



Contents lists available at ScienceDirect

Socio-Economic Planning Sciences

journal homepage: www.elsevier.com/locate/seps

“Fish-y” banks: Using system dynamics to evaluate policy interventions for reducing labor exploitation in the seafood industry

Renata A. Konrad ^{a,*}, Khalid Saeed ^b, Matt Kammer-Kerwick ^c, Palawat Busaranuvong ^d, Wai Khumwang ^e

^a School of Business, Worcester Polytechnic Institute, 100 Institute Rd, 01609, Worcester, MA, USA

^b Social Science & Policy Studies, Worcester Polytechnic Institute, 100 Institute Rd, 01609, Worcester, MA, USA ^c The IC² Institute, The University of Texas at Austin, USA

^d Mathematical Sciences Worcester Polytechnic Institute, 100 Institute Rd, 01609, Worcester, MA, USA ^e Computer Sciences Worcester Polytechnic Institute, 100 Institute Rd, 01609, Worcester, MA, USA

ARTICLE INFO

Keywords:

System dynamics

Fishing

Human trafficking Policy evaluation

ABSTRACT

Fishing is an important economic sector in many countries, and the industry's products constitute a source of protein for billions of people. Overfishing, incessant consumer demand, and poor regulation have left the industry susceptible to labor exploitation. A system dynamics model that describes the interactions of both ecological and economic systems while considering sustainability criteria both for the natural sphere (regeneration capacity of fish populations) and the economic sphere (profits and employment) was developed. The model evaluates interventions that reduce forced labor and labor trafficking, which are constituents of the economic sphere, while measuring legal and illegal labor. This study employs a novel interdisciplinary approach to the systemic planning and policymaking of initiatives that reduce forced labor while still valuing environmental and economic concerns, while accounting for the nonlinear feedback relationships and accumulation processes in the system. Using this model, the study presents empirical evidence and an explanation of how an emphasis on one policy over another impacts key metrics by providing results that are counterintuitive and highlight the need to consider the whole process - for example allocating a large portion of a budget towards awareness campaigns reduces fish stocks and over time forced labor increases. To be effective while minimizing unintended consequences, policies must be combined and implemented dynamically. Our case country in this study is Thailand—a prominent seafood exporter in the global spotlight for labor trafficking. We created a freely available online version of the model entitled “Fish-y Banks”.

1. Introduction

Seafood is one of the world's most widely traded food commodities [1], producing over 160 million tons of fish for global consumption annually [2]. As such, the seafood sector is one of the world's largest employers, with an estimated 260–800 million workers [3,4] and represents an important economic sector for many countries [2]. Aquaculture development is also of vital importance in alleviating global poverty [5]. The contribution of seafood to global diets is expected to increase from 20.2 kg in 2020 to 21.4 kg per capita in 2030 supplying over three billion people with at least 20% of their average animal protein intake [6].

The global growth in seafood demand outpaces fish population growth. Thus, this large industry faces significant environmental and social issues in its supply chains. Roughly a third of the world's fisheries are overfished (i.e., fish are harvested at rates higher than can be replenished), and fishery stocks within biologically sustainable levels decreased to 64.6% in 2019 [6]. Overfishing has led to the decline of numerous fisheries such as northern

Bluefin tuna and Atlantic cod [7,8]. Moreover, this over-exploitation of fish stocks has resulted in a declining catch per effort and falling profitability [9,10]. Despite managerial attempts to reduce overfishing, some argue that little progress has been made due to a general inability to endure the short-term economic and social costs of reduced fishing [11–14]. One consequence of overfishing is that fishing vessels must cast farther away from shore, into the deep water, and for longer durations to obtain a sufficient catch [15], giving rise to the practice of transshipment - the act of offloading catch from a fishing vessel to a refrigerated cargo vessel to return to port [16]. While such a practice has obvious economic benefits - allowing fishing vessels to maximize catch as well as minimize fuel costs - transshipments enable fishing vessels to stay at sea for months or even years at a time, during which they can evade monitoring, and enforcement [17,18].

