MODELING OF FISH SEIZURES AFTER THE IMPLEMENTATION OF THE CLOSED FISHING SEASON LAW IN THE AMAZON BASIN

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ABSTRACT

The organization of fisheries in the Amazon region is an important theme, since the current management model is based mainly on the closed fishing season policy. This strategy suspends the catching of specific fish stocks and provides subsidies to professional fishers. Thus, the present study analyzed, through mathematical modeling, the behavioral interfaces of illegal fisheries that occurred between 1992 to 2017 in the Amazon basin, considering the hydrological seasonality and the effect of the presence or absence of the Closed Fishing Season law (CFSL). The data were tabulated and used for the construction of two illegal fishing scenarios. The first showed negative impacts with the absence of the CFSL, indicated by the high number of seizures of illegal catches that occurred during the period in which river water level is rising and showed continued growth over time. However, the second scenario showed apprehension apexes occurring at the beginning of the high-water level and at beginning of the low water level, with a continuous decrease in the seizures of illegal catches due to the new law. Therefore, the scenarios show that the CFSL is an effective fishing management tool for the Amazon basin. Thus, the ecosystem model constructed is a promising instrument for testing hydrologic hypotheses and for formulating and monitoring management scenarios for fisheries in the region.

Keywords: Environmental changes; ecosystem modeling; illegal fishing.

MODELAGEM DAS APREENSÕES DE PESCADO APÓS A IMPLEMENTAÇÃO DA LEI DO DEFESO NA BACIA AMAZÔNICA

RESUMO

O ordenamento pesqueiro na região amazônica é um tema importante, uma vez que o atual modelo de gestão se baseia principalmente na política do defeso. Essa estratégia suspende a captura de estoques específicos de peixes e fornece subsídios aos pescadores profissionais. Assim, o presente estudo analisou, por meio da modelagem matemática, as interfaces comportamentais da pesca ilegal que ocorreram entre 1992 e 2017 na bacia Amazônica, considerando a sazonalidade hidrológica e o efeito da presença ou ausência da Lei do Defeso (LD). Os dados foram tabulados e utilizados para a construção de dois cenários de pesca ilegal. O primeiro apresentou impactos negativos com a ausência da LD, apontado pelo elevado número de apreensões de pescado ilegais que ocorreram durante o período da enchente, momento em que o nível da água do rio está subindo, e apresentou crescimento contínuo ao longo do tempo. No entanto, o segundo cenário mostrou ápices de apreensões ocorridas no início da cheia e no início da seca, com redução contínua das apreensões de capturas ilegais devido a lei LD. Dessa forma, os cenários mostram que a LD é uma ferramenta de gestão pesqueira eficaz para a bacia Amazônica. Assim, o modelo ecossistêmico construído é um instrumento promissor para testar hipóteses hidrológicas para formular e monitorar cenários de gestão para a pesca na região.

Palavras-chave: Alterações ambientais; modelagem ecossistêmica; pesca ilegal.

INTRODUCTION

Fishing activity in the Amazon basin differs from that of other regions of Brazil, due to the diversity of the species exploited, the quantity of fish caught and the high participation of riverside populations in fishing activities and high fish consumption (Ruffino et al., 2005). Among the existing fishing modalities in the region, multispecific commercial fishing is aimed at supplying urban centers and is directly influenced

by the highest seasonal river level (Barthem and Fabré, 2004; Freitas and Rivas, 2006), a phenomenon that controls productivity and energy flow from ecosystems of large rivers with adjacent floodplains (Junk et al., 1989).

The potential fishing production of the Amazon basin was estimated around 600,000 tonnes year^{-1}, using probabilistic simulation and effort and capture data from commercial fisheries in the region (Silva-Junior et al., 2017). However, some species of commercial interest have been showing signs of overfishing. A 50% drop in fisheries production between 1976 and 1986 at the port of Manaus was detected (Merona and Bittencourt, 1988), and which worsened in the 1990s (Batista and Petrere, 2003), mainly due to the lack of efficient fishery management measures (Oviedo et al., 2015).

Due to these adversities, fishery resources in the Amazon basin have been managed based on government policies, with the Closed Fishing Season law (Law n°. 9605, February 12th, 1998; Brasil, 1998) for species at risk of overfishing as the main regulatory norms. The closed season corresponds to the suspension of fishing activity when fish species are most vulnerable (reproduction period and migration), and mainly protects stocks with indications of declining production (Isaac et al., 1993; Kahn, 1998). This measure was based on the biology of the species and, for this reason, it is complex to define when the fragility of the species is greatest, and this situation may vary for each fishing region, so that it is not effective between species for the same period (Corrêa, 2007).

In addition, Law n°. 10779/2003 (Brasil, 2003) permits the granting of subsidies to professional fishers who fish in an artisanal manner. This fisher receives the payment of four monthly amounts of the value of a minimum wage each (on April 12th, 2019, this value was R$ 998.00 or U$ 258.55), which is paid as unemployment insurance, and refers to the months of when fishing is suspended; from November 15th to March 15th (Brasil, 2003). This legislation seeks to contribute to the reduction of fishing effort and ensure the permanence of this natural resource for future generations.

In view of these measures, which aim to control fish stocks, many managers and researchers have been questioning the effectiveness and evaluation of the closed season policy for Amazonian fish species. In theory, the catches of fish tend to decrease during the period reserved for the suspension of fishing activities, however, due to a precarious enforcement of the law, the catches are not fully quantified, which appears to be compromising the stocks of more susceptible species of fish. In addition, there are signs of inefficiency and non-compliance with current laws, in particular the Closed Fishing Season law (Sousa and Freitas, 2011; Corrêa et al., 2014).

Due to the aforementioned problems, fishery science experts have been seeking, through varied analysis techniques, a manner to generate information that can subsidize more correct decision making. The objective is to promote the rational use of fishing resources (FAO, 2002), which is possible to achieve if the fishing activity is understood in such a way that man, the fishing resource and the environment are the basis for this decision making (Hilborn and Walters, 1992; Batista et al., 1998).

One way of estimating fish stocks in a certain region is through the use of mathematical modeling. Through computer simulation of scenarios, modeling is able to represent the interactions between man and fish assemblages, and the perspectives for the adequate management of fishery production in the short and long term (Silva et al., 2015). With hydrological data and information on fisheries, it is possible to simulate scenarios that can represent a fishing system and thus predict the system's behavior under certain environmental circumstances (Bratley et al., 1987).

