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BIOLOGY

Environmental compensation to recover damages to permanent preserved areas caused by the occupation of continental fish farms: a case study in Santa Catarina, Brazil

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ABSTRACT: The environmental regulation of continental fish farming in Brazil is closely linked to land occupation and use. Areas used for this activity are mostly located in permanent preservation areas (PPA), close to rivers and springs, demonstrating the necessity of regulating this activity for its compliance with public policy. Santa Catarina is a leading state in fish farming and one of the first to regulate the use of PPAs. The feasibility of a proposal for environmental compensation to regularize the use of PPAs in Santa Catarina for fish farming; was therefore, assessed. The results showed that 74% of the fish farms analyzed need to regularize the occupation of production structures in PPAs. Regarding the proposed index of compensation for use in PPAs, the environmental compensation factor (ECF), through evaluation of the individual maps and subsequent integrated evaluation, all the fish farms identified with environmental liabilities in occupation had ratios of 1:2 and 1:3, and this index is a viable alternative for environmental regularization of the activity. It was further proposed that ECF be applied to small fish farms of up to four fiscal modules and that they have a standard minimum occupancy profile in relation to the total area of the property, as assessed in the present study.

Key words: environmental legislation, public policy, land use, aquaculture, fish farms.

A compensação ambiental como alternativa para a regularização ambiental de pisciculturas continentais: um estudo de caso em Santa Catarina, Brasil

RESUMO: A regularização ambiental da piscicultura continental no Brasil está intimamente ligada à ocupação e uso do solo, as áreas utilizadas para a atividade estão em sua maioria inseridas em áreas de preservação permanente (APP), próximas a rios e nascentes. Esse cenário demonstra a relação entre a atividade e o cumprimento da lei, referente às questões florestais no país. Santa Catarina é um dos estados líderes na piscicultura e um dos primeiros a regulamentar o uso de áreas de preservação permanente (APPs). Assim, foi avaliada a viabilidade de uma proposta de compensação ambiental para regularizar o uso de APPs em Santa Catarina para a piscicultura. Os resultados mostraram que 74% das pisciculturas analisadas precisam regularizar a ocupação das estruturas de produção em APPs. Com relação ao índice proposto de compensação pelo uso em APP, o fator de compensação ambiental (FCA), por meio da avaliação dos mapas individuais e posterior avaliação integrada, todas as pisciculturas identificadas com passivos ambientais em ocupação apresentavam relações de 1:2 e 1:3, sendo este índice uma alternativa viável para a regularização ambiental da atividade. No entanto, propõe-se que o ECF seja aplicado a pequenas pisciculturas, de até quatro módulos fiscais e que tenham um perfil de ocupação mínima padrão em relação à área total da propriedade, conforme avaliado no presente estudo.

Palavras-chave: legislação ambiental, políticas públicas, uso do solo, aquicultura, piscicultura.

INTRODUCTION

According to the Food and Agriculture Organization, FAO (2022), aquaculture production increased by 5.7%, considering the cultivation of algae and the breeding of aquatic animals, reaching 122.6 million tons worldwide (FAO, 2022). Aquaculture production in Brazil also recorded an increase in production with 841,005 tons of farmed fish produced in 2021, an increase of 4.7% compared to the previous year (PEIXEBR, 2022).

The southern region of Brazil, a leading region for farmed fish production (PEIXEBR, 2022), produced 269,300 tons in 2021, accounting for 32% of the total output in Brazil. Furthermore, Santa Catarina was the fourth state to produce the highest amount (53,600 tons). Fish farming in Santa Catarina presents distinguishing characteristics because it is developed primarily on small rural properties with an average of two hectares of water blades per property and family labor (SILVA et al., 2017).