Overfishing, insatiable consumer demand for inexpensive seafood, and poor regulation have created conditions ripe for labor exploitation [19], leading to pervasive and well-documented human trafficking in the seafood supply chain [20–22]. Skrivankova (2010) illustrates the relationship between labor

* Corresponding author. School of Business, Worcester Polytechnic Institute, 100 Institute Rd, Worcester, MA, 01609, USA. E-mail address:

rkonrad@wpi.edu (R.A. Konrad). <https://doi.org/10.1016/j.seps.2023.101731>

Received 30 September 2022; Received in revised form 8 September 2023; Accepted 16 September 2023

Available online 25 September 2023

0038-0121/© 2023 Published by Elsevier Ltd.

exploitation and forced labor, highlighting the process of human trafficking as a series of exploitative acts that moves workers toward forced labor [23]. Labor exploitation can be mapped onto a spectrum, ranging from what the International Labor Organization (ILO) refers to as “decent work” [24] at one end, through various labor and criminal law violations, to extreme exploitation or “forced labor” [25] at the other [26]. More formally, we defer to the UN Protocol to Prevent, Suppress and Punish Trafficking in Persons, Especially Women and Children (otherwise known as the Palermo Protocol) for a definition of trafficking.

Moreover, fishing involves hard and dangerous work, often referred to as 3Ds work (dirty, dangerous, and difficult) in an unforgiving environment [27]. The ILO stated that the sector “is notorious for severe decent work deficits and has come under scrutiny over the past years for the use of forced labor and child labor, as well as links to human traffickers and people smugglers” [28]. Testimonies indicate that victims are being denied multiple rights including just and favorable work conditions, adequate standards of living, freedom of movement, liberty, and security [27–29]. Even when removed from exploitative situations, they may face further rights violations when trying to access assistance, such as detention and deportation, prosecution for status offenses, or even re-trafficking.

Labor exploitation and trafficking in the seafood fishing industry involve players across the entire seafood supply chain, such as recruiters, local boat captains, government officials, and global consumers. An abundance of vulnerable (typically low-skilled migrant) labor plays a key role in meeting the demands of an extremely price-sensitive consumer market for seafood. Because illegal labor exploitation and trafficking are intentionally hidden, it is difficult to quantify the extent to which it occurs in the fishing industry [29].

Overall, consumer demand, environmental sustainability, labor trafficking, aquaculture, and socioeconomic development interact interdependently and form a large system with complex, dynamic, diverse, and nonlinear characteristics. Systemic factors such as (i) the need for income by fishers and laborers, (ii) vessel maintenance, (iii) consumer markets, and (iv) fish stocks form feedback loops in which consumer markets dictate revenues, subsequent wage costs, and demand stability. Alternatively, both fish and labor exploitation are viable sources of profit maximization for the fishers. The challenge for almost all countries is to maintain the economic benefits of the fishing sector while minimizing the environmental and social impacts, particularly on labor. Such integrated, socioeconomic–environmental systems are poorly understood [30]. Within this context, decision-making for mid- and long-term outcomes is a particularly challenging task, as policymakers must confront countless interactions over a time horizon where little remains constant. As a result of such uncertainties, interdependencies, and interactions, it is not unusual that policies lead to unexpected, often undesirable, results [31,32].

There is widespread agreement among relevant public sector, private sector, and civil society players that more collaboration is needed to effectively address human trafficking and forced labor in the fishing industry [33]. However, current efforts are largely independent, only address traffickers or survivors independently, and tend to focus on a single disruption strategy such as prevention or trafficker apprehension. Limited research exists regarding the unintended consequences of policies and decisions made by one group of stakeholders on another.

Therefore, this study analyzes the fishing industry by developing a system dynamics (SD) model focusing on labor markets and consumer demand in one country. We use the SD method to integrate the accumulation processes, feedback relationships, and nonlinear interactions among the feedback loops [30].

To this end, our objectives are as follows:

- Develop an SD simulation model to study social, economic, and regulatory policy interventions within a central budget aimed at reducing forced labor and trafficking while maintaining fish stocks and industry profit. In this model, we introduce a dual labor substructure to account for legal labor as well as forced labor;

- Create an interactive interface that allows decision-makers to study the implications of policy decisions; and
- Contribute to the nexus of anti-human trafficking and operations research literature as one of the first studies to examine environmental, economic, and social implications of policy decisions.