Therefore, this study aimed to compare the pattern of illegal fisheries, and their frequency and production along the five main rivers of the Amazon basin (Negro, Japurá, Solimões, Purus and Amazonas rivers), while at the same time correlating them with seasonal parameters for the rivers: rising (December to April), highest level (May and June), receding (July to September), and lowest level (October and November), as well as, considering the effect of the presence and absence of the Closed Fishing Season law as a moderator scenarios of this analysis.

MATERIAL AND METHODS

Study area

The study covered the main rivers of the Central Amazon (Purus, Japurá, Negro, Solimões and Amazon) where illegal fishing activities are known to have taken place (Figure 1). The Purus River is considered one of the most productive for commercial fishing (Petrere Junior, 1985). The importance of this river in terms of catches brought to the city of Manaus (capital of the state of Amazonas) goes back decades, since in the period of 1976 to 1998, its contribution to catches tripled, from 15.7% to 49.3% (Freitas and Rivas, 2006). The Japurá River is a tributary of the left bank of the Solimões River and directly influences the flow of this river. The Negro River is the second largest tributary of the Amazon River and is a typical black water river. It is known for its high diversity, though low abundance, of fish species (Barthem and Goulding, 2007). The Solimões River makes up the largest tributary in the western sub-basin of the Amazon region, after the confluence with the Negro river, it is known as the Amazon River. However, the flow of the Amazon River near the city of Manaus depends on the sum of the flows of the Solimões and Negro Rivers (Cappelaere et al., 1999).

Data collection

The information related to illegal fishing seizures was obtained from the Brazilian Institute of Environment and Natural Resources - IBAMA's Technical-Environmental Division in Manaus (Amazonas state), via the analysis of records (of five rivers presented in the Figure 1) contained in the Fisheries Inspection and Infringement Reports, for the period between 1992 and 2017 (protocol nº 02005.103474/2017-44). Information related to the variation of the hydrological level was acquired from the National Water Agency (ANA) and the Mineral Resources Research Company (CPRM) from the hydrological data collection - Hidro web. The following criteria were observed: selection of
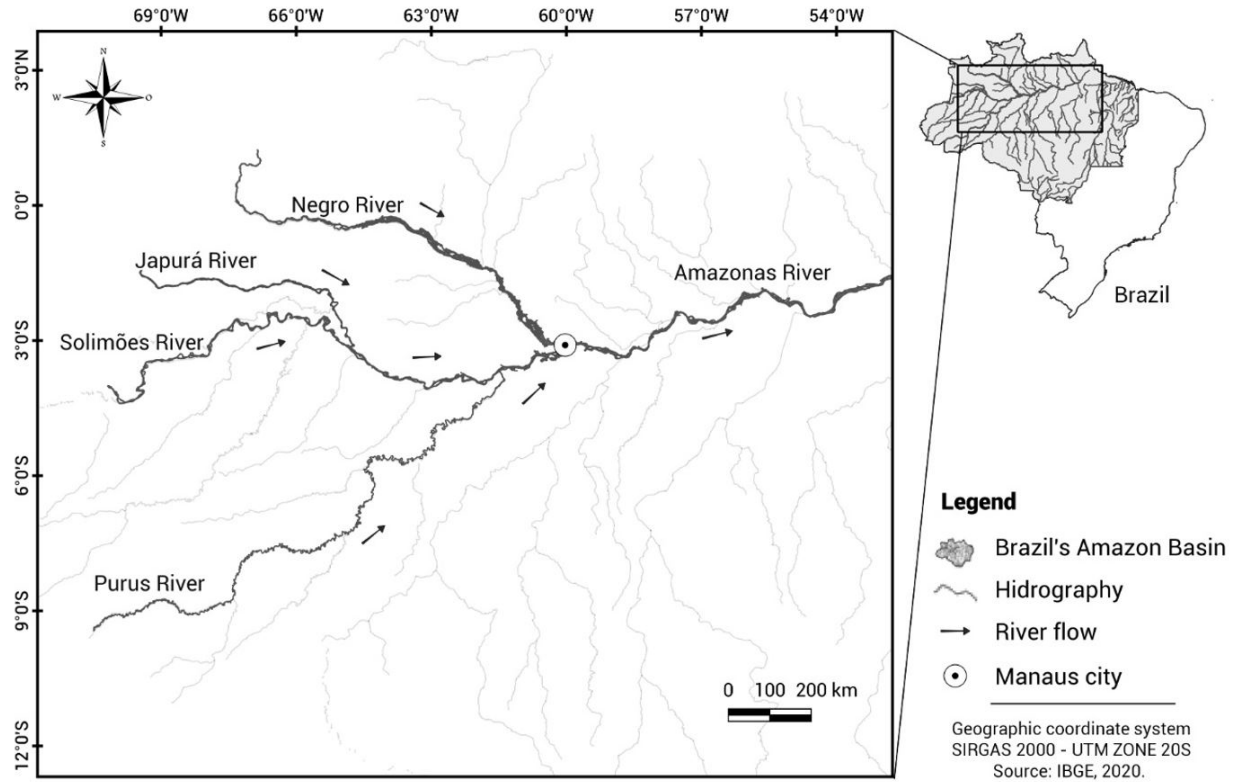
Figure 1. Spatial distribution of fish seizures and proximity to the city of Manaus, confluence of the Negro and Solimões rivers, forming the Amazon River.

the rain gauge station (station Nº. 1499000) which was closest to the five rivers selected for the study, and had influence of all outflows, which was identified at the height of the capital of the state of Amazonas, and also for presenting a consistent historical series of the river levels during the 26 years. This research was submitted to and approved by the Research Ethics Committee of the Federal University of Rondônia-UNIR, under the registration Nº. 09977718.0.0000.5300.

Ecosystem model of fish seizures in the Amazon basin

The ecosystem model was built from the identification of the variables of the fish seizure data, and developed using the Stella Software, version 8.0. Criteria were used to define the modeling procedures, with the aim of describing the dynamics of illegal fishing, in line with ecological and fisheries characteristics. The modeling process started with the construction of the model and its partition into sub-models, thus facilitating the insertion of the functional mathematical relationships for data input, its validation and the obtaining of scenarios (Figure 2).

