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REVIEW

Aquaculture expansion in Brazilian freshwaters against the Aichi Biodiversity Targets

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Abstract The Convention on Biological Diversity proposed the Aichi Biodiversity Targets to improve conservation policies and to balance economic development, social welfare, and the maintenance of biodiversity/ecosystem services. Brazil is a signatory of the Aichi Biodiversity Targets and is the most diverse country in terms of freshwater fish, but its national policies have supported the development of unsustainable commercial and ornamental aquaculture, which has led to serious disturbances to inland ecosystems and natural resources. We analyzed the development of Brazilian aquaculture to show how current aquaculture expansion conflicts with all 20 Aichi Targets. This case suggests that Brazil and many other megadiverse developing countries will not meet international conservation targets, stressing the need for new strategies, such as the environmental management system, to improve biodiversity conservation.

Keywords Biodiversity conservation · Blue revolution · Convention on Biological Diversity · Environmental management system · Megadiversity · Non-native invasive species

INTRODUCTION

Brazil contains extraordinary aquatic biodiversity, distributed in various biomes, ecoregions, Ramsar sites, and conservation hotspots (Vitule et al. 2012; Pelicice et al. 2017). This rich natural patrimony has enabled the country to play a central role in international debates, serving as an important negotiator to advance international conservation goals (Scarano et al. 2012). In 2010, during the tenth meeting of the Conference of the Parties of the Convention on Biological Diversity (CBD, Nagoya Protocol), for example, Brazil and 192 other countries established the Strategic Plan for Biodiversity 2011–2020, proposing 20 targets to reduce biodiversity loss on a global scale—the Aichi Biodiversity Targets (www.cbd.int).

Seven years after the CBD, however, national policies worldwide have conflicted with conservation goals and agreements (Joppa et al. 2013; Titensor et al. 2014; Di Marco et al. 2015). Following this international scenario, Brazil has implemented a series of policies to prioritize short-term economic development (Fearnside 2016; Pelicice et al. 2017); the expansion of the aquaculture industry is one instance (e.g., Bueno et al. 2015). Such policies call into question Brazil's commitment to meeting international agreements, because unsustainable aquaculture (e.g., commercial and ornamental) has great potential to damage aquatic biodiversity and ecosystem functions and services (Diana 2009; Vitule et al. 2014; Pelicice et al. 2017). Brazil is not a special case, as several Latin American countries have relied on harmful practices to achieve development, including Mexico, Costa Rica, and Colombia, among others (Ochoa-Ochoa et al. 2017; Pelicice et al. 2017). This scenario suggests that megadiverse developing countries will not meet some international conservation targets, and the Brazilian case may serve as model (e.g., Frehse et al. 2016; Pelicice et al. 2017) to understand the interaction between national development strategies and international conservation agreements.

To explore this problem, we analyze the interaction between the recent and current expansion of Brazilian aquaculture and the Aichi Targets to show potential conflicts and encourage discussions. We demonstrate how some components of aquaculture expansion (i.e., massive use of non-native species, poor management/absence of an environmental management system, aquaculture in public waters, and law revision in favor of unsustainable

environmental conditions) conflict with all 20 Aichi Targets. Finally, we then suggest ways to develop sustainable and responsible aquaculture in Brazil, using the Aichi Targets as a framework.

METHODS

We conducted an extensive and intensive literature survey of aquaculture development and impacts in Brazil and Latin America. This information was used to investigate conflicts between aquaculture expansion and each Aichi Biodiversity Target. In addition, using the Aichi Targets as a background and baseline framework, we indicated measures that could minimize conflicts and make aquaculture more sustainable (see Table 1).

Aquaculture expansion and environmental conflicts: An overview

Globally, aquaculture production has grown significantly over the past 30 years. In 2014, total production was 73.8 million tons, yielding US$ 160.2 billion (FAO 2016). In developing nations, in particular, fish production by aquaculture activities has increased steadily for several decades (FAO 2016).

Brazil has followed this trend. In recent years, federal investments were around US $1.32 billion (Plano Safra da Aquicultura; www.mpa.gov.br), aimed at launching aquaculture facilities in public waters, especially in hydroelectric impoundments (Bueno et al. 2015). Currently, Brazil is among the top 25 aquaculture producers in the world, with an annual yield of around 562.2 thousand tons, of which 84% (i.e., 474.3 thousand tons) come from inland waters (FAO 2016). National aquaculture yielded R$ 3 billion (ca. US $ 0.81 billion) in 2013, with an increase of 52% over the past 12 years. Ornamental aquaculture has grown 20% annually, concentrated mainly in the southeastern region. The main center is located in Muriaé, Minas Gerais State, responsible for more than 80% of the ornamental fishes entering the Brazilian domestic market, employing about 15 000 people and producing around 10 million freshwater aquarium fish per year (Magalhães and Jacobi 2013).