To ground our discussion, we review the literature on the use of analytical and simulation models that analyze decisions pertaining to anti-trafficking and sustainability in the fishing industry. We then describe our SD model. The model provides an illustrative example of how SD can simultaneously examine societal and economic concerns. By explicitly considering the interplay of legal and forced labor, fish stocks and consumer demand, and costs and profits, the model generates insights regarding how budgets should be allocated between different intervention options given system responses to spending. Our case country in this study is Thailand—a prominent seafood exporter in the global spotlight for labor trafficking. We then offer insights regarding model behavior and implications for policy evaluation and describe an interface developed for decision-makers. We conclude with a general discussion.

2. Background: simulation models examining labor exploitation and fishing intervention strategies

A broad range of analytical models exists to support the understanding of policymaking in complex systems and to test alternative policies. Among the available modeling methods, system dynamics (SD) is an appropriate tool for modeling complex problems and understanding the underlying structure responsible for a set of behaviors and is thus used as a “method for theorizing behavior” [34]. Over the last 60 years, a wide variety of SD applications, including approaches in biology, social science, management science, physical science, and industry, have been developed.

SD approaches have been widely applied to the fishing industry. For example, Dudley (2008) demonstrated the benefits of using SD for modeling fisheries by creating a framework adaptable to most fisheries [35]. This approach was adapted to construct SD models simulating changes in the management of fisheries; these models specifically examined individual transferable quota systems, ITQs [36,37] to identify areas where policy changes and management improvements may be most effective. Moxnes (2012) used an SD approach to test an alternative institutional arrangement (auctioned seasonal quotas, ASQ) against ITQs, suggesting the ASQ system provides lower financial risk for fishing firms [38]. Importantly, Moxnes (2005) created an SD model that incorporates operational, economic, and ecological facets. He developed an optimization method for policy sensitivity analysis in SD models using the case of a quota policy for cod fishery management [39]. The study found that the quota policy is highly sensitive to assumptions concerning fish price elasticity and increasing unit variable costs, suggesting that nonlinearities in the economics of the fishery cannot be “assumed away” and it is important to consider both economic relationships as well as biological ones [39].

Other SD applications include a model for managing specific species (e.g., Manila clam [40], gooseneck barnacle [41], and the Barents Sea capelin [42]). While these SD models are practical and rich in detail, they largely employ an ecological perspective focused on analyzing the management of fish stocks. Recognizing the need to better understand the dynamics and interactions of both ecological and economic systems, BenDor et al. (2009) developed a hybrid model combining SD and agent based modeling to understanding competition and cooperation between fishers [43]; however, this study did not consider labor exploitation or the interaction between legal and illegal activities present in the fishing industry.

Simultaneously, SD has been used to examine illicit markets. Dudley (2004) used causal loop diagrams to understand the consequences of various proposed strategies to control illegal logging, including the enforcement of laws, the strengthening of community rights, the prevention of outside labor in local forests, and the provision of alternative sources of income [44]. Phan (2008) developed a computable SD model to suggest interventions to simultaneously improve socio-economic and environmental sustainability in a

province in Vietnam grappling with illegal coal mining [40]. Similarly, both [35,45] capture the tension between the economic dependency of a local population on natural resources, and the overuse of these resources which create illicit markets and behavior. However, neither study addressed labor exploitation or trafficking. A handful of SD models have evaluated policy implications aimed at reducing sex trafficking, though [46,47]. One study used SD to evaluate recruitment tactics aimed at Overseas Filipino Workers (OFW) to identify policies that reduce the chance that OFW become trafficked [48].

Tensions between the ecological sphere (e.g., regeneration capacity of fish populations) and the economic sphere (e.g., profits) fosters illicit markets and illicit behavior (e.g., transshipment) as actors evade interventions that preserve the natural stock. SD has been used to study policy interventions aimed at managing natural resources, economic livelihoods, illicit markets, and human trafficking; however, to the best of our knowledge, the incorporation of all four of these areas in one model has not yet been considered in the literature or in practice. To contribute and advance the literature in socioeconomic evaluations as well as innovative SD applications, we investigate the nexus of these areas.