Model parameterization

The choice of variables for the analysis of the scenarios consisted of the selection of the most ecologically relevant components and

processes within the modeled system (Gomes and Varriale, 2001), where the following variables were chosen for representation:

Fish Stocks: the initial value of natural fish productivity estimated by Silva-Junior et al. (2017), who measured the size of the productive area for fishing in the Amazon region and its fishing stock as being 600 thousand tonnes per year (*Fish Stock(t)* = P). These data were incorporated into the model after conversion to kilograms and grouped into monthly values (Equation 1):

$$Fish\_Stock(t) = Fish\_Stock(t-dt) + (Replacement - Catch) * dt \quad (1)$$

in which: t = model run time (with t ranging from 1992 to 2017); dt = rate of change over time; Replacement = capacity of fish stock recovery; Catch = total of legal and illegal fisheries production.

Carrying Capacity: this variable represents the level of use of the fishing natural resources that the study region can support and was considered equal to the values of the fishing stock. This simplification was necessary due to the lack of data that would allow for an estimation of fish biomass of the region today, as suggested in the works by Souza and Freitas (2010) and Montenegro and Souza (2016).

Replacement: consists of the inflow, which is dependent on the carrying capacity, the fishing stock, and its own replacement rate, which represents the logistical function of Verhulst (1838), in which a population grows to a sustainable maximum and tends to
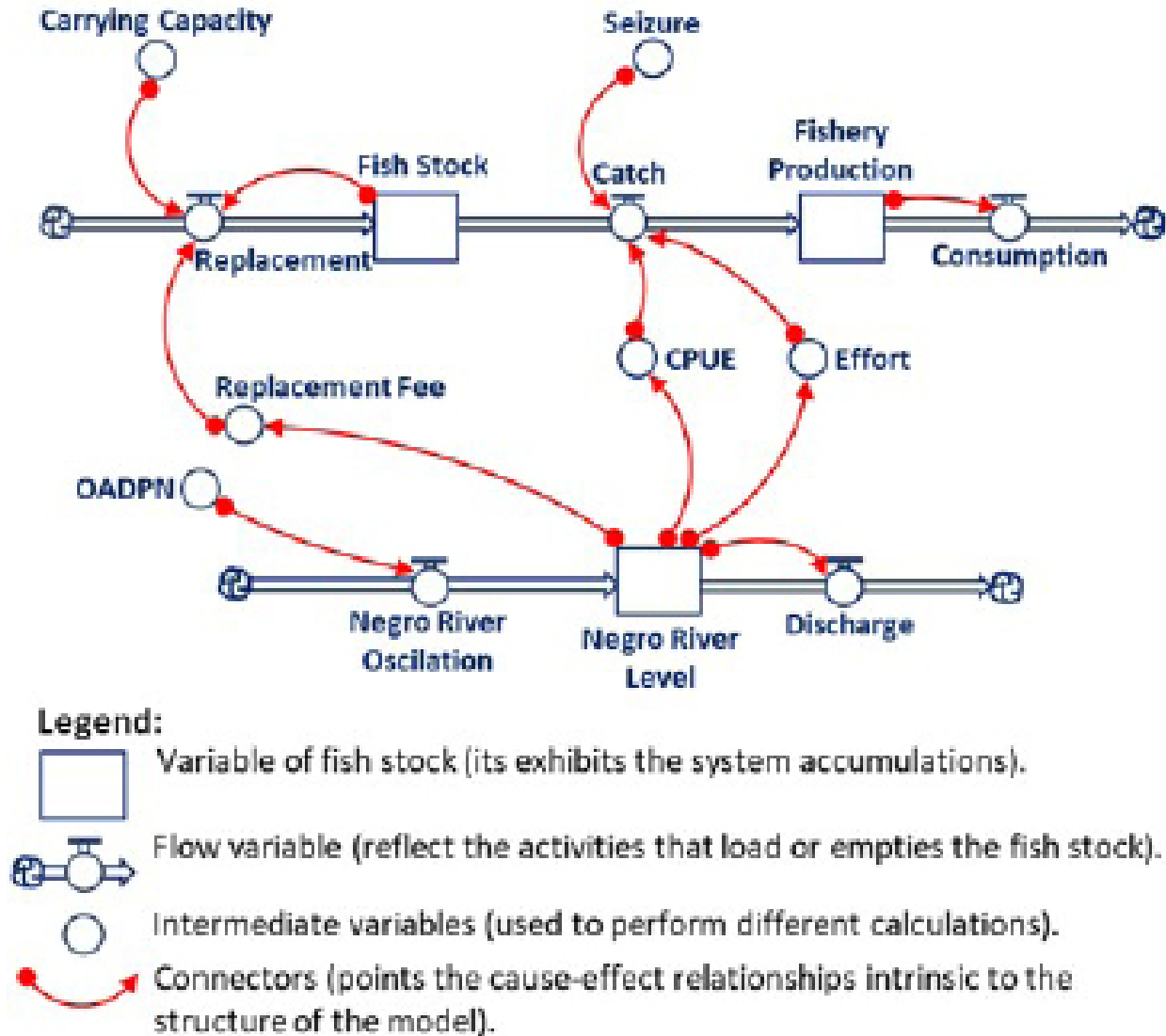
Figure 2. Model of the interrelationships between the seizures and the Negro River's water levels. Where = CPUE - catch per unit effort; OADPN - Random Oscillations in Normal Pattern.

stabilize at a given population size (Tavoni, 2013). This function is automatically derived by the Stella program to represent the replacement rate with its referred population growth (Souza and Freitas, 2014; Montenegro and Souza, 2016; Ramos, 2016; Inomata et al., 2018) (Equation 2):

$$Replacement(t) = rP\left(1 - \frac{P}{K}\right) \qquad (2)$$

in which: P = size of the fish stock in the environment; r = natural capacity for population growth; K = carrying capacity (constant = 50,000 tonnes/month); and t = running time of the model.

Replacement Rate: defined according to the work carried out by Lopes et al. (2017), who considered that starting from a river level value, the beginning of the reproduction of fish stocks occurs. Thus, the average value of the level of the Negro River in the period when the river is rising was calculated, for the period from

January to April (Bittencourt and Amadio, 2007), corresponding to the following logical function (Equation 3):

$$Replacement\_rate = \\ \left(IF\ Rio\_Negro\_level > 2468.17\ then\ (1)\ Otherwise(0.5)\right) \qquad (3)$$

in which: IF = indicator that represents the initial stage of the conditional logic function; then = signal that represents the logic function thesis, in which there is 100% reproduction in the environment; Otherwise = indicator that represents the thesis of the logical function in which 50% of reproduction is occurring in the study environment (Lopes et al., 2017).