The growth of Brazilian aquaculture entails a series of underexplored environmental problems because the activity does not follow sustainability principles and an environmental management system (EMS—EPA 2017; Pelicice et al. 2017). The so-called "Brazilian Blue Revolution" has neglected basic social and environmental issues, jeopardizing its own current and future development (Vitule et al. 2012, 2014; Magalhães and Jacobi 2013; Lima-Junior et al. 2014; Coelho and Henry 2017; Pelicice et al. 2014, 2017). In short, aquaculture expansion is supported by the following components: (i) production is largely based on non-native species, some with high invasive potential such as species of carp, tilapia, and ornamental poeciliids and cichlids; (ii) aquaculture stations are rife with poor management practices or ignore steps of the EMS practices (i.e., Plan, Do, Check, Act); (iii) fish farms, particularly cage aquaculture, are planned to occur primarily in hydroelectric reservoirs, conflicting with other uses (e.g., water supply) and facilitating biological invasions; (iv) policy-makers have proposed or revised laws to stimulate the aquaculture industry, weakening environmental protection. In the next sections, we analyze these four components to explain how Brazilian aquaculture expansion conflicts with all 20 Aichi Biodiversity Targets (Table 1, Fig. 1).

Prioritizing non-native species

Although Neotropical fish diversity could yield economically viable species (Valladão et al. 2016; Saint-Paul 2017; but see Occhi et al. 2017), Brazilian aquaculture is based on non-native species, including many intracountry extralimital artificial expansions, and hybrids (Lima et al. 2016; Magalhães and Jacobi 2017). For instance, the Ministry of Fishing and Aquaculture (MFA—incorporated by Ministry of Agriculture) allowed importation of 501 non-native species for the ornamental trade (MFA 2012); most part of them are already farmed in Brazilian ornamental aquaculture. In 2015, Nile tilapia *Oreochromis niloticus* (Fig. 2a) alone 150 accounted for 219 329 tons, which corresponded to 45.4% of total fish production (IBGE 2016). The prominence of tilapia is due to several factors, such as high market demand, a complete technological package, and economic return to the farmer (Pedroza-Filho et al. 2014a, 2015). Other species frequently raised include non-native common carp *Cyprinus carpio*, rainbow trout *Oncorhynchus mykiss*, guppies/mollies *Poecilia* spp., swordtails and platies *Xiphophorus* spp., and goldfish *Carassius auratus* (Fig. 2b), in addition to several hybrids (Hashimoto et al. 2012; Magalhães and Jacobi 2017; Occhi et al. 2017). Neotropical species cultivated outside their native range are also common, such as piau *Megaleporinus macrocephalus* and the ornamental oscar *Astronotus ocellatus* (Lima et al. 2016). Not surprisingly, commercial and ornamental aquaculture has been the main vector promoting fish introductions across Brazil (Britton and Orsi 2012; Ortega et al. 2015; Frehse et al. 2016; Magalhães and Jacobi 2017).

Impacts from these non-native species include negative effects on water and habitat quality, interactions with native organisms, and the emergence of diseases (Canonico et al. 2005; Diana 2009; Vitule et al. 2009; Cucherousset and Olden 2011; Córdova-Tapia et al. 2015; Deines et al.

Table 1 Summary of all 20 Aichi Biodiversity Targets and conflicts and recommended solutions associated with the expansion of commercial and ornamental aquaculture in Brazil. Key references provide further information and examples about each topic

Aichi Targets	Conflicts	Solutions	Key references
Target 1. Educate people about biodiversity	Brazilian commercial and ornamental aquaculture is based on non-native species, and there is no specific action to educate people about risks of introductions. People are largely unaware of the issue, and the official incentive to develop unsustainable aquaculture will cause more misunderstandings	Regionalization of aquaculture (use of native species from local river basins)	Vitule et al. (2009), Pelicice et al. (2014, 2017), Azevedo-Santos et al. (2015), Magalhães and Jacobi (2017) and Occhi et al. (2017)
Target 2. Biodiversity valuation for national and local development	Aquaculture based on non-native species can create jobs and income in the short term, but it demands large governmental subsidies and does not consider social and environmental costs over long time scales. Current policies do not consider Brazilian biodiversity as a path to alleviate poverty in the long run	Regionalization of aquaculture to create local jobs and increase food security	Agostinho et al. (2007), Britton and Orsi (2012), Mace et al. (2012) and Deines et al. (2016)
Target 3. Ceasing incentives to harmful activities	The government has provided US$ 1.32 billion to launch aquaculture, which has been historically based on unsustainable practices, with strong impacts on biodiversity and ecosystem functioning	Governmental support to develop research on native species and Environmental Management System (EMS). Financial support to implement sustainable technologies on farms	Klinger and Naylor (2012), Bueno et al. (2015), Vitule et al. (2015) and Ministério da Pesca e Aquicultura (www.mpa.gov.br)
Target 4. Implement plans for sustainable production	Brazilian commercial and ornamental aquaculture has been largely unsustainable, and current policies do not promote better practices and sustainability principles. Attempts to naturalize non-native fishes and to create aquaculture parks in reservoirs indicate that policies are not concerned with sustainable production	National aquaculture plans based on regionalization and EMS practices	Australia Productivity Commission (2004), Azevedo-Santos et al. (2011), Klinger and Naylor (2012), Garcia et al. (2014), Vitule et al. (2014), and David et al. (2015)
Target 5. Slow down or cease habitat loss	Aquaculture has affected important and vulnerable riparian ecosystems, such as estuaries, wetlands and streams, promoting deforestation and environmental degradation. Cage aquaculture in reservoirs has affected important ecosystem services such as water quality. The growth of the activity will cause further losses	National aquaculture plans based on regionalization and EMS practices. Implementation of sustainability certification	Starling et al. (2002), Figueredo and Giani (2005), Bush et al. (2013), Rosa et al. (2013) and Pelicice et al. (2017)
Target 6. Sustainable use of fisheries resources	Contrary to common sense, the expansion of commercial and ornamental aquaculture does not relieve pressure on wild stocks. For example, inland fisheries and aquaculture produce different and complementary goods. In addition, the activity causes many impacts on ecosystems and wild populations	Official support to develop small-scale aquaculture based on multiple native species, integrated with other activities (e.g., agriculture)	Naylor et al. (2000), Agostinho et al. (2007), Diana (2009) and Watson et al. (2014)

