Holy Mackerel! an Exploratory Agent-Based Model of Illicit Fishing and Forced Labor

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Abstract. This paper introduces an agent-based model to explore the existence of positive feedback loops related to illegal, unregulated, unreported (IUU) fishing; the use of forced labor; and the depletion of fish populations due to commercial fishing. The author hypothesizes the use of forced labor adversely impacts economic activity, provides incentive for illicit activity, and depletes the population of fish. Left unchecked, such a dynamic may lead to irreversible environmental impacts, exacerbate international tensions, and yield significant economic losses. The lack of reliable data on human trafficking and global fisheries makes statistical analysis extremely difficult. This model serves to consolidate several behavioral and impact assumptions into a single exploratory model in order to test these assumptions and establish a proof of concept to guide future research.

Keywords: Trafficking in persons · Forced labor · IUU fishing · Agent-Based modeling · Overfishing · International conflict

1 Introduction

Human trafficking is a global scourge from which no country is immune. The use of force, fraud, or coercion to compel individuals into sex trafficking or forced labor happens everywhere – from the least developed to the most advanced; from kleptocracies to democracies. The U.S. Department of State's 2015 Trafficking in Persons Report documents 188 countries in which victims of modern slavery are found, and the International Labor Organization estimates 21 million victims worldwide and an illicit economy of $150 billion per year attributed to human trafficking [1, 2].

While these statistics are staggering, efforts to quantify human trafficking are riddled with challenges. Despite an international legal definition of "trafficking in persons," jurisdictions within the international system operate under drastically different definitions of the crime. This complicates efforts to collect, validate, and aggregate data. In addition, human trafficking is a hidden crime in that victims are often unwilling to self-identify, and instances are obscured by the presence of other crimes such as

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K.S. Xu et al. (Eds.): SBP-BRiMS 2016, LNCS 9708, pp. 400–409, 2016.
DOI: 10.1007/978-3-319-39931-7_38

other forms of illicit trafficking (e.g. drugs, weapons), unlawful fishing, prostitution, and immigration violations. Ultimately, reliable data simply does not exist. This has not prevented advocates, activists, and policymakers from citing such data as they craft approaches to combating human trafficking.

One area of human trafficking that has garnered public and policymaker attention is the use of forced labor in supply chains, particularly in the seafood industry [3, 4]. Despite increased anecdotal evidence and a nascent understanding of actor behavior, concrete data on forced labor within the seafood industry remains scant. As a result, there is a significant gap in the ability of policymakers to make evidence-based policy, as well as a strong need for analytical techniques that thrive in the absence of "big data." To fill this gap, this paper uses exploratory modeling – an approach that allows for the testing of various assumptions and hypothesis when confronted with "insufficient knowledge or unresolvable uncertainty preclude[ing] building a surrogate for the target system" [5]. Rather than drilling down to increasingly granular micro-levels of the system, this paper attempts to consolidate broader system-level information and assumptions to test hypotheses and reveal deeper insight into the overall system.

As such, this paper introduces a simple agent-based model that explores the existence of a positive feedback loop between forced labor; illegal, unregulated, unreported (IUU) fishing; and overfishing. This author hypothesizes that IUU fishing and labor exploitation serve in conjunction to drive down labor costs, and therefore market prices for fish. Furthermore, the author postulates lower market prices push fishermen to catch and sell more fish to sustain their businesses and to compete in the market. This hypothesis holds that the use of forced labor hurts legitimate businesses, incentivizes illicit activity, and depletes the population of fish. Left unchecked, such a dynamic may lead to irreversible environmental impacts, exacerbate international tensions, and yield significant economic losses.

Policymakers are currently pursuing separate policies to address forced labor in the fishing sector and IUU fishing. There are efforts to incentivize more transparent and lawful supply chains, including eliminating forced labor from seafood supply. At the same time, policies on IUU fishing generally focus on environmental impacts such as depleted fish stock and economic losses [6]. There are signs that the two policy interests are ripe for convergence, suggesting that this is an opportune time to leverage modeling to inform policy on these issues. The new Trans-Pacific Partnership trade deal addresses both forced labor and environmental issues, and interagency efforts on IUU are increasingly aware of forced labor in the fishing industry [7, 8]. Agent-based modeling may prove a useful tool for providing policymakers deeper insights into the fishing industry, potentially resulting in diplomatic solutions, more exacting policy, and innovative program development such as tailored public-private partnerships.