This variable was represented by a logical function, taking into account that the replacement rate depends only on the hydrological cycle, since most species of fish form schools and migrate to spawn during the rising river level season and highest seasonal river level (Santos and Santos, 2005). Therefore, the highest

seasonal river level was chosen to simulate the replenishment of fish stocks since it is the biological recruitment phase. With this function, it is considered that when the river level is above the average (2,468.17 cm), 100% of the fish are reproducing (Souza and Freitas, 2009) and that below this level, only 50% will be replenishing their stocks.

Catch per Unit of Effort (CPUE): Conceptually, it is the catch (C) divided by the fishing effort unit (f) (Petrere Junior, 1978). However, catch and fishing effort data are not available and the monthly value of CPUE was included externally to the model, together with the level of the Negro River. As consequence, the Fishery Production stock variable in the model exhibits only the seizures values.

Fishing effort (f): this is the index that is related to fishing mortality (FAO, 1988), as well as the number of fishers multiplied by the days of actual fishing (Petrere Junior, 1978). It was inserted into the model by the graphical function, defined by the variables, Negro River level by the monthly value of (f), and indicated that the two variables are of a direct nature, meaning that their values increase or decrease proportionally with one another (Cardoso and Freitas, 2008; Hurd et al., 2016; Garcez et al., 2017).

Catch (C): It should represent the legal catches and it was established from the CPUE values and effort (f), according to Equation 4:

$$CPUE = \frac{C}{f} \Rightarrow C = CPUE * f \tag{4}$$

In addition to Equation 4, the variable for seizure, which represents data from illegal fishing, was added to Equation 5 to estimate the Fishery Production (FP):

$$FP = CPUE * f + Seizure \tag{5}$$

Seizure: this represents the historical series of fish seizures (real scenario) carried out by IBAMA, since it was calculated externally to the model and served as a basis to illustrate scenarios 1 and 2 proposed for analysis.

Fishery production (FP): This variable corresponds to the sum of legal and illegal (seized) caught fish, which represents the entry flow of the model (Equation 6). Nevertheless, the CPUE was maintained externally to the model and the Fishery Production stock variable shows exclusively the seizures values.

$$FP(t) = FP(t - dt) + (C - Consumption) * dt \tag{6}$$

Consumption: this variable was inserted in the model with the same methodological characteristics as adopted by Lopes et al. (2017), where it was assumed that everything produced by the fishery is consumed, thus, the consumption flow was equal to the value of production.

Negro River level: information regarding the historical series of river levels was obtained from the hydrometric station of Manaus, received in this model via the inlet flow, "oscillations of levels of the Negro River - LNR". The inserted function is conceived in Equation 7.

$$LNR = Level\ of\ the\ Negro\ River\ (t - dt) + $$
$$(Oscillation\ of\ the\ Negro\ River - outflow) * dt \tag{7}$$

Oscillation in the levels of the Negro River: this flow represents the inflow of water at the level of the river, to represent this variable, highest river level values (2,997 cm, river level in 2012) and lowest river level values (1,363 cm, river level in 2010) were considered. These were record values, which occurred above and below the average, respectively.

Thus, to make the scenarios created appear more realistic, the amplitude gained more extreme values to represent more intense oscillations at the river level. To generate the hydrological cycle model in the form of waves, over a period of 12 months, the function inserted in this variable was represented by the trigonometric function of cosine. Such a procedure was necessary for the function curve to follow the pattern observed in the data of the real historical series of the river level, so that the beginning and the end of the modeled period (x-axis) corresponded to the first and last months of the year, coinciding thus, with the lowest values of the river level oscillation (y-axis), based on the equation described by Lopes et al. (2017) and expressed in Equation 8.

$$coswave\left(\frac{amplitude\ above\ the\ mean}{2}, 12\right) + $$
$$\left(\frac{amplitude\ above\ the\ mean}{2}\right) + minimum\ mean \tag{8}$$

where: *coswave* is represented by the trigonometric function of cosine; *amplitude above the mean*: this is the difference between the mean between the maximum value of the time series of the data and the minimum value. Afterwards, this value was divided by two, in order to contemplate the amplitude above the mean; the number *12*: represents the months of the year (period of a complete hydrological cycle, with its seasonal oscillations); *minimum mean*: minimum value of the average of the data of the historical series of river levels, corresponding to the lower arc of the cosine function curve.

When replacing the values, the following cosine function was obtained, which was used as a basis to optimize the other representations of the hydrological model, in Equation 9.

$$-coswave\ (817.12, 12) + 817.12 + (1363) \tag{9}$$

In order to generate the final model, which reproduced the hydrological cycle in a more realistic way, a converter called Random Oscillations within the Normal Standard (*RONS*) was adapted to Equation 9, whose objective was to characterize the oscillations of the waves in a random manner, thus the function was constituted in the model presented in Equation 10.

$$-coswave\ (817.12, 12) + 817.12 + (1363) + RONS \tag{10}$$

Random Oscillations within Normal Standard (*RONS*): *Random* (111.1813, -177.6829) - represents a randomness at the river level, for this purpose the *Random* function, already endorsed by Lopes et al. (2017), was employed. In this case, only the values for the study area in question, and whose values were

randomized around the already established hydrological cycle, upwards or downwards, were used. This pattern is more similar to reality, as it better represents the river level's localized high spots, rising and falling water within normality, which is caused by various climatic factors that occur throughout the Amazon basin. Such a procedure implies that equation 10 will undergo an increase or a regression in its respective values, ranging from +111.1813 or -177.6829 centimeters over the analyzed period. These values were established from standard deviations from the mean of the highest and lowest levels, respectively. This function provided the formation of waves, which in the model simulates the flood pulse in the study region, as described by Junk et al. (1989).

Discharge: this depicts the outflow of the Negro River in which it is directly related to the seasonal variation of the water level.

Model run time

The model had, as units of time, months and years. In the first, 12 months were used to represent a hydrological cycle; the second was the study period (26 years), followed by its extension to 75 years, which aimed to represent the disparities of the modeled scenarios, the seasonality and the simulations of the long-term variables. The chosen rate of change over time (dt) was 0.25, as this better represents the seasonal variations as a function of time for the flood pulse (Lopes et al., 2017), and was correlated with the seizure activities in illegal fishing.