3. Method: the proposed model “fish-y banks”

Environmental sustainability, economic prosperity, and socioeconomic development interact interdependently in a system with complex, dynamic, diverse, and nonlinear characteristics. Incorporating this interdependence is non-trivial—the SD modeling method was used as the analytical procedure. The goal of this SD model is to introduce interventions that reduce forced labor and trafficking, which are constituents of the economic sphere. One system-level view was formulated as a quantified SD model using the Stella Architect software. The model builds on Fish Banks, Ltd [49–52] by incorporating a dual labor substructure which considers legal labor as well as forced labor. The proposed model is named “Fish-y Banks” in recognition that this addition to the Fish Banks model includes illicit behaviors by some participants—in other words, “fishy” or dubious behavior. First, several qualitative conceptual models were formulated as causal loop diagrams (e.g. Ref. [53]). Subsequently, these models were used as the basis for a quantified SD model. The final model expands on earlier versions to elaborate on the structure of both legal and exploited labor markets. This model captures the interactions within the labor market and individually and simultaneously simulates a greater variety of policy-related interventions. Specifically, the model simulates the fishing industry by disturbing its equilibrium, established using data from Thailand’s fishing industry in the period 2016–2018.

3.1. Data collection

Primary and secondary data were used for the “Fish-y Banks” model. Primary data focused on exploitation activities and were captured by expert elicitation and interviews with stakeholders involved in prevention and rehabilitation initiatives and law enforcement. A desk study was conducted to review relevant academic and grey literature to establish preliminary causal links in fishing; expert elicitations were used to augment the information gathered on the causal loop of the model. Secondary data regarding the fishing industry (e.g., number of licensed ships, number of persons on a ship, and costing data) were extracted from national and international data repositories and reports. Secondary data were used to populate the model. Details can be found in Technical Supplement S1.

3.2. Model description

The commercial fishing supply chain is represented as a stock and flow diagram (model). The model covers the activities that meet consumer demand for fish products and their respective inter-variable relationship and feedback loops, highlighting the dynamic behavior in the fishing supply chain. To ground the reader, we discuss three aspects of the model: (i) fish supply, (ii) fish demand, and (iii) production which are comprised of submodels. The fish supply which concerns fish stocks, which are implemented through two submodels: Fish Yield and Fish Availability. The driver of production (e.g., catching fish) is consumer demand, represented by the submodel Fish Prices. Prices for fish stimulate production. Production activities are represented by Labor, Ships, Liquidity, and Investment submodels. Notably, the Labor submodel considers both legal and illegal (forced) labor.

Figs. 1–3 are the stock and flow diagrams for the Investment, Liquidity, and Labor submodels respectively that contain variables relevant to the tension between legal and illegal labor. The submodels in the figures consider costs related to fishers’ financial outlays, including capital invested in their vessels, labor onboard their vessels (both legal and exploited or forced labor), and any financial penalties incurred for violated regulations and laws. The feedback loops originating from these models capture the interactions between legally and illegally employed (forced labor) labor and liquidity. When fishers decrease their investments to offset vessel upkeep (costs), exploited labor increases. In turn, the increased demand reduces the “price” of forced labor. However, the change in labor prices does not directly affect investment but rather affects exploited labor investment, which is a fraction of the Investment submodel. By applying policies aimed at reducing forced labor, we observe the effects on labor (both forced and legal), fish stocks, and industry profits.

In its entirety, this model is made up of 148 differential equations involving 205 variables, the details of which can be found in Technical Supplement S1. Our model is publicly available.¹ For details regarding the SD modeling approach, we refer the reader to Ref. [30].

3.3. Causal loop diagram

Identifying the structural elements of an SD model that are responsible for a particular behavior is a challenging task in a complex multi-state model [54]. The causal loop diagram (CLD)² maps out the key feedback loops that drive fishers’ and consumer behavior in the Thai fishing industry, as seen in Fig. 4.

¹ <https://exchange.iseesystems.com/public/khalidsaeed/fishy-banks/index.html#page1>.

² The arrows between variables depict the direction of causal influence. Two types of connections exist, either “+,” or “-” which depict how a dependent variable will change

(decrease or increase) depending on the change in the independent variable. A positive causal link *reinforces* the initial causal influence; that is if the independent (cause) variable *increases*, then the dependent (effect) variable also *increases*, similarly if the cause variable *decreases*, then the effect variable also *decreases* [55].