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The new Forest Code (FC) in Brazil was enacted with the commitment of the productive sector to regulate environmental damage to public lands that could be attributed to commercial use on rural properties. This law created a special set of rules, policies and norms with more built-in flexibility to achieve environmental regulation of rural properties with liability for damages before July 22, 2008. Simultaneously, the new FC provided a series of instruments to help both government and rural producers manage the environmental aspects of rural properties and possessions and monitor and combat illegal deforestation. Thus, it became incumbent on fish farmers in Santa Catarina to adhere to the new FC, which required that producers take compensatory responsibility to damages to Permanent Preservation Areas (PPA).

Specifically, if an activity like fish farming occupies land considered to be part of a PPA, such activity is considered to have caused environmental damage and thus liable for compensation by law to mitigate or repair such loss. Any anthropic interference that inflicts damage to environmental heritage, be it natural, cultural, or artificial, can result in immediate or potentially unfavorable disturbances to the ecological balance, healthy quality of life, or any other aspects of the community or specific individuals (MILARÉ, 2021).

However, according to Article 4, Section VII, Federal Law 6.938/1981, such damage can be "repaired" by "imposing on the polluter and the predator the obligation to recover and/or compensate for the damage caused (...)." According to Article 36 of Federal Law 9.985/2000, enterprises that cause significant environmental impacts may comply with this law by supporting the development and maintenance of conservation units (CUs) as fair compensation. Nevertheless, the law suggests other compensatory measures, such as suppressing vegetation in PPAs and the Atlantic Forest.

In this case, suppressing vegetation in PPAs in compliance with Articles 7 and 8 of Federal Law 12.651/2012 would constitute a legal obligation of recomposition in cases of public utility, social interest, or low environmental impact. Thus, such vegetation suppression would also require governmental authorization in accordance with the framework established by legal provisions or regulations.

One strategy that makes it feasible for fish farming production units to maintain and carry out forest restoration would be the adoption of an environmental compensation mechanism, as provided by law. Environmental compensation is a broad concept that encompasses various types of socioenvironmental compensation strategies, including impact assessments, environmental licensing, and policies aimed at biodiversity and natural resource conservation (GARDNER et al., 2013). Through Ordinance No. 98 of May 18, 2020 (complemented by Ordinance No. 43/2021), the Environmental Institute of the State of Santa Catarina (IMA) established a compensatory strategy for the use of PPAs in which potentially polluting activities are proposed to be installed or are already installed and in operation. However, this ordinance is not in effect and is undergoing technical and legal reviews by the same environmental agency.

Here, we present a case study aiming to quantify the extent of PPA recovery in the State of Santa Catarina via a method of environmental compensation based on mapping technology and ecological indices.

MATERIALS AND METHODS

Case study- Environmental regulation of continental fish farms in Santa Catarina

The municipality of Grão-Pará (Santa Catarina, Brazil) was selected as the study area because of its importance in the production of Tilapia (*Oreochromis niloticus*, Linnaeus, 1758) and the configuration of the activity, which is mainly conducted by family farming units, as in much of the state (EPAGRI, 2020). Land ownership of the municipality was structured by considering rural properties as small- or medium-sized units, characterizing them as a representative fish farming practices in Santa Catarina.

Agricultural performance in Santa Catarina can be evaluated based on farmers' participation in The National Program for Strengthening Family Farming (PRONAF), a strategic government program facilitating access to rural credit. According to EPAGRI (2021), the Agricultural Research and Rural Extension Company of Santa Catarina, the involvement of fish farmers was significant, reaching 13.42% and 14.04% of the total resources used in the country in 2019 and 2020, respectively. It is worth noting that family farming has a strategic position in the state since it is responsible for a large part of the food production chain. The municipality includes 50 commercial fish farming units with an annual production of 1,035 tons, and Tilapia (*Oreochromis niloticus*, Linnaeus, 1758) is the main species, accounting for 99.9% of the total output (CEDAP, 2021).

For the purpose of this study, 15 commercial fish farms in the municipality were selected. All these properties were classified as small rural properties by having up to four fiscal modules. Following the guidelines of the National Institute for Colonization and Agrarian Reform, a fiscal module in Grão-Pará is equivalent to 14 hectares. The total area of these properties and their corresponding equivalence in fiscal modules are documented in table 1, while the geospatial distribution of the samples is represented in figure 1.