Scenario building

To simulate different events, a set of differential equations was maintained and the changes were restricted to the input values of specific rates or derived relationships. The information obtained in the process of characterization of the region was used in the construction of conditions regarding possible effects on fish seizures with the absence and presence of the Closed Fishing Season law during the hydrological cycle.

It is understood as illegal fishing, clandestine fisheries activities, whose profile is opportunistic, considering that it has been practiced during the closed fishing season and/or in protected areas, as well as the non-registered of fishermen and vessels without registration. And having as main instrument in force, the Policy of Closed Fishing Season (Law No. 9,605, 1998), which suspends the capture of certain fish stocks at risk of overfishing. The construction of the scenarios is linked to as much as the Closed Fishing Season law (Law n°. 10779, of Nov. 25, 2003; Brasil, 2003) which influenced the fisheries.

For the experiment, two scenarios were simulated: (i) the effect of the interrelationship between illegal fishing and the regime of the Negro River was tested with the effects of the absence of the Closed Fishing Season law; (ii) the same interrelations were also inserted, however with the full presence of the effects of this law. However, the scenarios were associated with the seizure variable, which represents the historical series of illegal fishing statistics, with the intention of creating these behavioral interfaces from the effects of the Closed Fishing Season law in the 1992 to 2017 time series.

In addition, the model was calibrated by adjusting the incorporated parameters in order to represent the study area properly, and thus consistent with the observed reality. Subsequently, the model was tested for other events and its behavior evaluated in order to verify the adequacy of the adjustments, for situations other than the one for which the parameters were defined (e.g., periods greater than 50 years). After the analysis, it was possible to confirm the robustness of the model.

RESULTS

The simulation showed that, in the first months of the evaluated period, the fish stock grew sharply and reached stability of around 50,000 tonnes of fish, where it presented a wave-shaped seasonal pattern (Figure 3).
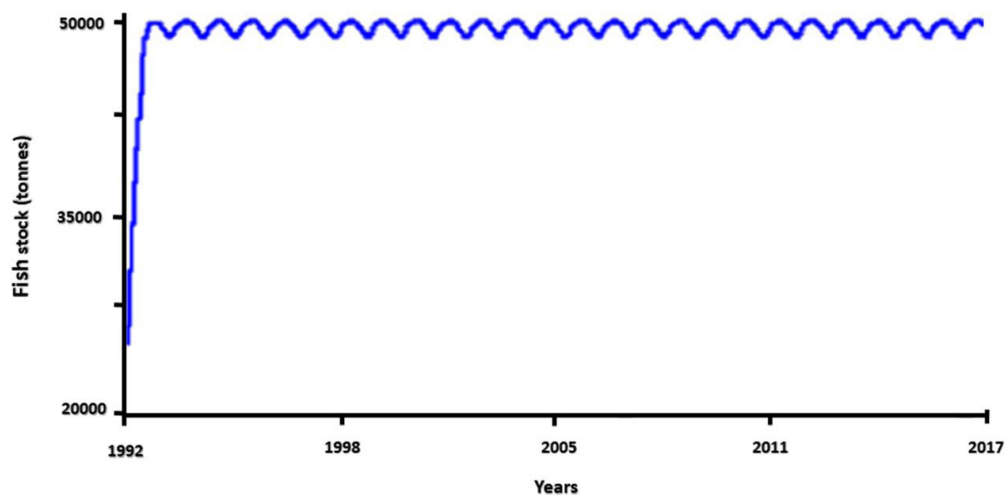

Figure 3. Temporal distribution of fish stock (in tonnes).

The fluvial regime of the Negro River was revealed with its seasonal peculiarities over the course of a year. When confronted with CPUE and fishing effort, it was found that the values represented by the former behaved in an inversely proportional manner in regards to the level of the Negro River (Figure 4A). The fishing effort values, on the other hand, followed the same seasonal pattern shown by the river level (Figure 4B). However, the data revealed that the highest CPUE values occurred in periods of low water level and high-water level, indicating that the fishers increase the intensity of their fishing at that time interval. On the other hand, the fishing effort showed high values only during period of the high-water level (Figure 4B). Consequently, the CPUE values indicated an inverse relationship to the fishing effort values (Figure 4).

During the annual simulation, the CPUE showed a peak in the month of January, which then decreased until the month of July, where it presented its lowest value, followed by growth until a second peak, in the month of December (Figure 4A).