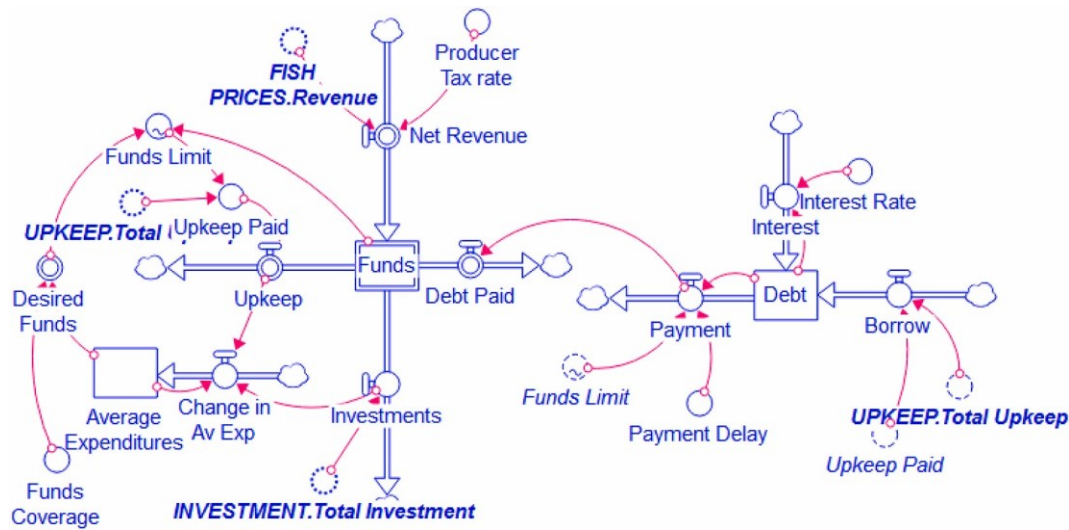


Fig. 1. Investment submodel.

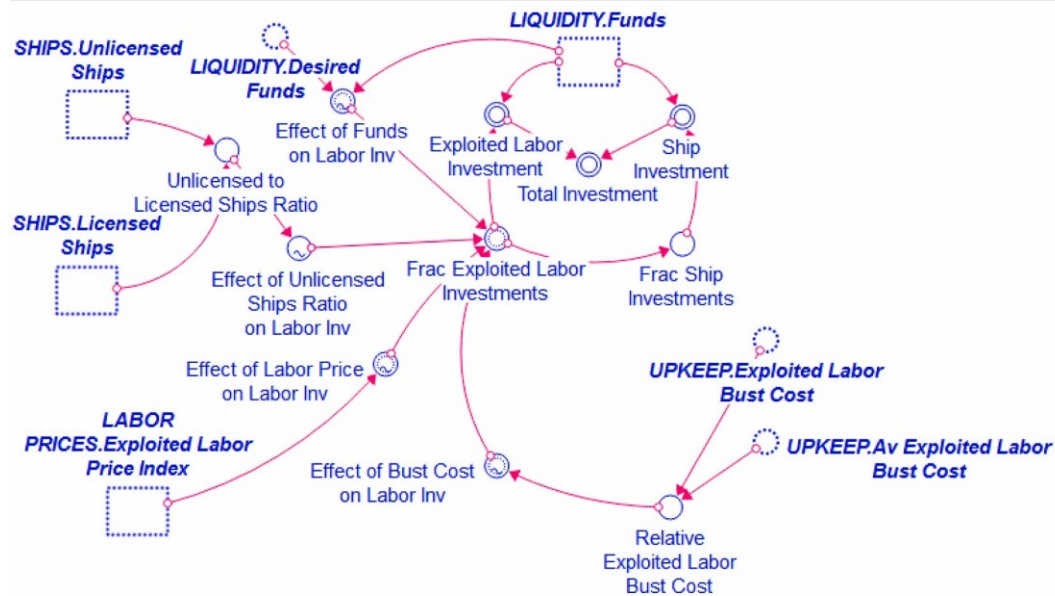


Fig. 2. Liquidity submodel.