2 Workings of the Agent-Based Model

In addition to the aforementioned challenges of quantifying human trafficking and the extent of forced labor in the fishing industry, data on fish stocks and the prevalence of IUU fishing are also difficult to find. This is due to several factors, including the vastness of the ocean; territorial disputes in places like the South China Sea; unclear jurisdiction in international waters; and the economic interests of sovereign countries that maintain secrecy around natural resources they seek to exploit. Therefore, this agent-based model was built in NetLogo [9] with adjustable attributes to accommodate available data, test values where data is unavailable, and explore various assumptions. Various scenarios can be subject to experiment in order to learn more about the interplay of forced labor, IUU fishing, and overfishing. The model space is a 100×100 Cartesian plane, which roughly scales to the portion of the South China Sea with Hong Kong to the north, Brunei and Malaysia to the south, Vietnam to the west, and the Philippines to the east. This is only a rough fit and is not meant to be a reliable geographical representation.

2.1 Model States

Each run of the model can be run in one of three states. The first is the absence of IUU fishing in which boats pursue fish according to standard rules and adhere to common labor practices. In this state, boats only fish during "on season." The second state is the presence of IUU fishing but the absence of forced labor. The prevalence of IUU fishermen as a percentage of total boat population is adjustable for each run. IUU boats in this state engage in fishing activity during the "off-season" but adhere to wage standards. The third state is the presence of both IUU fishing and forced labor. In this state, IUU boats engage in substandard labor practices and fish during the off-season, while the other boats do not. Having three states allows the observer to compare outcomes of the various states to determine the impact of IUU and forced labor.

Global Attributes.

Attribute	Description
Number of boats	Number of boats
Fish population	Number of fish at the outset of a model run
Fish per boat	Number of fish a boat should carry at a given time (serves as a safety standard or fishing quota). Law-abiding boats adhere while IUU boats exceed this number, according to their own "Fish capacity" attribute described below.
IUU fishing	True/false statement that determines whether a subset of boats engage in IUU
IUU prevalence	Percentage of total boat population engaged in IUU
Forced labor	True/false statement that determines whether IUU boats engage in substandard labor practices
Minimum wage	Standard wage all law-abiding boats pay workers. IUU boats pay workers a random wage below this number (0 to n-1)

Seasons. The model has two seasons: on-season and off-season. On-season lasts 36 time steps and off-season lasts 16 time steps. Together, this constitutes a full calendar year, broken down into 52 time steps (1 time step = 1 week). The 16-week off-season represents the real-world off-season imposed on catching Grouper fish such as that imposed by the Thai government and others around the world. This off-season coincides with the annual period during which Grouper fish lay eggs and those eggs hatch (usually February through May). Fish reproduction in the model occurs during the off-season. Law-abiding boats in the model only fish during on-season. Boats that engage in IUU and forced labor (if these features are activated) also fish during off-season. Boats that adhere to the season schedule return to port and take their fish to market during off-season.

2.2 Agents

Boats. Boats represent fishermen and their economic interests, as they troll the ocean in pursuit of fish. Each boat starts at a port at the edge of the model space. These ports also serve as local markets where boats sell their catch. As boats pursue fish, they accrue operating costs and labor costs. The operating costs are the same for all boats, representing standard costs such as fuel and food. Labor costs vary from boat to boat, depending on whether the boat adheres to wage standards (legitimate fishermen) or engage in illicit labor practices (IUU fisherman) such as substandard wages or forced labor. In addition to illicit labor practices, IUU fisherman also engage in fishing activities during "off-season" and exceed any quotas or safety standards regarding the number of fish that can be at a given time.

Boat Attributes.

Attribute	Description
Fish capacity	Number of caught fish a boat is willing to hold at any given time
Worker capacity	Number of fisherman a boat can hold
Fish total	Actual number of fish on board
Worker pay rate	Rate at which each worker is payed
Cost	Boat's total operating cost
Vision	Radius within which a boat can see fish
IUU?	True/false statement indicates whether boat engages in IUU/forced labor