Table 1 continued

Aichi Targets	Conflicts	Solutions	Key references
Target 7. Sustainable management of aquaculture	Current policies to develop aquaculture are based on financial resources, concession of areas, and law revision. There is no parallel effort to establish principles of sustainability, such as the use of native species and the adoption of sound management (i.e., EMS) to reduce eutrophication and pollution	National aquaculture plans based on regionalization and EMS practices. Permission to farm non-native species only in stringently closed systems. Follow Aichi Biodiversity Targets to develop sustainable policies	Klinger and Naylor (2012), Bush et al. (2013), Pelicice et al. (2014), Bueno et al. (2015) and Jones et al. (2015)
Target 8. Pollution control	Commercial aquaculture is a leading cause of eutrophication. The growth of the activity, mainly in public waters, will affect water quality and conflict with other uses of freshwater resources	Adoption of EMS practices; Apply the polluter-pays principle	Agostinho et al. (1999), O'Bryen and Lee (2003), Figueredo and Giani (2005) and Montanhini Neto et al. (2015)
Target 9. Control and eradication of alien species	The country has done very little to control and eradicate non-native aquatic organisms. The plan to develop national aquaculture with non-native species illustrates that current policies neglect risks and costs of biological invasions	National aquaculture plans based on regionalization, EMS practices. Risk analysis and thorough surveys to define target non-native species for aquaculture. Permission to farm non-native species only in stringently closed systems	Naylor et al. (2001), Cucherousset and Olden (2011), Britton and Orsi (2012), Vitule et al. (2012, 2014), Azevedo-Santos et al. (2015), Ortega et al. (2015), Frehse et al. (2016) and Pelicice et al. (2017)
Target 10. Minimize impacts on coral reefs and vulnerable ecosystems	Commercial aquaculture has also developed over coastal areas, mainly to raise non-native shrimp and oysters. Expansion of the aquaculture industry will affect vulnerable ecosystems such as coral reefs, estuaries, and mangroves	National aquaculture plans based on regionalization and EMS practices. Implementation of areas with ecological or economic priority	Diana (2009) and Lima et al. (2016)
Target 11. Establish systems of protected areas	Environmental laws that protect natural ecosystems have been revised to foster aquaculture. This includes naturalization of non-native fishes, creation of aquaculture parks, and incentives to develop ornamental aquaculture. Activities that promote biological invasions threaten the integrity of adjacent protected areas	Implement areas with ecological or economic priority. Apply the polluter-pay principle to raise funds to establish marine and freshwater protected areas	Azevedo-Santos et al. (2011), Lima-Junior et al. (2014), Pelicice et al. (2014), Padial et al. (2017) and Pelicice et al. (2017)
Target 12. Prevent the extinction of threatened species	The development of unsustainable aquaculture negatively affects conservation strategies. Aquaculture causes several impacts on ecosystems (e.g., species invasions, eutrophication, emergence of diseases, habitat destruction), worsening the conservation status of endangered species and accelerating the loss of biodiversity	National aquaculture plans based on regionalization, EMS and BMPs. Implement areas with ecological or economic priority. Implement marine and freshwater protected areas	Agostinho et al. (1999), Naylor et al. (2000); Canonico et al. (2005), Casal (2006), Diana (2009), Magalhães and Jacobi (2013, 2017), Occhi et al. (2017) and Pelicice et al. (2017)

Table 1 continued

Aichi Targets	Conflicts	Solutions	Key references
Target 13. Preservation of genetic diversity	Brazilian commercial and ornamental aquaculture has developed, raised, and disseminated different hybrids and transgenic organisms across the country, with no concern about genetic diversity and potential impacts on wild stocks (i.e., genetic erosion). In addition, aquaculture activities affect wild populations in multiple ways and, consequently, decrease genetic diversity	National aquaculture plans based on regionalization, EMS. Implement areas with ecological or economic priority. Implement marine and freshwater protected areas. Permission to farm non-native species, hybrids, and transgenic organisms only in stringently closed systems	Hashimoto et al. (2012), Magalhães and Jacobi (2013, 2017), Alves et al. (2014), Occhi et al. (2017) and Pelicice et al. (2017)
Target 14. Conservation of ecosystems that provide essential services	Aquatic ecosystems provide vital services (e.g., biodiversity, water quality, food security) that are degraded by unsustainable aquaculture. Cages in reservoirs directly affect ecosystem functioning and reduce water quality for human consumption—affecting poor and vulnerable traditional communities (e.g., fishermen, rural and indigenous people)	National aquaculture plans based on regionalization, EMS and BMPs. Implement areas with ecological or economic priority. Implement marine and freshwater protected areas. Aquaculture as a small-scale complementary activity	Figueredo and Giani (2005), Starling et al. (2002), Agostinho et al. (2007) and Pelicice et al. (2017)
Target 15. Restoration of degraded ecosystems to mitigate climate change	The functioning of most aquatic ecosystems in Brazil is already disturbed by various human activities (e.g., dams, overfishing, agribusiness); expansion of unsustainable commercial and ornamental aquaculture will exacerbate this scenario. It will decrease the effectiveness of conservation plans designed to restore degraded ecosystems (i.e., eutrophication) and to control carbon emissions (i.e., deforestation of riparian zones)	National aquaculture plans based on EMS and BMPs. Apply the polluter-pays principle to raise funds to support habitat restoration	Agostinho et al. (2005), Magalhães et al. (2011) and Pelicice et al. (2017)
Target 16. Fair and equitable access to genetic resources	The federal incentive to develop unsustainable commercial and ornamental aquaculture with non-native species conflicts with legitimate concerns about the perpetuation, access, and equitable sharing of natural and genetic resources	National aquaculture plans based on regionalization	Pelicice et al. (2014, 2017) and Vitule et al. (2012, 2014)
Target 17. Develop an updated national biodiversity strategy	Changes in legislation to boost commercial and ornamental aquaculture undervalue biodiversity and its services in favor of economic activities. Even if there were an updated national biodiversity strategy (there is none), aquaculture expansion would be an obstacle	Follow the Aichi Biodiversity Targets to develop sustainable policies	Scarano et al. (2012), Pelicice et al. (2014, 2017), Vitule et al. (2012, 2014, 2015), Governo de Tocantins (2016) and Governo de Mato Grosso (2017)