Scenarios 1 and 2 of fishing seizures related to the hydrological cycle showed specific peculiarities for two extremes. In the first, where the total absence of the closed season was attributed, there was a seasonal increase in fish catches for the periods of the highest seasonal river level and beginning of the rising seasonal river level, where fish seizures reached around 26 tonnes (Figure 5A). While in the second scenario, with the presence of the Closed Fishing Season law, it was found that the highest values of seizures occurred in the periods of rising water levels
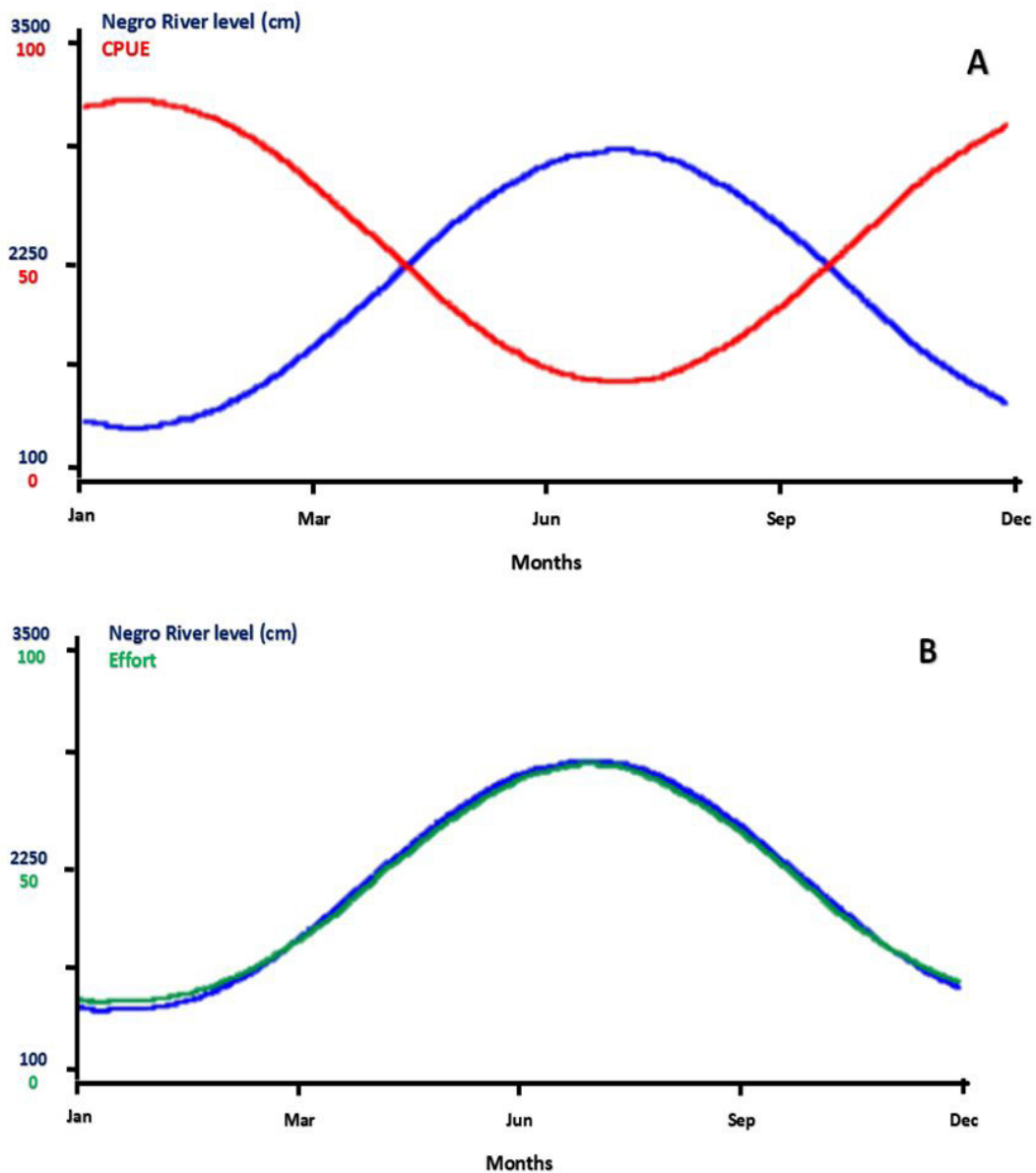

Figure 4. Values of CPUE (A) and fisheries effort (B) related to the variations in the Negro River's water levels.
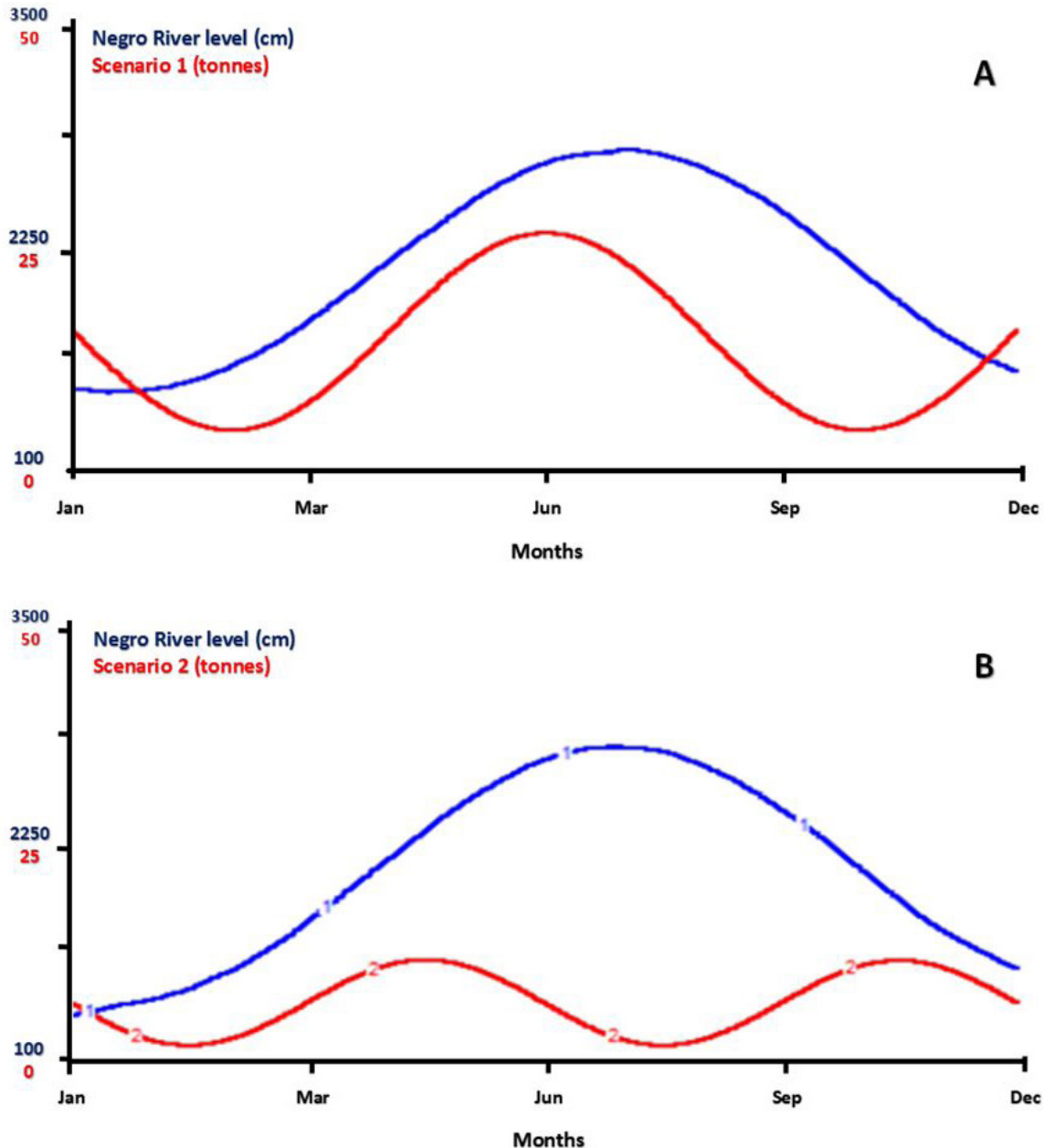
Figure 5. Variations of the Negro River's water levels versus scenario 1 (A) (Total absence of the Closed Season law) and versus scenario 2 (B) (Full presence of the Closed Season law).

and the end of receding water levels, with an apprehension of approximately 12.5 tonnes per period (Figure 5B).

