. Without significantly more literature analysing the implications of ABS for aquaculture, the international regimes and national ABS laws will continue to evolve without taking into account aquaculture breeding and product development needs.

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