Mapping the properties for analysis

The extent of PPAs occupied by production nurseries was analyzed for each fish farm. After analysis, areas that should be compliant with the law were identified according to Article 61 of the Forest Code, which involves the use of 5-, 8-, and 15-m wide protection strips, depending on property size.

These maps were constructed by digitally imaging properties using QGIS Browser 2.18® software with UTM projection, zone 22 S, and SIRGAS 2000 Datum. RapidEye satellite imagery (5.0 m) based on 2020 data was also used.

Environmental compensation factor

The extent of PPAs occupied by fish farming units and, thus, liable for recovery, was calculated using the Environmental Compensation Factor (ECF) obtained from ecological indices determined by criterion area (A), forest typology (T), rarity (R), and connectivity (C) as:

$ECF = A + T + R + C$

For each criterion established by Administrative Rule no. 43/2021 (IMA), the indices were listed for composition analysis (Table 2). These indices were weighted considering the size and importance of the PPAs, the expression of vegetation typology, rarity in terms of endemism and vulnerability, connectivity considering remnant corridors of the Atlantic Forest biome, and the presence of conservation units (CU). The compensation applied to each property is defined according to the occupation scenario identified in each project. After calculating ECF, the area for compensation (AC) can vary in proportion between 1:2 and 1:4 (Table 3) based on the technical criteria established by the ordinance.

Georeferencing the ECF index

Each rural property was evaluated based on its environmental map, and layers were processed for each of the indices presented in table 3 and figure 2.

PPAs

Analysis of this attribute was based on the hydrographic database of the Brazilian Foundation for Sustainable Development from which shapefiles of the springs and single and double rivers were obtained for the municipality of Grão-Pará. From these layers, projection buffers of riverine PPAs were generated based on Article 61 of the Brazilian FC, which, as noted above, defines the width of protection strips as 5, 8, or 15 m. The width of rivers on the property was measured individually using satellite images with a spatial resolution of

Table 1 - Total area of the rural properties analyzed located in the municipality of Grão-Pará (SC) and equivalency to the fiscal module.

Rural Property	Total area $(m)^2$	-----------------------------Fiscal Module----------------------------		
		0 a 1	≥ 1 a 2	≥ 2 a 4
P1	14.9		1.1	
P2	33.6			2.4
P3	21.8		1.6	
P4	17.1		1.2	
P5	22.5		1.6	
P6	33.6			2.4
P7	33.5			2.4
P8	21		1.5	
P9	16.7		1.2	
P10	8.3	0.6		
P11	19.5		1.4	
P12	10.8	0.8		
P13	42			3.0
P14	47.2			3.4
P15	13.4	1.0		