Reinforcing feedback loops, denoted as 'R' in the CLD, depict ever-increasing or ever-decreasing behavior, while balancing feedback loops, denoted as 'B,' indicate a stable behavior. We describe some of these loops in Table 1. The best way to read Fig. 4 is to start with a variable of interest and follow its relationship to other variables. Exploited Labors – our ultimate variable of interest – comes directly from the demand for such labor (B10). The demand for exploited labor is influenced by liquidity which is driven by vessel upkeep costs (which account for vessel maintenance, operating and total labor costs – legal and illegal) and funds. Upkeep is also part of a balancing loop (B1) whereby, over time, the impact of preventative measures designed to deter exploitation (e.g., fine associated with inspections) decrease the prevalence of exploitation. Consequently, decreases in the level of exploitation increases the costs required for fishing (by having to hire labor legally and pay fair wages as well as to adhere to safety standards) thus decreasing profit margins. Certain interventions aimed at decreasing exploitation exhibit a reinforcing behavior (R2). For example, if an individual exits an exploitive situation but sufficient preventative policies (such as rehabilitation) are not in place to reduce vulnerability, the individual is once again vulnerable to exploitation.

3.4. Model validation

SD model validation does not have a single established procedure [56]. However, recent SD studies (e.g. Ref. [57]) follow the proposed validation methodology in Ref. [56], which includes (i) direct structure tests, (ii) structure-oriented behavior tests, and (iii) behavior pattern tests. The model developed here is validated using some of the tests suggested in Ref. [56]. The focus of this process is primarily on validating the structure of the model and then, to some extent, validating the behavior of the model within the assumption of the model.

To assess the validity of the model structure by direct comparison with the real system structure, we used several direct structure tests [56]. For example, the dimensional consistency test (automatically performed by the Stella software) checked the consistency of units used in the model equations. Additionally, a structure-confirmation test [58] was conducted to ensure that the model does not contradict the real system: wherever possible, mathematical relationships between variables with the available knowledge about the real system were compared. We were unable to validate some relationships, such as the nature of exploitative practices by recruiters, despite

generated behavior pattern [58]. As suggested in Ref. [56], these tests involve simulations applied to the entire model and facilitate uncovering potential structural flaws. An extreme-condition test checked the robustness of the model [30,56]. For example, one condition test examined in this study includes an extremely low fish population. As expected, the prices rise sharply with limited fish supply, consumer price sensitivity drives down demand drastically, and initially, fishers attempt to maintain profits by increasing exploited labor, but as fish stocks disappear, so too does any form of revenue and eventually forced labor.

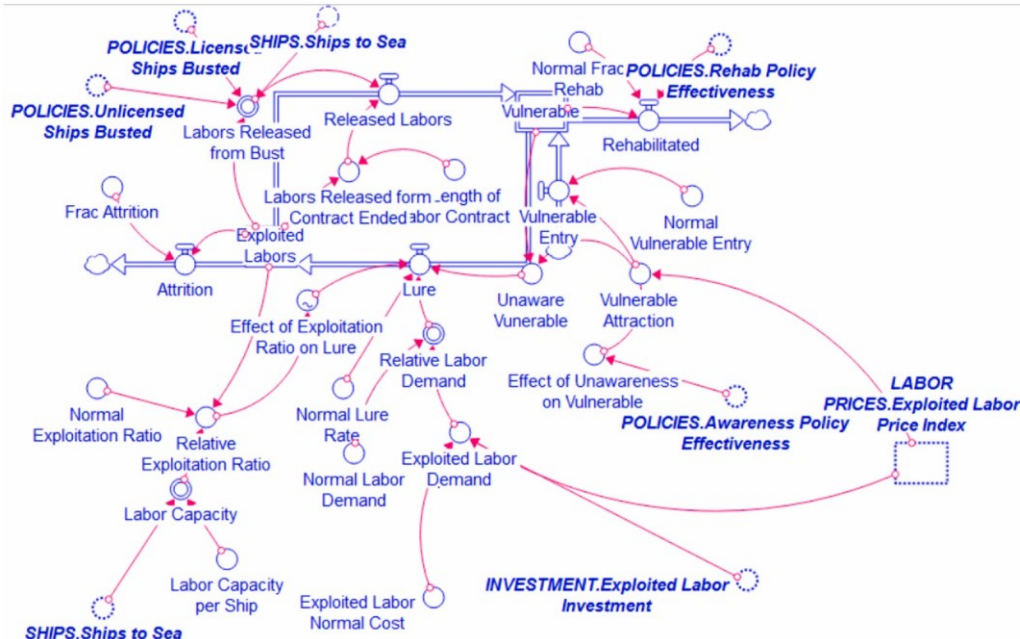


Fig. 3. Labor submodel.