Table 1 continued

Aichi Targets	Conflicts	Solutions	Key references
Target 18. Valuation of traditional knowledge	Traditional fishermen have been strongly encouraged to abandon existing fishing activities to become fish farmers. In addition, the incentive to cultivate non-native species across the country ignores local ecological knowledge (LEK)—usually based on small-scale sustainable practices and the use of native biota	National aquaculture plans based on regionalization. Aquaculture as a small-scale complementary activity	Agostinho et al. (2007) and Hallwass et al. (2013)
Target 19. Advance knowledge on biodiversity (values, functioning, and trends)	Biodiversity assessments and monitoring are not preceding or following the expansion of commercial and ornamental aquaculture. In addition, there is little effort to advance regional aquaculture with local native species	National aquaculture plans based on regionalization	Pelicice et al. (2014, 2017) and Azevedo-Santos et al. (2015)
Target 20. Financial resources to implement the Strategic Plan for Biodiversity 2011–2020	While current policies focus US$ 1.32 billion on developing especially commercial aquaculture, the National Fund for the Environment invested, over its entire history (1989–2014), ca. US$ 0.06 billion in environmental/conservation projects. Aquaculture and other unsustainable activities (e.g., agribusiness) are prioritized over the Strategic Plan for Biodiversity	Follow the Aichi Biodiversity Targets to develop sustainable policies	Scarano et al. (2012), Ministério da Pesca e Aquicultura (www.mpa.gov.br), Fundo Nacional do Meio Ambiente (www.mma.gov.) and Pelicice et al. (2017)

2016; Zhang et al. 2017). Aquaculture with non-native species conflicts directly with Aichi Target 9 (prevention, control, or eradication of non-native species), but the activity is in disagreement with most Aichi Targets (Fig. 1, Table 1).

It is recognized that only a few introduced species become invasive, pestiferous, or harmful (Tens Rule—Williamson and Fitter 1996). However, the Tens Rule is one of the hypotheses with the least empirical support among all invasion hypotheses (Jeschke et al. 2012). We must bear in mind that negative impacts from aquatic invaders are more difficult to detect, especially because aquatic species are not easily observed/monitored, often experience time lags, engender indirect effects, and interact synergistically with other anthropogenic disturbances (Vitule et al. 2009; Braga et al. 2017). For aquatic inland ecosystems, therefore, the Tens Rule may cause confusion among stakeholders and the public, leading them to underestimate the real risks of biological invasions (Jarić and Cvijanović 2012). In addition, freshwater ecosystems are the most heavily invaded ecosystems in the world, subjected to massive propagule pressure, suffering from multiple disturbances caused by non-native species (Pyšek et al. 2010).

Fish escapes, poor management, and the absence of an environmental management system (EMS)

A main strategy of the Brazilian government is to increase fish production in public areas, particularly cage aquaculture in hydroelectric reservoirs (Valadão Flores and Pedroza Filho 2014; Bueno et al. 2015; Lima et al. 2016). However, cages do not ensure safe confinement, since accidental escapes and deliberate releases are routine in Brazil (Azevedo-Santos et al. 2011; Britton and Orsi 2012) and elsewhere (Naylor et al. 2005; Jensen et al. 2010; Sepúlveda et al. 2013; Thorvaldsen et al. 2015). Because Brazilian aquaculture is extensively based on non-native species, the installation of new aquaculture facilities will increase propagule pressure and cause massive releases of non-native organisms into aquatic ecosystems (Frehse et al. 2016; Lima et al. 2016)—a process already underway (Azevedo-Santos et al. 2011; Ortega et al. 2015; Frehse et al. 2016; Magalhães and Jacobi 2017; Pelicice et al. 2017).