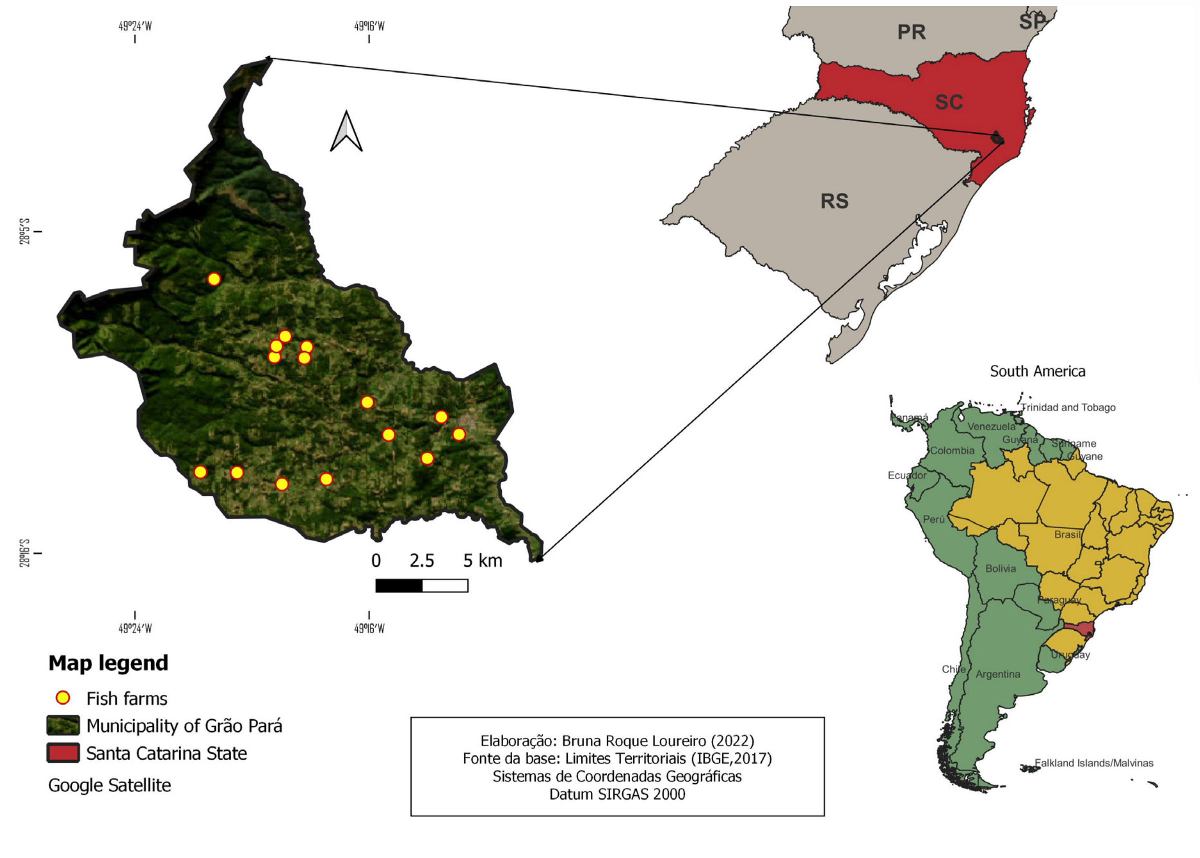

Figure 1 - Spatial distribution of fish farms studied in the Grão-Pará (SC) municipality.

5.0 m from RapidEye. All rivers within the analyzed properties showed widths of up to 10 m.

Forest typology

To assess this attribute, a publicly accessible database intended for noncommercial purposes, was obtained from the MapBiomas project, version 6.0, of the Annual Series of Land Cover and Land Use Maps of Brazil for the base year 2020 (https://mapbiomas.org/). Using publicly accessible data, it was possible to assess the forest typology of the studied fish farms based on land use and land cover data, as represented on individual maps.

Rarity

To evaluate this attribute, data on the occurrence of threatened and rare species from the INVENTÁRIO FLORÍSTICO FLORESTAL DO ESTADO DE SANTA CATARINA (IFFSC, 2020) were considered. Threatened species of the main phytophysiognomies of Santa Catarina were identified using some data available found at https://www.iff.sc.gov.br/, while others were identified in partnership with the project for to make the database fully available.

As georeferenced data for this indicator are scarce in the literature, shapefiles of IFFSC sampling units were used with data on the occurrence of threatened species, according to CONSEMA and MMA, and rare species, according to OLIVEIRA et al. (2019). Based on these data, a radius of 5.0 km was considered a potential zone for registering threatened species in areas with confirmed occurrence.

Connectivity

This attribute was analyzed using a database made available by the Institute of Environment of Santa Catarina (IMA). The GeoSeUC platform, developed by IMA, allows online consultation for geographic information of environmental interest, such as CUs (approved by CNUC (National Register of Conservation Units)) and watersheds. The shapefiles “Corridors of remnants of Atlantic Forest biome vegetation and ecological corridors established by Act of the Government of the State of Santa Catarina,”

Table 2 - Criteria to determine the environmental compensation factor (ECF) and its indices, according to the proposal of the Institute for the Environment of the State of Santa Catarina (IMA, 2021).