When scenarios 1 and 2 are compared separately, with the real values of fish seizures (real scenario) over the study period (26 years), different patterns for the quantity of fish seizures between the situations presented were exhibited. Scenario 1, when compared to the real seizures, showed high levels of seizures, which remained to grow throughout the study period (Figure 6A). However, the real scenario exposed high activity in the production of illegal fishing between the years of 1998 to 2005. On the other hand, when the real scenario with the full extent of the Closed

Fishing Season law is considered (scenario 2), a decrease in the values of seizures that follow a continuous downward trend over time becomes evident, and these values are lower than those recorded for illegal production (Figure 6B).

When comparing scenarios 1 and 2, it was observed that in the first years of simulation, the minimum and maximum values of seizures in illegal fishing in the first scenario (3.7 to 30.19 tonnes month^{-1}) were twice the values in relation to the second scenario (1.17 to 14.33 tonnes month^{-1}). These differences were also noted during the 26-year simulation, where in scenario 1 the values of seizures were increasing and progressive,
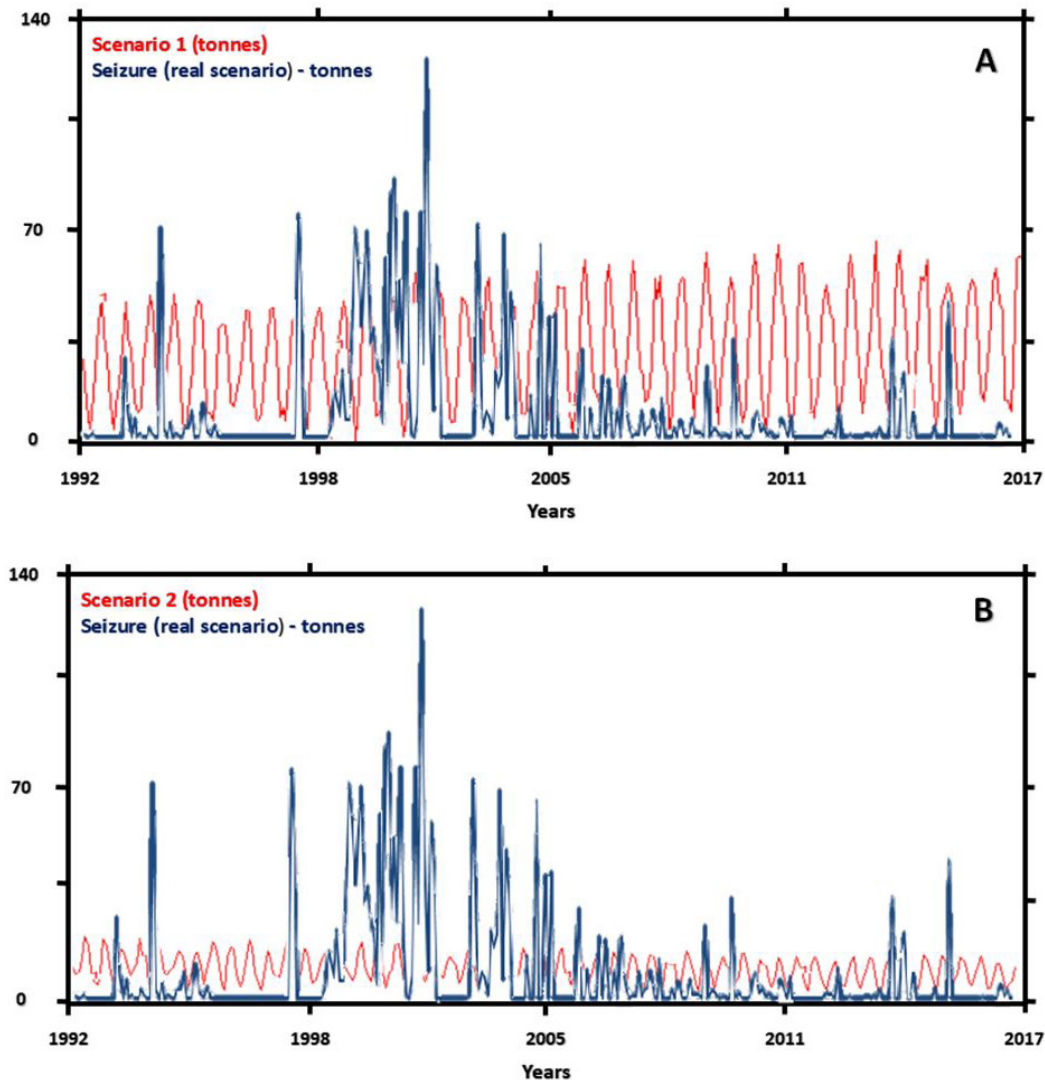
Figure 6. Comparative values between seizures in the real scenario with scenario 1 (A) and scenario 2 (B), occurring during the 26 years of illegal fisheries in the Amazon basin.

reaching maximum final values of 47.8 tonnes month^{-1}. On the other hand, the second scenario continued to show lower and decreasing seizure levels which reached around 0.81 tonnes month^{-1} at the end of the simulation.

By increasing the time scale of the systemic simulation to 75 years of illegal fishing, the data revealed different patterns for each scenario employed. For scenario 1, the values of seizures reached the highest levels, around 72.58 tonnes month^{-1}. While the number of seizures for scenario 2 showed minimum values, with a tendency to reach zero in the number of seizures recorded at the end of the time series (Figure 7).

DISCUSSION

Illegal fishing in the Amazon basin, as has been registered in recent decades, has threatened the stability and survival of fishing communities (Dias et al., 2013), which is reflected by the high records of illegal fishing (Corrêa et al., 2014; Cavole et al., 2015). This is mainly caused by the existence of a rich aquatic biodiversity, which is an attractive factor for formal and informal fishers, and is aggravated by the large territorial extension of the Amazon basin, which makes it difficult to monitor those who make a living from the region's fishery resource (Gasalla and Ykuta, 2015).