Fish. The number of fish in the model can be adjusted to accommodate various fishery estimates, geographical regions, and species. Each fish starts at a random x and y coordinate in the model space and schools according to the rules of Wilensky's NetLogo Flocking model [10]. Wilensky's model provides each fish a standard set of rules from which schools emerge endogenously. This ensures schools remain in the model regardless of population shifts, reducing the possibility of unintended outputs of the model. Half the fish population are female and can reproduce at an adjustable rate of reproduction (See "Annual eggs" below). The female fish carry a "maturity" attribute by which female fish grow capable of reproduction. The default maturity value and rules are set to represent actual average age at which Grouper fish in the South China Sea mature and become fertile, estimated to be roughly 5 years (or 260 time steps in this model). This attribute is adjustable. The number of offspring is also adjustable to allow for the replication of real-world fish behavior such as growth/decline rates according to environmental issues, climate change, predation, disease, and other factors that are not hardcoded into this model. All eggs hatch new fish and the live fish population increases accordingly. Mature female fish procreate the same time each year, deemed "off-season" during which law-abiding fishermen refrain from fishing activity. IUU fishermen do not adhere to this rule.

Fish Attributes.

Attribute	Description
Maturity	Numerical value (0–260 time steps) to emulate 5 year maturity period before female can reproduce
Annual eggs	Number of offspring each mature female fish produces each off season

2.3 Model Behaviors

During each run of the model, several coordinates on the edge of the model space are deemed "port." Boats return to ports in the off-season and when they take fish to market. Each boat trolls the ocean seeking fish within its "vision" range. It then catches fish within a radius of two lattice squares ("patches" in NetLogo parlance), which is equivalent to roughly two miles (remember, each time step is equivalent to a week). Once a boat reaches its "fish-capacity," it take its fish to market. Two behavior rules of marketing are possible in this model that must be selected before each model run. The first rule has boats return to the nearest port to their location once they reach fish capacity. The second rule sets their port of origin as their home to which they always return. This simulates the difference between a truly international market and localized markets.

Local Markets. Once a boat arrives at a port, it sets it's per fish asking price by dividing its "cost" by the total number of fish it caught. This value is added to that particular port's running list of fish prices, the average of which determines the local market price. Boats then sell their catch at the local market price, adding the value of their catch to their revenue. This is a rudimentary implementation of the cost-of-production theory of value and Gordon's Economic Theory of a Common-Property Resource [11]. In addition to being relatively simple organizing principles for economic activity, this construct provides realistic stability in market prices by ensuring single transactions do not drastically swing prices. This is important because the number of boats in this model is proportionate but significantly fewer in number than real-world observations. Such a small number of agents raises the possibility of skewed data outputs.

Global Market. Each time a boat sells its catch at a port, its fish total is added to the global "market" which counts the number of fish caught and sold over the entire run of the model. At each time step, ports also send a mean of their local price to a global list of fish-prices. The average of the global list serves as the global market price of fish.

It is by comparing these outputs and the number of live fish at various time steps that the observer can experiment with variable values and model states (i.e. normal, IUU, forced labor).

IUU and Forced Labor. In model states that include IUU fishing, IUU boats continue to fish in the off-season while law-abiding boats return to port. IUU boats also set their "fish capacity" at a random number between the global value of the "fish-per-boat" attribute and 125 % of "fish-per-boat." This represents the fact that IUU fishermen do not, by definition, adhere to established quotas, and often disregard accepted safety or labor standards that may dictate the amount of weight allowed on a fishing vessel. If "forced labor" is in effect, IUU boats engage in labor exploitation and their worker-pay-rate is set at a random float between zero and the minimum wage. This represents substandard wages, to include slavery (NOTE: in some cases, labor recruiters are used by fishermen who then are indebted to said recruiters. In such cases, they still accrue a small wage, although that wage is passed on to pay their debts. This is a practice called "debt bondage," and is considered a form of forced labor. This explains why forced labor victims may still be paid in this model) [12].

3 Initial Findings

After several thousand runs of the model in various model states, initial findings suggest a clear decline of global revenue with the presence of IUU fishing and further decline with forced labor. For the purposes of this paper, the author maintained a fish-to-boat ratio of 667:1. This was largely due to limits in computation power; something future work will seek to address. Runs in various model states and at several values for IUU prevalence indicate that economic losses increase along with the prevalence of IUU fishing and labor exploitation.