In addition, aquaculture is based on poor management practices and does not follow EMS steps, which has caused additional disturbances (Agostinho et al. 2007; Magalhães and Jacobi 2017). For example, the activity has been

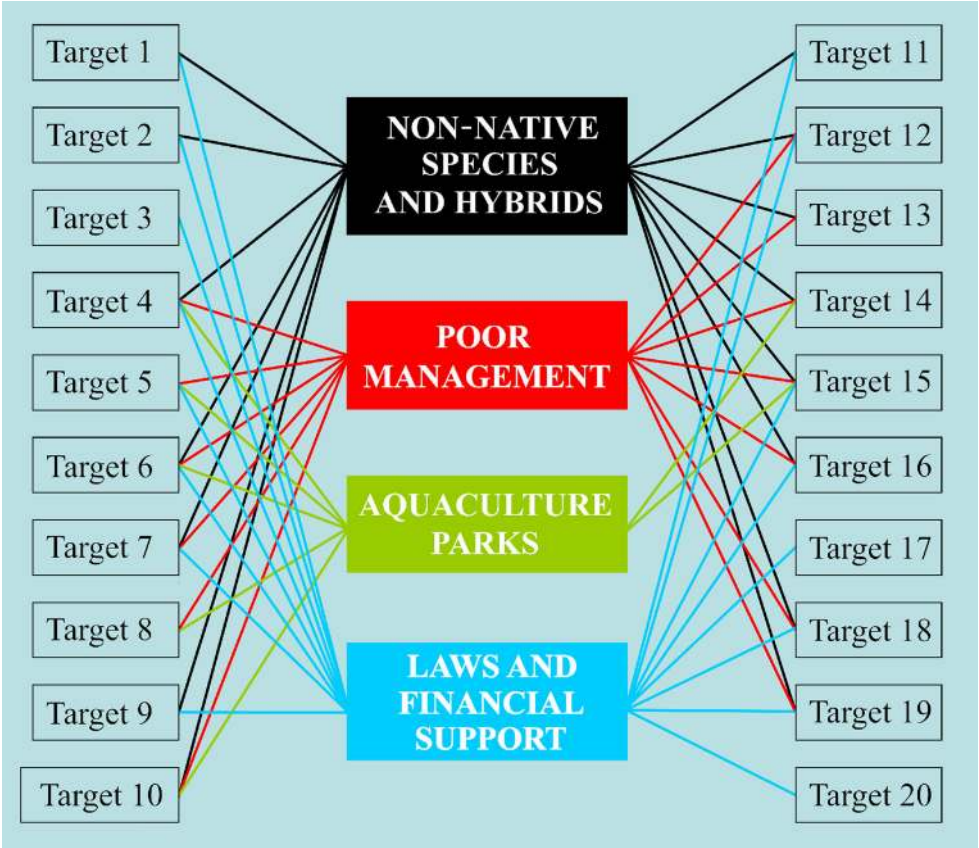

Fig. 1 Direct conflicts (connections) between components of commercial and ornamental aquaculture expansion (colored boxes) and all 20 of the Aichi Biodiversity Targets. Table 1 presents further information

responsible for the construction of ponds in riparian zones (i.e., Preservation Areas) (Fig. 2c), pollution of streams and rivers, eutrophication (Fig. 2d), secondary introductions (Fig. 2e), spread of pathogens and parasites, biotic homogenization, and extensive aggregation of organisms (Table 2). Ponds in riparian areas disturb aquatic biodiversity by affecting riparian buffer zones and other aquatic habitats (Fig. 2c), e.g., streams, wetlands, estuaries, and mangroves (Diana 2009; Magalhães and Jacobi 2017; Pelicice et al. 2017). These problems are commonplace in aquaculture because instruction, planning, and regular inspections are weak in Brazil (Magalhães and Jacobi 2017; Pelicice et al. 2017). This is particularly troubling if we consider that aquaculture with non-native species has reached megadiverse regions, such as the Tocantins River and Pantanal wetlands (Lima et al. 2016).

Owing to poor compliance with basic sustainability principles, poor management practices, and the absence of an EMS Cycle, the expansion of Brazilian aquaculture conflicts with several Aichi Targets (Table 1, Fig. 1). Targets 7 and 8 specifically mandate sustainable management or an EMS for aquaculture and pollution control, i.e., two aspects neglected by current development.

Aquaculture parks in reservoirs

More than 200 parks have been mapped in hydroelectric reservoirs to develop small- and large-scale fish farms (Fig. 2f) (Lima et al. 2016). Because river regulation and reservoirs facilitate the establishment and spread of non-native organisms pre-adapted to lentic conditions (Havel et al. 2005; Johnson et al. 2008; Liew et al. 2016), impoundments will experience mass invasion events.

Many Brazilian river basins (e.g., Tocantins, São Francisco, Paraná) are now a series of large reservoirs (Agostinho et al. 2016), offering conditions for invaders. Furthermore, no law regulates the transit of cages, boats, and fish fry among reservoirs/aquaculture parks, which will enhance primary and secondary introductions, e.g., the highly invasive golden mussel *Limnoperna fortunei* (Fig. 2e) and the macrophyte *Hydrilla verticillata*, toxic algae like *Microcystis*, and aggressive pathogens like *Ichthyophthirius multifiliis* (Table 2). If this were to happen, biotic homogenization (Petesse and Petrere Jr. 2012; Daga et al. 2015) may take place on a continental scale, including facilitative interactions and invasional meltdown (Simberloff and Von Holle 1999; Braga et al. 2017).