Regarding the variables modeled here, the fish stocks exposed a high growth in the first months, with subsequent stabilization, and showed fluctuations resulting from the coexistence with the hydrological regime of the Rio Negro. This pattern of rapid growth followed by oscillatory stabilization in the values of the fishing stock has already been the subject of research carried out in the Brazilian Amazon (Souza and Freitas, 2014; Montenegro and Souza, 2016; Lopes et al., 2017; Inomata et al., 2018).
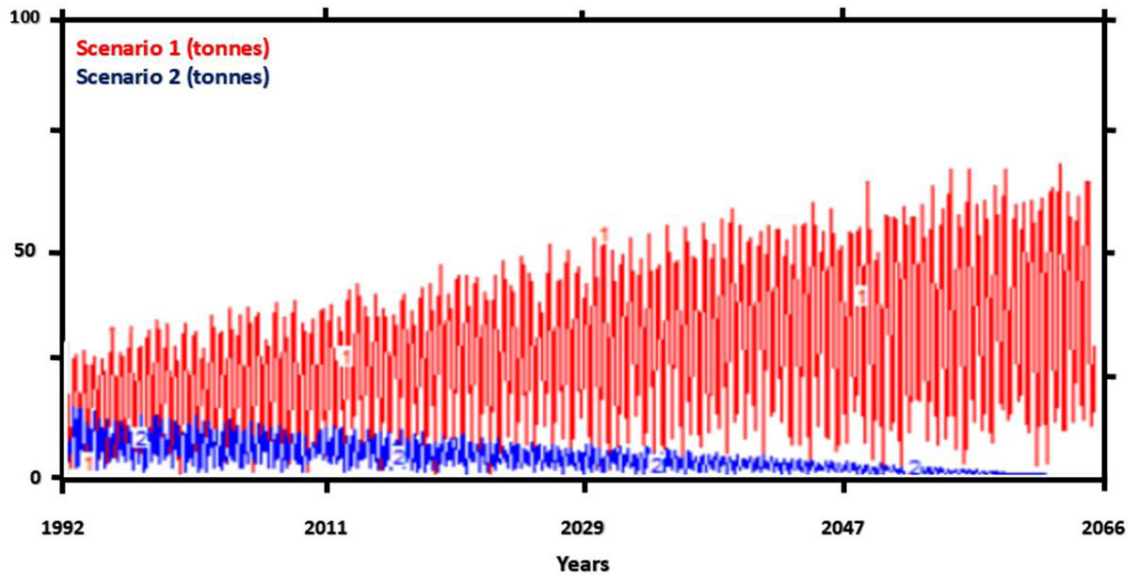
Figure 7. Simulations of scenarios 1 and 2 for 75 years of illegal fishery activity (1992-2066).

The utilization of the Negro River's levels as a variable in the system was of essential relevance in order to make the simulations more realistic, since fishing in the Amazon region depends on the seasonality of the river levels (Souza and Montenegro, 2016; Sousa et al., 2017), or rather, the periods between December to April (rising), May and June (high), from July to September (receding), October and November (low) (Bittencourt and Amadio, 2007).

The results showed that the increase in the variation of the river regime is followed by a decrease in the CPUE variable. This inversely proportional pattern has already been recorded in other studies, and it occurs as a result of the dispersion of fish species in the aquatic environment during the rising river levels and the increase in their catch during the low river levels, when the aquatic environment is reduced, which forces the fishers to increase or decrease their fishing effort, and which consequently influences fishing production (Ruffino and Isaac, 1994; Barthem, 1999; Souza, 2003; Cardoso and Freitas, 2007; Inomata and Freitas, 2015).

Thus, by using scenarios 1 and 2, the present study shows that, for the Amazon basin, there is a direct relationship between the enforcement of the Closed Fishing Season law on illegal fishing activity and the seasonality of the Negro River's levels, where high levels of seizures were identified in illegal fishing during the period of high water levels (period of reproduction of most migratory fish species), and diminished values of these seizures at the beginning of the rising water levels and low water levels. These are factors that may be linked to more incisive monitoring in the first case, followed by compliance with the prohibition of fishing for most species, due to the duration of the closed season, in the second case (Silva et al., 2019). Thus, even though modeling involving systemic thinking is a new idea in the Amazon region, the applicability of this ecosystemic methodology has already been carried out in studies that represent the dynamics and sustainability of fisheries stocks in the face of anthropogenic and natural phenomena (Souza, 2003; Souza and Freitas, 2010; Souza

and Freitas, 2014; Montenegro and Souza, 2016; Lopes et al., 2017; Inomata et al., 2018).

This study, when compared to the results of the simulation for scenario 1, with the values of occurrences of real seizures recorded over a period of 26 years, showed a continuous growth in seizures over time. On the other hand, the values of the catches exposed in the real scenario, occur gradually in the first decade, followed by a drop in these numbers in the following decade, indicating a trend of stability in the numbers of catches from illegal fisheries, after the period in which the Closed Fishing Season law year came into force (2003), and this pattern has continued to this day. In scenario 2, there was a constant drop in the number of seizures displayed in the study's temporality, indicating that the Closed Fishing Season law can be an extremely important factor for the reduction of illegal fisheries and possible protection of fish stocks.

It is well known that the future of a common resource to which there is free access, in general, may tend towards extinction in a short period of time (Hardin, 1968). Thus, the study's temporality was extended until the year 2066, with the aim of analyzing the long-term simulations and the respective disparities of the fishing scenarios, whether under the Closed Fishing Season law or not. From 2017 onwards, there was a continuous trend of growth in seizures from illegal fishing activities for approximately 50 years, reaching alarming levels in terms of quantity apprehensions for scenario 1. However, when considering compliance with the Closed Fishing Season law, it is clear that the simulation (scenario 2) acts as an inhibitor of illegal fisheries, where the number of seizures continues to decrease, reaching minimum seizures and below what occurred in the real scenario.

In view of the above considerations, it is understood that the use of systemic modeling is well-suited to the problem and useful for monitoring the behavior of fish seizures arising from illegal fishing, especially for the transformation of secondary databases

into more accurate information. The proposed modeling, if well used, would greatly improve monitoring of fishing activity in the Amazon region (Montgomery, 2004).

CONCLUSION

The absence of the Closed Season Law in fishing activities was considered in scenario 1 and resulted in an increase in fish seizures over time. In the other scenario, the Closed Fishing Season law was included, which reflected a continuous decrease in the numbers of fish seizures in the simulated period. Thus, it can be understood that the use of systemic simulations, presents itself as a useful and valuable tool for testing hypotheses, as well as for formulating and monitoring management scenarios that are related to the management of Amazonian fishery resources.

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