CRITERIA	INDEX (A)
Permanent Preservation Areas[1]	
Waterways less than 10 m wide	0.2
Waterways 10 to 50 m wide	0.4
Waterways 50 to 200 m wide	0.6
Waterways 200 to 600 m wide	0.8
Waterways wider than 600 m	1.0
Areas around lakes and natural ponds in urban areas	0.3
Areas around artificial water reservoirs resulting from damming or impoundment of natural waterways within the range defined in the project's environmental license	0.2
Areas around springs and perennial water bodies, whatever their topographic situation	1.0
Slopes or parts thereof with a slope greater than 45°, equivalent to 100% of the line of greatest slope (check the slope in the codes)	0.8
Restingas, as dune fixers or mangrove stabilizers	1.0
Mangroves, including their extensions	1.0
Edges of the tableland, up to the line of rupture of the relief, in a strip that is never less than 100 m in horizontal projections	0.8
Hilltops, hills, mountains, and mountain ranges with a minimum height of 100 m and an average inclination greater than 25º, the areas delimited from the contour line corresponding to 2/3 (two-thirds) of the minimum height of the elevation always concerning the base	0.8
Areas at an altitude above 1,800 m, whatever the vegetation	1.0
In veredas, the marginal strip, in horizontal projection, with a minimum width of 50 m from the permanently marshy and waterlogged space	0.3
Forest Typology[2]	
No vegetation or grass/herbaceous vegetation	0.2
Secondary vegetation in the initial stage of regeneration of the Atlantic Forest biome	0.3
Secondary vegetation in the medium stage of regeneration of the Atlantic Forest biome	0.6
Primary or secondary vegetation in an advanced stage of regeneration of the Atlantic Forest biome	1.0
Rarity[3]	
Presence of flora and fauna species threatened with extinction	0.8
Presence of restricted-range species in the area directly affected by the project	1.0
Connectivity[4]	
Corridors of remnants of vegetation of the Atlantic Forest biome and ecological corridors instituted by an Act of the Santa Catarina State Government.	0.4
Buffer zone and ecological corridors of Conservation Units (Law 9.985/2000, Art. 25)	0.5
Inside a Conservation Unit	0.8

[1]Federal Law 12.651/12 - 14.675/09.
[2]Federal Law 11.428/06, Federal Decree 6.660/08, and Federal Decree 5.300/04.
[3]Federal Law 12.651/12, Federal Law 11.428/06.
[4]Federal Law 9.985/2000.

"Buffer zone and ecological corridors of Conservation Units (Article 25, Law 9.985/2000)," and "Conservation Unit" were all accessed using this platform. Based on the projection of these layers, assessing whether fish farms that registered PPA occupation conflicted with these indicators was possible.

The sum of the ECF was obtained by identifying each criterion listed in table 2, and the compensation applied to each property was defined based on the scenario identified in each project. After calculating ECF, the compensation area (CA) varied between 1:2 and 1:4 (Table 3) based on the technical criteria established by the ordinance.

RESULTS AND DISCUSSION

In the present study, four fish farms did not require environmental adaptation, but eleven did,

Table 3 - Ratio of the compensation area (CA) according to the environmental compensation factor (ECF).

Environmental compensation factor (ECF)	Compensation area (CA)
Up to 1.0 (ECF < 1.0)	Ratio 1:2
Between 1.0 and 3.0 (1.0 ≤ ECF ≤ 3.0)	Ratio 1:3
Greater than 3.0 (ECF > 3.0)	Ratio 1:4

as identified on individual projects. Therefore, these farms were slated as suitable for compensation, and the eleven properties were evaluated individually for each attribute listed in table 2. At the end, the values obtained were summed to obtain the ECF. From this value, the proportion of compensation was determined using the criteria shown in table 3, thereby obtaining the final area within the occupied PPA to be assessed for compensation due.