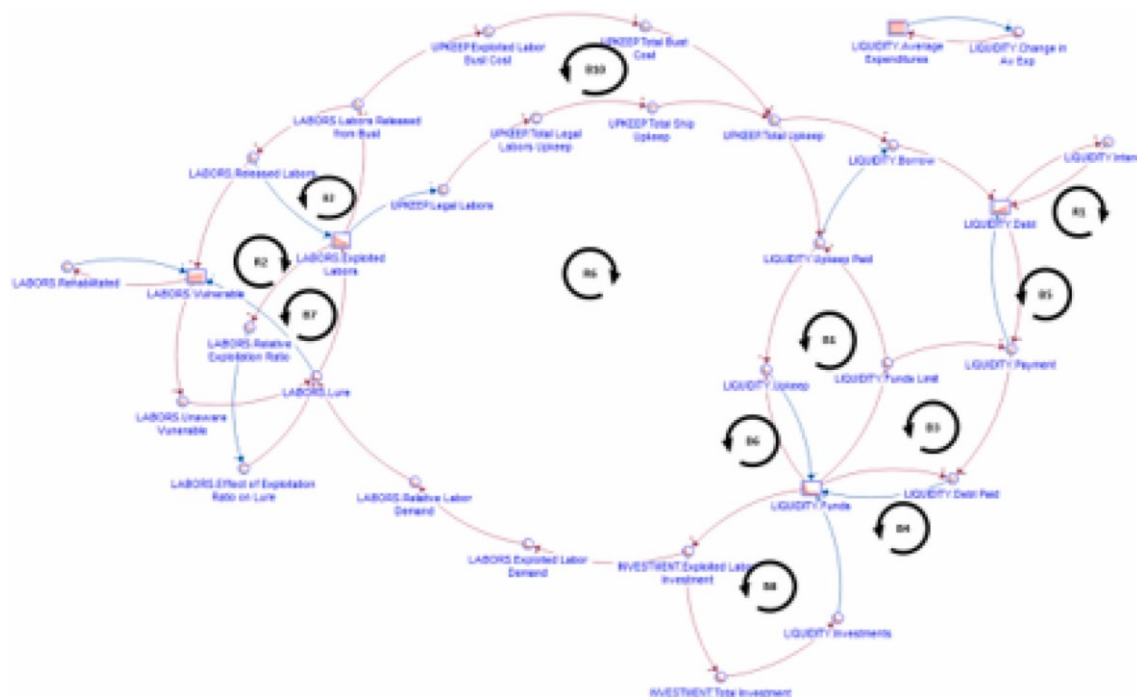


Fig. 4. Causal loop diagram highlighting feedback loops.

that our understanding of the process is based on desk research and interviews.

Structure-oriented behavior tests were also conducted. This study included the extreme-condition test and sensitivity analysis to indirectly assess the validity of the structure by applying certain behavior tests to the model-

The reference mode in our case is a policy history rather than a time history. Hence, we initialize our model in a hypothetical equilibrium to create a point of reference. Our first set of policy experiments then create outcomes that arose from interventions, which replicate the policy history. Further policy

experiments attempt to meet the dual objectives of minimizing labor exploitation as well as sustaining the industry.

Table 1

Description of select feedback loops that drive fishers' behavior in the Thai fishing industry.