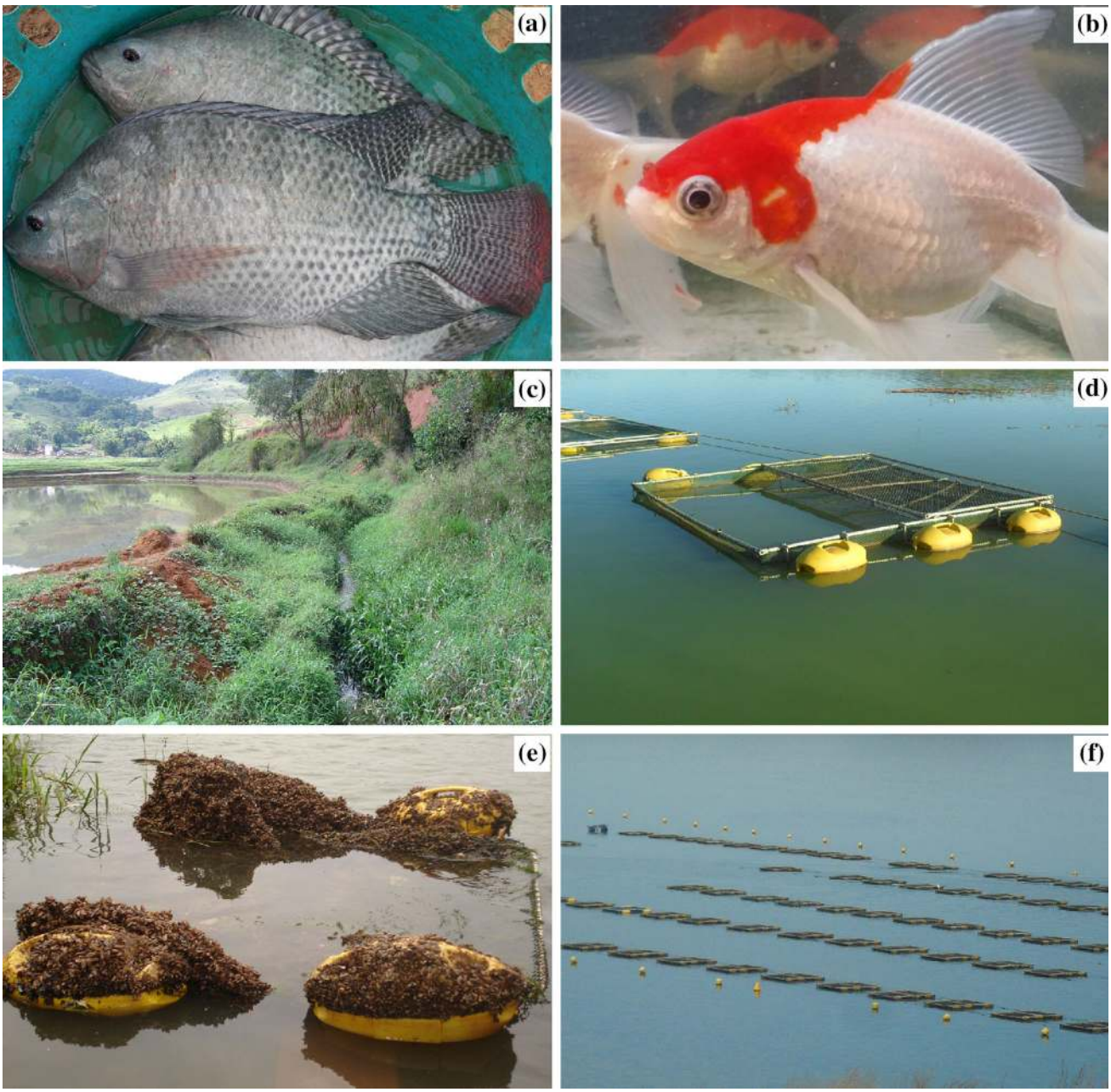

Fig. 2 Examples of disturbances associated with commercial and ornamental aquaculture in Brazil: **a** introduction of non-native species (Nile tilapia *Oreochromis niloticus*); **b** introduction of ornamental non-native species (Goldfish *Carassius auratus*—red cap oranda variety); **c** construction of ornamental ponds in riparian zones; **d** eutrophication caused by cage aquaculture; **e** secondary introductions (golden mussel *Limnoperna fortunei*); **f** aquaculture parks in hydroelectric reservoirs

Expansion of aquaculture in reservoirs will conflict with other uses of freshwater resources. An example is the degradation of water quality for human consumption, because cage aquaculture enhances eutrophication processes (Figueredo and Giani 2005; Zhang et al. 2017) (Table 1, Fig. 2c–d). It is important to emphasize that Brazilian legislation restricts aquaculture development to 1% of reservoir surface area, and studies will determine the areas destined to become aquaculture parks (Bueno et al. 2015). There is, however, no consensus on whether this area suffices to maintain water quality. Some studies, for example, show that aquaculture parks did not affect water quality (e.g., Montanhini Neto et al. 2015), while others argue that the limit proposed by law cannot prevent eutrophication (e.g., David et al. 2015). In addition, fish escapes may cause successful introductions that may contribute to eutrophication by releasing nutrients into the water column, e.g., tilapias (Starling et al. 2002).