Generally; however, the areas with compensatory liability in small fish farms were minimal relative to the total area of the property (Table 1) with an average of 1.0%. Indeed, among the environmental liabilities related to occupation in the PPAs, all were in the proportions of 1:2 or 1:3 (eight in 1:2 and three in 1:3), and none was classified in the proportion of 1:4.

The analysis of individual production units for each property followed the procedures given in figure 2, which shows how the images for rarity, forest typology, PPA, and connectivity were evaluated.

All fish farms in this study were liable for compensation, even though the recovery area in all

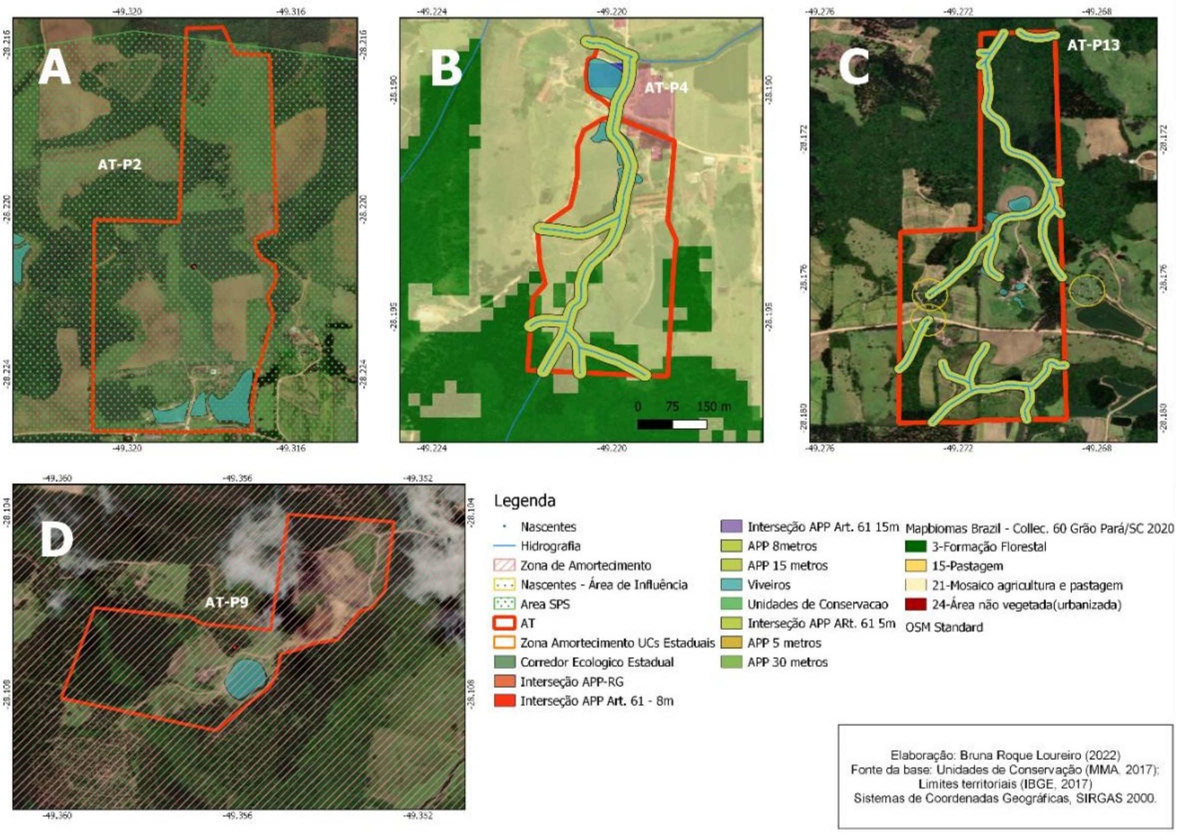

Figure 2 - Evaluation maps of different attributes for fish farms. A: Rarity. B: Forest Typology. C: Permanent Preservation Area (water courses and springs). D: Connectivity.

was low in proportion to the total area of the property, it is important to consider that the area occupied by the PPA does not necessarily equate to high environmental impact. For example, the fish farm with the largest occupation of PPA, an area of 1.63 hectares, had an ECF index of 0.9 and a compensation ratio of 1:2. Conversely, a fish farm with low occupancy in the PPA and an area of 0.32 hectares obtained an ECF of 2.1 and a recovery ratio of 1:3 (Table 4).