The model was runs for several thousand iterations for 260 time steps (equivalent to five years) in which boats sell fish at any port in the model space. Total global revenues from fish sales was measured at each time step. The resulting data shows progressive decline in economic output as the prevalence of IUU fishing increases. Further declines results from the introduction of forced labor. This was measured by comparing outputs from runs of the model without IUU fishing, runs with IUU fishing but no forced labor, and runs with IUU fishing and forced labor. With an IUU prevalence of 7 % the total global revenue over the several thousand runs declined by 6.6 % without forced labor compared to runs without IUU, and 6.9 % with forced labor compared to runs without IUU. These figures jumped dramatically as prevalence increased. At 27 % IUU prevalence, economic activity declined by 7 % without forced labor and 19 % with forced labor; at 34 % prevalence, 19 % and 26 %; and at 67 % prevalence, 33 % and 45 %, respectively. If boats are restricted to selling their catch only at their home ports, economic activity declined even further in some cases, but revenue in the model is not particularly sensitive to this parameter. In these scenarios, a 7 % IUU prevalence yields a decline of 7.1 % without forced labor and 7.4 % with forced labor. At 27 %

prevalence, there is an 18 % decline without forced labor and a 16 % decline with forced labor; at 34 % prevalence, 23 % and 25 %; and at 67 % prevalence, 33 % and 45 %, respectively.

The presence of IUU fishing also had a drastic impact on fish population. Over the aforementioned model runs, total fish population at the end of 260 time steps dropped as the prevalence of IUU increased. First, boats sell fish only at their home port. With 7 % IUU prevalence, the total fish population dropped 12 % without forced labor and 27 % with forced labor. With 27 % prevalence, the population dropped 65 % without forced labor and 43 % with forced labor; with 34% prevalence 79 % and 66 %; and with 67 % prevalence, 89 % and 85 %, respectively. Interestingly, the presence of forced labor generally does not result in further decline, and some cases show the opposite effect.

However, runs in which boats sell fish globally (at the nearest port) show a clear negative impact on total fish population. In such scenarios, a 7 % IUU prevalence yields a 24 % population decline without forced labor but a 37 % decline with forced labor. With a 27 % IUU prevalence, the population declines by 39 % without forced labor and 58 % with forced labor; with 34 % prevalence, 64 % and 73 %; and with 67 % prevalence, 95 % and 96 %, respectively.

Unlike revenue, total fish population appears to be very sensitive to whether boats can sell only at their home ports or globally. Further study of this phenomenon is required, but this likely results from boats that sell globally being able to more quickly take their catch to market and return to sea. This means each boat spends more time catching fish and less time travel to and from the ports of sale since they simply move to the nearest port rather than back to their home port.

Additionally, initial study of each time step finds that IUU fishing leads to female fish being caught a higher rate before they are able to reproduce. Note that the maturity rate of female fish in this model is much longer than a single fishing season. The presence of IUU fishing also means that fertile fish are removed from the population at a faster rate. This results in a more rapid depletion of fish stock. Figure 1 shows the decline of total fish population by counting total population immediately after each reproduction season. The fish population is less likely to replace caught fish as prevalence of IUU increases. In fact, the slope of these lines becomes much steeper as IUU prevalence increases. Stated differently, Fig. 2 shows the declining average catch rate of each boat over time and at various levels of IUU prevalence. As prevalence of IUU increases, the number of fish a boat catches per time step declines. This is a result of fish stock depletion but also highlights the economic implications as boats have fewer fish to take to market and require more time at seas to reach fish capacity (i.e. fewer fish at increased overhead costs). In addition to the clear environmental and economic implications, the potential for significant international conflict is already manifest. For example, Erickson and Kennedy suggest one role for China’s “Maritime Militias” – local militias supported by the People’s Liberation Army often drawing from local fishing communities – is to undertake “confrontations with other states’ fishing and naval vessels, due to the depletion of fishery resources and the need to fish farther from shore” [13].