Table 2 Examples of secondary introductions associated with commercial and ornamental aquaculture in Brazil

Species	Causes of introduction
Plankton	
Kellicottia bostoniensis	Unintended release with target species
Mesocyclops ogunnus	Unintended release with target species
Macrophyte	
Azolla cf. *microphylla*	Unintended release with target species; contaminated cages
Ceratophyllum demersum	Unintended release
Egeria densa	Unintended release
Egeria najas	Unintended release
Eichhornia crassipes	Unintended release
Hydrilla verticillata	Unintended release with target species; contaminated cages
Limnophila sessiliflora	Unintended release with target species; contaminated cages
Pistia stratiotes	Unintended release
Salvinia auriculata	Unintended release; contaminated cages
Protozoa	
Ichthyophthirius multifiliis	Unintended release with target species
Trichodina reticulata	Unintended release with target species
Cnidaria	
Cordylophora caspia	Unintended release
Craspedacusta sowerbii	Unintended release with target species
Platyhelminthes	
Bothriocephalus acheilognathi	Contaminated stocks
Cichlidogyrus sclerosus	Contaminated stocks
Cichlidogyrus tilapiae	Contaminated stocks
Diphyllobothrium latum	Contaminated stocks
Nematoda	
Camallus cotti	Contaminated stocks
Annelida	
Barbronia weberi	Contaminated stocks
Crustaceans	
Argulus spp.	Contaminated stocks
Daphnia lumholtzi	Unintended release with target species
Daphnia magna	Unintended release with target species
Daphnia similis	Unintended release with target species
Dilocarcinus pagei	Unintended release with target species
Lamproglena monodi	Contaminated stocks
Lernaea cyprinacea	Contaminated stocks
Macrobrachium amazonicum	Unintended release with target species
Macrobrachium jelskii	Unintended release
Macrobrachium rosenbergii	Unintended release
Mesocyclops ogunnus	Contaminated stocks
Procambarus clarkii	Unintended release
Uca rapax	Unintended release with target species
Mollusks	
Biomphalaria spp.	Unintended release with target species
Corbicula fluminalis	Unintended release with target species
Corbicula fluminea	Unintended release with target species
Corbicula largillierti	Unintended release with target species
Helisoma duryi	Unintended release with target species
Limnoperna fortunei	Unintended release with target species; contaminated cages
Melanoides tuberculata	Unintended release with target species; contaminated cages
Physa acuta	Unintended release with target species.
Pomacea diffusa	Unintended release with target species; contaminated cages
Pomacea spp.	Unintended release with target species; contaminated cages
Fish	
Amatitlania nigrofasciata	Unintended release
Astronotus ocellatus	Unintended release
Knodus moenkhausii	Unintended release with target species
Phalloceros sp.	Unintended release with target species
Poecilia latipinna	Unintended release
Poecilia reticulata	Unintended release with target species
Poecilia sphenops	Unintended release
Poecilia velifera	Unintended release
Poecilia vivipara	Unintended release with target species
Tanichthys albonubes	Unintended release
Amphibian	
Lithobates catesbeianus	Unintended release with target species

Aquaculture parks can also release large loads of contaminants such as antibiotics, which may cause the emergence of antibiotic-resistant bacteria and fungi (Cabello 2006).

All these problems cannot be overlooked, because several hydroelectric reservoirs are sources of drinkable water; in addition, several Brazilian regions with high economic development have faced severe water crises recently (e.g., Minas Gerais, Rio de Janeiro, and São Paulo; Vitule et al. 2015), while others have intrinsic water deficits (e.g., Brazilian semi-arid regions). Aquaculture expansion, at this time, will conflict with policies aimed at preserving and restoring freshwater resources and further emphasizes the conflict between the Aichi Biodiversity Targets and aquaculture incentives (Table 1, Fig. 1).

Revising laws to launch aquaculture

The Brazilian government, in its various spheres, has revised laws to foster agribusiness activities (Fearnside 2016; Tollefson 2016), and similar efforts have been applied to aquaculture (Pelicice et al. 2017). For instance, Proposed Law #5989 of 2009 intends to "naturalize" non-native fishes by decree (Pelicice et al. 2014). The main objective of this law, partially approved by the Brazilian Congress, is to allow rearing of non-native fishes in federal waters—including highly invasive species such as bighead carp *Aristichthys nobilis*, grass carp *Ctenopharyngodon idella*, common carp *Cyprinus carpio*, silver carp *Hypophthalmichthys molitrix,* and Nile tilapia *O. niloticus*. It is worth noting that the same strategy was pursued in Colombia (Colombia, 2015). Approval of Proposed Law #5989 of 2009 will cause the spread of non-native fishes across the country through deliberate and accidental releases, especially *O. niloticus*, which is preferred by farmers. Another example is the modification of Resolution #413 of 2009 to accelerate the licensing process for aquaculture parks (Lima-Junior et al. 2014). According to the new resolution, licenses would be granted within 4 months, a period insufficient to conduct high-quality assessments and impact studies. Other controversial measures are state initiatives to allow the farming of non-native tilapia in regions of the Amazon River basin (Padial et al. 2017) and the Araguaia–Tocantins river basin (Governo de Tocantins 2016). Another state regulation (Normative Instruction of São Paulo Fisheries Institute) will allow the production of more than 50 non-native species, including the Asian pangasiid catfish *Pangasianodon hypophthalmus*, in São Paulo State (São Paulo 2016). The same wave of law revision has favored ornamental aquaculture: normative instructions (#16 and #21, both of 2014) allowed the capture and rearing of 2000 ornamental fish species from the Amazon basin and have facilitated their transport across Brazil (Vitule et al. 2014). More recently, Mato Grosso State, mid-west region, approved a decree allowing tilapia aquaculture in cages (Governo de Mato Grosso 2017), threatening biodiversity hotspots such as the Pantanal floodplain.

These revisions and incentives conflict directly with almost all Aichi Biodiversity Targets (Fig. 1), especially Targets 3 and 4, which call for an end to harmful activities and the implementation of sustainable production, respectively (Table 1).