Based on table 4, for the 11 fish farms identified as those liable for compensation, 100% of properties scored in the “Waterways less than 10 meters wide” criterion.

In the forest typology, 54.6% of the properties were in the “No vegetation or vegetation of grasses/herbaceous plants” category, and 45.4% were in the “Secondary vegetation in the initial stage of regeneration” category. For the rarity criterion, 27.3% were in the category “There are species of flora and fauna threatened with extinction”, and 73.7% did not score for this attribute. For connectivity, almost all fish farms (91%) were classified under “Vegetation remnant corridors and ecological corridors instituted by Government Act,” and only 9.0% were classified under “Buffer zone and ecological corridors of Conservation Units.”

Although, the current FC allowed the maintenance of activities, the minimum restoration of these areas is mandatory and must be carried out in accordance with the conditions set forth in Article 61 of that same law.

Continental fish farming; is therefore, supported by maintaining its production units, as long as it carries out recovery as determined by liabilities generated by occupation. This highlights the ecological importance given to PPA recovery.

Furthermore, the Atlantic Forest biome requires urgent actions aiming recoveryand restoration since protected areas represent only 14.4% of the remaining vegetation (RIBEIRO et al., 2009). Therefore, any anthropic activity occupying these areas needs to respect minimum restoration, and if that is not possible, then mechanisms, such as environmental compensation, can be a viable alternative to repairing the environmental damage, however it is necessary to adopt technical criteria, such as listing which parameters should be considered for this compensation.

Table 4 - Analysis of fish farms using the criteria established for calculation of the environmental compensation factor. Marginal Protection Strip (MPS) in meters; Environmental Compensation Factor (ECF); Permanent Preservation Area (PPA) occupied in hectares (ha) and area to be compensated in hectares (ha).

---Compensation for use in PPA (Atlantic Forest Biome)---					
Rural property	MPS (m)	EFC	Occupied PPA (ha)	Area to be compensated (ha)	Proportion of occupied area in relation to the total area of the property (%)
	Art. 61				
P1	8	0.0	0	-	0
P2	15	0.8	0.19	0.38	0.6
P3	8	0.8	0.18	0.36	0.8
P4	8	0.8	0.28	0.56	1.6
P5	8	0.9	0.34	0.68	1.4
P6	15	2.1	0.32	0.96	0.9
P7	15	1.7	0.17	0.51	0.5
P8	8	1.7	0.38	1.14	1.8
P9	8	0.0	0	-	0
P10	5	0.8	0.05	0.1	0.6
P11	8	0.8	0.23	0.46	1.2
P12	5	0.0	0	-	0
P13	15	0.9	0.29	0.58	0.7
P14	15	0.9	1.63	3.26	3.5
P15	5	0.0	0	-	0
--Index EFC: ---					
-----------(ratio 1:2)-----------		------------------(ratio 1:3)--------------------		----------------------------(ratio 1:4)----------------------------	

Interestingly, by analyzing the individual maps of fish farms considered in this study, we observed that partial removal of productive structures built in PPAs could not take place to comply with the minimum recovery rule. Consequently, nurseries in their entirety would have to be removed, effectively closing production on a small farm. This situation would result in insecurity and significant economic implications for commercial producers who depend solely and exclusively on the activity. It would also have a “trickle-down effect” on the chain of small producers for whom social programs, such as the National School Food Program (PNAE) and the Food Acquisition Program (PAA), are mandated by Brazilian public policy.

Reviews, such as those carried out by PERIN et al. (2021), point out several PAA benefits found in case studies carried out in different regions of the country. Among the main positive effects observed for family farming, the following stand out: increased income and volume of production, higher prices for farmers’ products, expanded marketing, and retention of farmers in the field.

