AN ECOLOGICAL MODEL FOR QUANTITATIVE RISK ASSESSMENT OF HAWKSBILL SEA TURTLE (ERETMOCHELYS IMBRICATA): THE CASE OF A TOURISTIC ENVIRONMENT IN NORTHEASTERN BRAZIL

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ABSTRACT

Turtles are the main components of the biodiversity of the ecosystems they inhabit. Their importance to the environment is enormous. This work focused on a Quantitative Ecological Risk Assessment of the Hawksbill Turtle, which is currently labeled as Critically Endangered by the International Union for the Conservation of Nature (IUCN). Our research partners with the Non-Governmental Organization EcoAssociados, which works with data collection and risk management of marine turtles in PG to provide essential data to perform the Hawksbill Turtle probabilistic model. As a result of our research, some objectives were achieved, for example: graphs that show the probability of X% increase/decline in the number of Hawksbill Turtle and a graph of the probability of half-loss, both for the next 100 years and for various scenarios of conservation measures and/or human impact; including an uncertainty interval. The results were reported to the risk management team.

1. INTRODUCTION

Porto de Galinhas (PG) is one of Brazil's most touristic places due to its paradisiac beaches (i.e., Muro Alto, Cupe, Maracaipe, Merepe). In 2019, PG received approximately 1.2 million tourists, generating 20 thousand direct and indirect jobs and around U$ 400 million income from tourism. In 2020, even during all the restrictions due to the COVID-19 pandemics, these numbers were higher than 500 thousand tourists and U$ 220 million dollars income [1]. With immense biodiversity, PG is a touristic center and a sanctuary for many important marine species. PG's ecological importance gave rise to Non-Governmental Organizations (NGOs), such as EcoAssociados (EA), to balance tourism and conservation.

PG is a spawning region for HT, with an average of 170 nests per season. This species is considered to be very important for PG's ecosystem and economy for many reasons, e.g. [2]: (i) HTs attract thousands of tourists every year to watch their birth; (ii) they selectively feed on some groups of marine sponges and help maintain biodiversity in coral reefs; (iii) allow rare species to compete for space and nutrients successfully; (iv) transfer the energy and nutrients stored in the feeding areas (i.e., marine environment) to spawning beaches (i.e., terrestrial environment) in the form of Eggs, providing a concentrated source of high-quality nutrients to plants and animals on the coast.

Urbanization and seaside constructions, such as resorts and hotels, grow exponentially in PG. Without planning and control by entities, such growth can cause many adverse effects to the HT, such as habitat destruction; artificial lighting that decreases Egg's survival rate due to disorientation caused by the light on newborns; trash on the beaches that turtles may ingest, and suffer obstruction in their digestive system. Additionally, the uncontrollable numbers of tourists may accidentally trample on nests and reduce their chance of birth success.

For this work, the ecological risk is defined as the probability of having ecological adverse effects in the short and long-term [3–5]. More specifically, we intend to develop ways of quantifying HT regional

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extinction risk (i.e., the probability that HT will no longer spawn/occur in a specific region during the next 100 years). PG's risk of HT regional extinction is getting higher every day for all the impacts mentioned above. EA collects data on HT in PG and has worked to minimize this risk through many control actions, such as (i) translocation of Eggs from more to less threatened areas; (ii) nest monitoring and nest release; (iii) monitoring the artificial lighting of hotels, resorts, and condominiums. However, they execute those actions on a subjective basis (i.e., the control plan is defined day by day based on EA's biologists' knowledge and experience). There is no mathematical model or tool to guide them in the decision-making allowing the conservation strategies to have maximum effectiveness in reducing the risk of extinction of the managed species.

Generally, retroactive data are needed to model a turtle population dynamics, showing how the sub-population will be modeled behaves. The data can be the average number of nests per year; the average number of Eggs per nest; rate of success of nests; survival rates for each life stage of the turtle; quantitative reports on the impacts to be modeled; ecotoxicological data for the HT when exposed to oil and BTEX (i.e., group of compounds by hydrocarbons: benzene, toluene, ethylbenzene, and xylenes). There is only one model for HT in the literature [6]. However, it is not stochastic, so it cannot account for uncertainty in parameters and results. Furthermore, the model is from 1997, and a lot has changed in the world.

In this context, this work aimed to develop the first stochastic HT model in the literature that overcomes the drawbacks mentioned above and is tailored for quantitative risk assessment. Through this model and using reproductive and non-reproductive data of HT since 2009, we conducted a Quantitative Ecological Risk Assessment (QERA) in PG.

2. DESCRIPTION

Figure 1 shows a simplified schematic representation of our model for the life cycle of HT. Based on [7], we have defined four life stages: (i) Egg, (ii) Oceanic juvenile, (iii) Neritic Juvenile, and (iv) Adult. There are three zones, or areas, for HT: the (a) terrestrial, i.e., the beach area that is not regularly inundated with water; (b) neritic, i.e., zone of the ocean where sunlight reaches the ocean floor, with a relatively shallow depth extending to about 200 meters; and (c) oceanic, i.e., where sunlight may not reach the ocean floor, and the water depths drop to below 200 meters).