Sustainable aquaculture

We recognize the importance of aquaculture for food security and income (Pant et al. 2014; Moura et al. 2016). In Brazil, unfortunately, aquaculture has proven difficult or unsuccessful in many southeastern basins, causing species invasion, loss of freshwater resources, and social disruption (Agostinho et al. 2007; Britton and Orsi 2012; Ortega et al. 2015; Forneck et al. 2016; Magalhães and Jacobi 2017; Pelicice et al. 2017). Even economic viability is questionable when farmers do not receive adequate instruction (particularly when fishers are converted to farmers), the domestic market is not able to consume the production, and external markets face difficulties owing to non-tariff barriers (Pedroza-Filho et al. 2014b; Valadão Flores and Pedroza Filho 2014). Commercial and ornamental aquaculture could lead to more solid socioeconomic development if implemented under sustainability principles (Klinger and Naylor 2012; Jones et al. 2015; Pelicice et al. 2017). There is an urgent need for collaboration among the aquaculture industry, conservation scientists, and policy-makers to build a more sustainable approach (Azevedo-Santos et al. 2017). The Aichi Biodiversity Targets may provide important guidance for policy-makers by prioritizing ecosystem functioning and biodiversity together with human development.

A rigorous and multi-scale planning process is needed to revise current policies and practices. It should be based on detailed, unbiased scientific assessments that weigh social, economic, and environmental dimensions equally, considering different temporal/spatial scales and regional aspects (i.e., native species, regional markets, traditional communities) (Jones et al. 2015). This process would identify costs and benefits, winners and losers (Deines et al. 2016), as well as conflicts between Aichi Targets and aquaculture components (Fig. 1). A "win–win strategy" for aquaculture development must follow two basic assumptions: (i) a process of "regionalization" and (ii) a stringent and mandatory Environmental Management System (EMS) (Table 1).

Aquaculture regionalization consists of employing species that are native to the focus region (i.e., native to river basin). This measure agrees with most Aichi Biodiversity Targets. We have some candidate species like the giant arapaima *Arapaima gigas*, discus fish *Symphysodon aequifasciata,* streaked prochilod *Prochilodus lineatus*, pacu *Piaractus mesopotamicus*, and red pacu *Piaractus brachypomus*—species cultivated in other parts of the world (Lin et al. 2013) and even in some regions of Brazil where there are restrictions on raising alien species. The use of native species would benefit native biodiversity and aquaculture. For example, (i) people would understand the value of local biodiversity (Target 1), while (ii) native biodiversity would be integrated into national and local development plans (Target 2), alleviating poverty and

fostering regional economies and local income. In addition, (iii) the prevention, control, and eradication of non-native species (Target 9) would be facilitated, since propagule pressure would decrease. Another positive result is the diversification of the food production chain, increasing the resilience of local markets (see Troell et al. 2014).

Parallel to regionalization, a stringent Ecological Monitoring System (EMS: Plan, Do, Check, Act) would serve to organize the activity. EMS is a series of practices directed to reduce environmental impacts from human activities (EPA 2017—https://www.epa.gov/ems). Thus, EMS would help implement sustainable aquaculture with attenuated ecological impacts (Target 4, 8), decrease habitat loss and pollution (Target 5), and improve control of non-native species (Target 9). Because aquaculture is a business, governmental and market regulations may help establish sustainable standards. For example, the National Environmental Law #6938 of 1981 that enacts the Polluter-Pays Principle could be used to raise funds for conservation (Target 11), to support research, or to implement environmentally friendly technologies. Furthermore, sustainability certification could be used to encourage good practices on farms (Bush et al. 2013).

Non-native species should be restricted to specific activities (e.g., research, public aquaria, stringent confinement), but these practices should be minimized. Permission to use non-native species should follow a rigorous risk analysis and intensive surveillance (Vitule et al. 2009; Pelicice et al. 2017). In addition, permission should consider basic conditions: (i) non-native species should never be farmed in priority areas for conservation, nor in neighboring areas; (ii) production should occur in "closed systems" with sound management to prevent escapes and pathogen releases (Brengballe 2015); (iii) effluent waters should be treated; (iv) ponds should not be built in riparian areas; (v) wire screens and filters should be installed in ponds to avoid fish escapes; (vi) governmental inspection and environmental education should be mandatory for the aquaculture chain (e.g., Azevedo-Santos et al. 2015). These recommendations are needed to regulate aquaculture activities and to maintain the integrity of biodiversity and ecosystem services in the country. Here, we do not advocate a new form of xenophobia, but the application of Prevention and Precautionary Principles, both recognized by International and Brazilian laws (Sampaio et al. 2015).

The expansion of aquaculture in Brazil reveals the conflict between national policies of developing countries and international conservation objectives. The CBD and the Aichi Biodiversity Targets are concerned with the persistence of biodiversity, ecosystem services, and human well-being, but developing countries have relied on unsustainable activities that erode their freshwater ecosystems and biodiversity (Pelicice et al. 2017).

CONCLUSION

Aquaculture development in freshwater ecosystems of Brazil is clearly against Aichi Biodiversity Targets, because the activity has neglected sustainability principles, threatening the maintenance of biodiversity and ecosystems. Brazil is a signatory of the Aichi Targets, so the time is ripe for Brazil and other megadiverse developing countries to set consistent policies consonant with international agreements. Concerning the Aichi Biodiversity Targets, we are only three years away from the closing date.

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