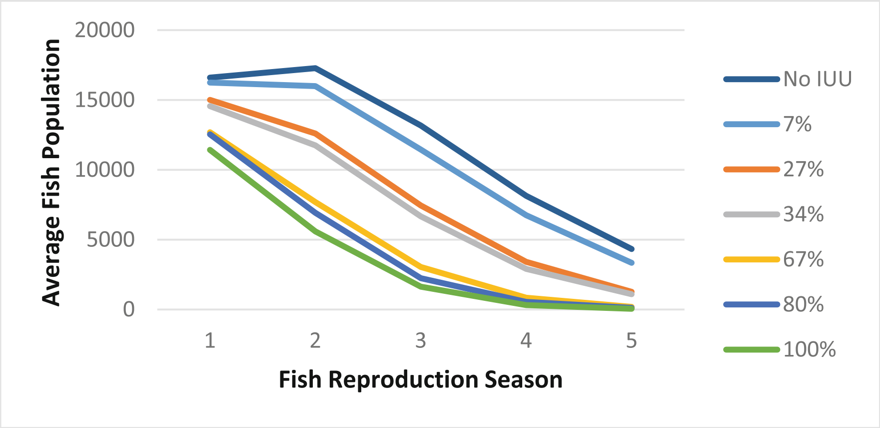

Fig. 1. Fish population after each reproduction season

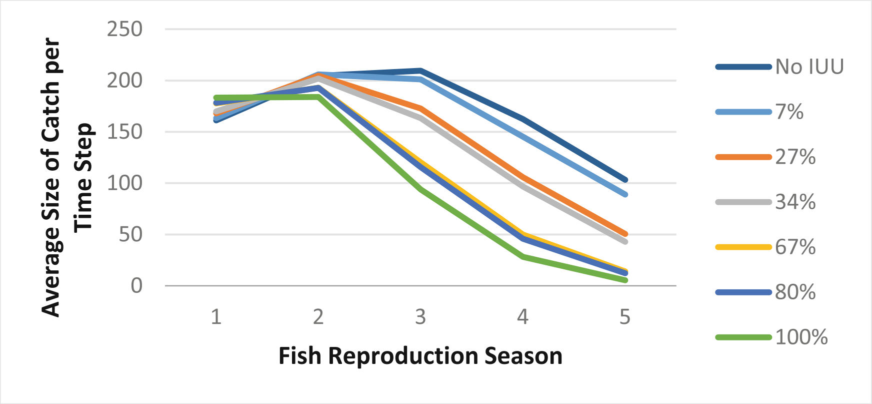

Fig. 2. Average catch rate per boat per time step

4 Future Work

This model set out to test a connection between IUU fishing, forced labor, and overfishing. It is a highly-abstracted proof-of-concept. Much work is required to match the existing model with available data on fisheries and law enforcement activities. Moreover, the behavior and attributes of the model as described in this paper do not yet truly explore the behavior that may lead to overfishing. Future iterations of this model will attempt to translate real-world economic incentives into computer code. In other words, business decisions of various agents are not currently represented. Will law-abiding boats continue fishing if IUU boats continue to drive down market prices? Or, will some law-abiding boats find incentive to engage in illicit activity themselves? Similarly, as IUU boats generate significant revenue, will they seek to become more established as legitimate businesses? Perhaps law enforcement activity incentivizes this as the risk of illicit activity increases. Further research on such behavior is underway. These additions will help explore the connection with overfishing in more depth.

This model also provides a basic starting point to test various law enforcement strategies. Ports, if taken as independent jurisdictions, may have varying legal requirements that they enforce at different rates. It is well known that heavy enforcement and regulatory burden pushes business to other jurisdictions. The impact this has on global markets is an area of on-going research, as is the effectiveness of enforcement models and international cooperation. This model merely scratches the surface of this dynamic and already yields interesting results on how selling globally has impacts that differ from selling at a predetermined home port. As behavioral shifts change the spatial distribution of fish and inspire further changes in fishing behavior, one can expect additional emergent qualities.

National interests can also be added to the model, such as territorial claims that would limit where law-abiding boats can fish. A future iteration may also explore how overfishing might lead to more confrontation between national vessels in disputed territories or how more active countries may contribute to overfishing at a disproportionate rate. As mentioned, states in the South China Sea are already involved in geostrategic posturing that is, in part, driven by fish stock depletion and economic claims to natural resources. As boats pursue dwindling fish stocks further out to sea, one might observe increased infringement on territorial claims, territorial disputes, political tensions, and even direct military conflict.

Finally, the real-world rate of reproduction for a single Grouper fish is more than 1 million fish per year. Limits to average computer memory makes this rate of growth difficult to sustain in this model. Therefore, a realistic rate of depletion or reproduction is difficult to achieve. The user must then rely on realistic ratios. However, this limits the granularity and level of confidence one can have in the outcomes of this model. Running this model on computers that are more powerful will enable more realistic numbers of agents and values for various attributes. The fish agents can be adjusted to focus on the characteristics of other species or even a more robust and diverse ecosystem. Implementing this model in other modeling environments might better accommodate higher volumes of agents, more robust verification and validation efforts, as well as an ability to add parameters to this proof-of-concept.

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