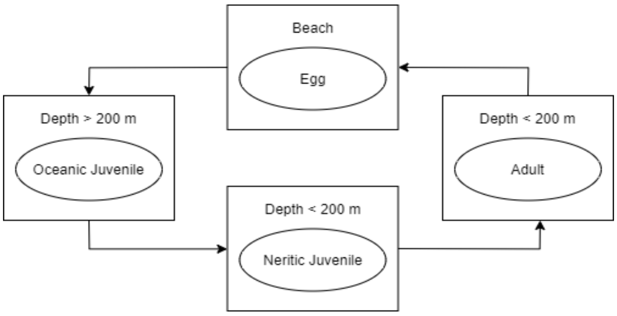

Fig.1 – HT life cycle.

Since the start of the model, it was clear that hazards would be linked to harmful anthropogenic actions generated in PG. Therefore, a close to the ideal scenario SCN-0 was defined, considering today's maritime environment (i.e., the human impacts are more general, not specific to PG). SCN-1 refers to the impact of artificial lighting without any control measure taken by responsible entities [8]. SCN-2 impact caused by the BTEX residues of the 2019 oil leak [9–11]. SCN-3 no control measures to ensure successful nesting and breeding of adult females. The SCN-4 is a possible future oil spill in PG. SCN-5 is the worst scenario, which simulates what would happen if there were no mitigation plan, with all impacts coinciding. SCN-6 is the scenario where all human impact occurs with the control measures carried out by EA.

We defined the model with two main structures, the sex and stage structure. We described the sex structure by dividing it into males and females, with the same stages, but with only the adult female generating Eggs. Also, we discretized the stage structure in 4 phases (Figure 1). To estimate the model parameters, reproductive and non-reproductive data have been gathered since 2009 by the NGO EA. To estimate the frequency and assess the exposure of each selected SCN, we used the data from EA, educated guesses from biologists, and the following studies [8], [12]. The model presented was used to conduct a QERA for Turtles by following the same general steps proposed by [13]: (i) characterize the problem; (ii) describe the scenarios (SCNs); (iii) parameterize the model and initial conditions; (iv) assess frequency; (v) assess exposure, and (vi) quantify and categorize the risks. Each of these steps generates a specific result of the QERA.

Because of the long life that HT may have (i.e., on average 50 years), we assumed that the time-step is one year and the duration of the simulation would be 100 years, which is the same duration used in the IUCN risk criteria [14]. RAMAS Metapop v.6.0 software was adopted for running the simulations with 10,000 replications. This software is a computational tool for constructing a metapopulation approach and running probabilistic simulation via the Monte Carlo method [15].

3. DISCUSSION

The main result of the HT model was the graph of the probability of half loss over time that compared each SCN risk category [14], achieved after 100 years. Moreover, the following conclusions could be taken analyzing the graph.

The benchmark scenario (SCN-0), without any human actions, already showed that turtles are classified as VULNERABLE, and not to aggravate this category, mitigation measures must be implemented. it is relevant to emphasize that SCN-6 was one of the scenarios with the most significant risk of half loss because it dealt with the accumulated probability of human impacts (even considering the NGO's mitigation measures from EA). But even so, it is evident that such measures are of paramount importance, as they were sufficient to reduce the risk of half loss concerning the SCN-5 by almost 80% in less than 45 years. Also, it is noticeable that the SCN-6 risk category remains VULNERABLE at the end of the simulation, indicating that mitigation measures focused only on the Egg stage are not enough to minimize the damage and bring the category down. Although dealing with great uncertainty in the parameters and overestimating the risks, the results are still worrying. The SCN-4 showed that an oil spill in PG would be sufficient to elevate the risk by almost 50%. Even with mitigation measures added, the HT population would certainly not withstand a catastrophe of this magnitude when added to the other human impacts existing. SCN-2 has light relevance in the first years after the accident (2019) because of the quick cleaning of the crude oil. However, the chemical residues that remained in the water were not ignored, and it is remarkable how their consequences are substantial over time. The SCN-1 showed that only a simple isolated human action, if not supervised by the responsible entities, can impact the HT population, increasing the risk of half loss by almost 100% in less than 50 years. It is plentiful to note how dangerous artificial lighting is to the permanence and survival of HT in PG.

4. CONCLUSION

The paper shows innovative research since no study has yet used this Methodology to simulate any turtle's future in a stochastic manner. This paper successfully estimates plausible SCNs for the ecological risks caused by oil spills and human impact on Brazil's northeast coast for the next 100 years.

We reported this research's results to the involved entities to better understand the possible SCNs and their peculiarities. Such results help a cost-effectiveness analysis so that managers prioritize action plans that effectively reduce ecological risks within budget. From the results, we conclude that the long-term ecological risks for HT's future in PG strongly depend on the competent authorities and environmental agencies' mitigation measures. The faster and more effective the actions, the more unlikely the HT population in PG will change from an "Endangered" risk category to "Critically Endangered". The HT turtle serves as an indicator of the ecosystem's health because if it becomes Critically Endangered, PG's entire ecosystem also turns Critically Endangered.