Local characteristics that have environmental impact, such as area size, forest typologies, ecological corridors and priority CUs, are essential in calculating the environmental compensation assessed for use and occupation in PPAs. According to GAMA et al. (2013), different strategic indices can be applied for conservation and recovery of preservation areas, such as assessment of existing remnants, quality of each river section, and identifying priority sites for ecological restoration.

Therefore, these strategic indices must be considered when evaluating the typology, connectivity and rarity of forests. GALETTI & DIRZO (2013) even proposed an environmental suitability map that would allow interconnecting remnants of natural elements in the landscape. This would allow fauna to remain and continue diverse gene and biological flows, such as pollination and seed dispersal, thereby ensuring the support of both natural and anthropogenic ecosystems (HAWES et al., 2008; ROTHER et al., 2013). So, the choice of areas to be recovered through compensation must be planned, taking into account aspects that effectively enable the recovery of the landscape.

Adopting the model for compensatory damages, as suggested in this case study, requires a robust public database of georeferenced data containing the minimum information suggested by the ordinance to evaluate each attribute. Other features can be considered and incorporated into the analysis according to local criteria, considering the unique characteristics of land use and the occupation of the municipality where the property is located.

It is also essential to emphasize the relevance of state and federal regulations in the matter of compensation and interventions in PPAs, as provided for in CONAMA national Resolution nº 369/2006. Just as it was adopted in the states of Santa Catarina and Minas Gerais, State Decree No. 47,749/2019 established the criteria for environmental compensation which should be at least equivalent to the intervention area by maintaining a 1:1 ratio.

Additionally, environmental agencies should consider collaborating with rural property owners to choose the most strategic areas within the property for recomposition, considering connectivity with existing forest remnants and PPAs. The ecological restoration chain in the Atlantic Forest is well established owing to an older demand to recover degraded areas (SILVA et al., 2015). However, a consistent trend of reduction in the costs of restorative actions (BRANCALION et al., 2015) could give a boost to small producers required to compensate for the occupied area within the property they own.

Compliance with the laws is key to preserve the remnants of Brazilian flora, fauna and water resources. A total of 53% of all remaining native vegetation in the country is located on private rural land, not protected areas (SOARES-FILHO et al., 2014). In the Atlantic Forest, which is historically the most degraded biome in the country and also where more than 60% of the Brazilian population live, this proportion reaches 90% (RIBEIRO et al., 2009).

The limited data related to rarity parameters; however, may have led to the underestimation of this classification of the strip to be included in the recovery of the PPA since the data used were restricted to information about species surveyed by the state forest inventory. A more accurate analysis would have included a local survey of rare specimens not yet identified. Also, few studies in the literature have addressed this issue since compensation for using permanent preservation areas is still a work in progress, mainly owing to the absence of regulation in many Brazilian states.

CONCLUSION

The environmental assessment of rural properties that develop continental fish farming makes it possible to measure environmental liability regarding the use and occupation of PPAs. Based on the analysis of laws pertaining to compensation for the use of PPAs, these identified liabilities represent a small percentage of the occupation relative to the total area of the property.

However, the proposed measure can be adapted to activities carried out on small rural properties of up to four fiscal modules with low environmental impact. Therefore, evaluating all attributes and indicators that may be important in the specific assessment of the property where fish farming is carried out is essential. Consequently, is it possible to accurately identify the area of liability and, thus, obtain a more reliable ECF.

As continental fish farming is both economically and socially important to Santa Catarina, it is equally important to propose measures and alternatives to resolve issues relating to the environmental liabilities of this activity and to establish a fair environmental assessment methodology. Thus, it is clear that this topic is deserving of more intensive research, along with strengthening our environmental databases, especially at the local level. The availability of open-source data, especially information relevant to the replication of this model, such as the status of land use, rare species and priority areas for recovery, will enable the adoption and implementation of this proposal.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

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AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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