We aim to continue developing this model to simulate other impact SCNs related to HT, such as waste in the ocean, sand compacting by trampling, and SUAPE industries' effects on PG HT subpopulation. Additionally, we intend to use the Methodology and learning acquired in this study to develop new models. Environmental agents, researchers, and consultants worldwide can use our model with some changes as an essential decision-making tool to answer any questions about the sea turtles' management and future in coastal areas.

5. REFERENCES:

[1] Diario de Pernambuco, “Porto de Galinhas tem destaque na retomada do turismo brasileiro,” *01/12*, 2020. https://www.diariodepernambuco.com.br/noticia/economia/2020/12/porto-de-galinhas-tem-destaque-na-retomada-do-turismo-brasileiro.html (accessed Dec. 15, 2020).

[2] M. Wilson, E.G., Miller, K.L., Allison, D. and Magliocca, "Why healthy oceans need sea turtles: the importance of sea turtles to marine ecosystems," *OCEANA*, (2010), [Online]. Available: https://oceana.org/sites/default/files/reports/Why_Healthy_Oceans_Need_Sea_Turtles.pdf.

[3] H. O. Duarte, "A methodology for quantitative ecological risk assessment for industrial accidents," Universidade Federal de Pernambuco (UFPE), Recife, (2011).

[4] H. Duarte *et al.*, "An ecological model for quantitative risk assessment for schistosomiasis: The case of a patchy environment in the coastal tropical area of Northeastern Brazil," *Risk Anal.*, vol. 34, no. 5, pp. 831–846, (2014), doi: 10.1111/risa.12139.

[5] H. O. Duarte and E. L. Droguett, "Quantitative ecological risk assessment of accidental oil spills on ship routes nearby a marine national park in Brazil," *Hum. Ecol. Risk Assess.*, vol. 22, no. 2, pp. 350–368, (2016), doi: 10.1080/10807039.2015.1067760.

[6] M. Y. Chaloupka and J. C. Limpus, "Robust statistical modelling of hawksbill sea turtle growth rates (southern Great Barrier Reef)," *Mar. Ecol. Prog. Ser.*, vol. 146, pp. 1–8, (1997), [Online]. Available: https://www.int-res.com/abstracts/meps/v146/p1-8/.

[7] P. Lutz, J. Musick, and J. Wyneken, *The Biology of Sea Turtles*, vol. 2. CRC Press LLC, 2000.

[8] A. E. C. Sayegh, T. N. Simões, E. M. dos Santos, and A. C. da Silva, “Iluminação artificial e orientação dos filhotes de Eretmochelys imbricata (Linnaeus, 1766), litoral sul de Pernambuco, Brasil,” *Rev. Ibero-Americana Ciências Ambient.*, vol. 11, no. 4, pp. 89–101, (2020), doi: 10.6008/cbpc2179-6858.2020.004.0008.

[9] IBAMA, “LOCALIDADES AFETADAS,” Brasília, 2019. [Online]. Available: https://www.ibama.gov.br/phocadownload/notas/2019/2019-10-26_LOCALIDADES_AFETADAS.pdf.

[10] P. G. L. Pena, A. L. Northcross, M. A. G. de Lima, and R. de C. F. Rêgo, “Derramamento de óleo bruto na costa brasileira em 2019: emergência em saúde pública em questão ,” *Cadernos de Saúde Pública* , vol. 36. scielo , 2020.

[11] C. Madeiro, “Óleo no Nordeste: O que se sabe até agora sobre a contaminação das praias... - Veja mais em https://noticias.uol.com.br/meio-ambiente/ultimas-noticias/redacao/2019/10/22/oleo-no-nordeste-o-que-se-sabe-ate-agora-sobre-a-contaminacao-das-praias.htm?cmpid=co,” *UOL*, 2019. https://noticias.uol.com.br/meio-ambiente/ultimas-noticias/redacao/2019/10/22/oleo-no-nordeste-o-que-se-sabe-ate-agora-sobre-a-contaminacao-das-praias.htm.

[12] C. L. Mitchelmore, C. A. Bishop, and T. K. Collier, "Toxicological estimation of mortality of oceanic sea turtles oiled during the Deepwater Horizon oil spill," *Endanger. Species Res.*, vol. 33, no. 1, pp. 39–50, (2017), doi: 10.3354/esr00758.

[13] H. O. Duarte, E. L. Droguett, M. das C. Moura, P. G. S. C. Siqueira, and J. C. de Lira Jr, "A novel quantitative ecological and microbial risk assessment methodology: theory and practice," *Hum. Ecol. Risk Assess.*, pp. 1–24, (2019), doi: 10.1080/10807039.2019.1596736.

[14] IUCN, *IUCN Red List Categories: Version 3.1*. Gland, Switzerland and Cambridge, UK: IUCN Species Survival Comission, (2001).

[15] M. H. Kalos and P. A. Whitlock, *Monte Carlo Methods*. Weinheim: Wiley-VCH, (2008).