Loop	Feedback loop
B1	LIQUIDITY.Upkeep→LIQUIDITY.Funds→LIQUIDITY.Funds Limit→LIQUIDITY.Upkeep Paid
B10	LIQUIDITY.Payment→LIQUIDITY.Debt Paid→LIQUIDITY.Funds→INVESTMENT.Exploited Labor Investment→LABORS.Exploited Labor Demand→LABORS.Relative Labor Demand→LABORS.Lure→LABORS.Exploited Labors→LABORS.Labors Released from Bust→UPKEEP.Exploited Labor Bust Cost→UPKEEP.Total Bust Cost→UPKEEP.Total Upkeep→LIQUIDITY.Borrow→LIQUIDITY.Debt→input (in macro)
R2	LABORS.Lure→LABORS.Exploited Labors→LABORS.Labors Released from Bust→LABORS.Released Labors→LABORS.Vulnerable→LABORS.Unaware Vulnerable

4. Case study: Thailand

4.1. Fishing and labor trafficking and exploitation in Thailand

Thailand is one of the world's largest seafood exporters [59]. Low-skilled migrant workers from neighboring countries provide a nearly unlimited source of vulnerable labor, who make up a significant portion of Thai's labor in the fishing industry [60]. Paradoxically, the factors supporting Thailand's prominence as a global seafood exporter, such as its reliance on a migrant labor force, are the same factors that have focused international attention on human rights abuses and working conditions on Thai fishing vessels and in Thai seafood processing areas. For instance, a 2017 study found that 76% of migrant workers in the Thai fishing industry had been held in debt bondage, and almost 38% had been trafficked into the Thai fishing industry between 2011 and 2016 [61]. Despite international, regional, and national legal frameworks in place to protect human rights, trafficking, forced labor (including child labor), unscrupulous recruitment, exploitative employment practices, and subhuman working conditions have all been documented in Thailand's fisheries industry [4,33,60,62,63].

The European Union delivered a pivotal policy for addressing forced labor in Thailand's fishing industry with its 2015 decision to give Thailand a "yellow card" warning because insufficient action had been taken to tackle illegal, unreported, and unregulated fishing; if escalated, Thailand could face a ban on exporting seafood to the EU. Should this ban on export occur, Thailand could lose exports estimated at an annual value of 100 billion Baht, roughly US \$ 290 billion [64]. In 2014, the United States government published its annual U.S. Trafficking in Persons Report, placing Thailand in its lowest Tier 3 ranking because the Thai government did "not fully comply with the minimum standards for the elimination of trafficking" and because a "significant portion of labor trafficking victims within Thailand [is] exploited in commercial fishing, fishing-related industries" [65]. The combined actions of the US and EU encouraged the Thai government, suppliers, and retailers to take action to eliminate forced labor and human trafficking from seafood supply chains, including multi-stakeholder initiatives. However, reforms reportedly still fall short of addressing the EU and US concerns [60,64, 66].

Rehabilitation, justice and public awareness are greatly needed to tackle exploitation, forced labor, and trafficking in the seafood industry [67]. Multiple stakeholders are involved in implementing and coordinating interventions for the prevention of trafficking and the protection of victims—including governments and associated organizations, NGOs, and the source and destination communities of trafficking victims. Some actors argue that these activities should be coordinated by a central body, such as the ASEAN to coordinate activities and effectively allocate resources [67]. We assume there is a central body coordinating interventions and thus study the impact of allocating a central budget among intervention activities.

4.2. Experimental setup

4.2.1. Initial conditions

To formulate the model's initial conditions, we used data from the United Nations Food and Agriculture Organization (FAO) from 2016. In Asia, fishing vessels have an average of 10 workers, of which an estimated 30% of all labor is exploited [68]. Thailand reported 13,000 vessels, of which 10,000 were licensed [69]. We conservatively assumed that the ratio of licensed to unlicensed ships is 10:5.

4.2.2. Measuring system performance: model outputs

By simulating policies that reduce forced labor, we observe the effects on labor (both legal and forced), fish stocks, and industry profits. Broadly speaking, we consider policy interventions aimed at three sectors: (i) vulnerable populations; (ii) the fishers (employers); and (iii) the consumer. From field reports, we gathered five commonly employed interventions targeting those at risk of exploitation and vessel owners and considered two interventions affecting seafood consumers that have been discussed but not widely implemented [70,71].

Table 2 briefly introduces the seven policy interventions considered in the simulation model that are designed to intervene in the practice of illegal labor and trafficking in the Thai fishing industry. The table provides the scale used to change the intensity of a particular policy. Certain policies use a per-unit scale (e.g., Fine per Unlicensed Vessel, in which a USD amount per vessel is used); others use a numeric scale (e.g., Awareness, in which the intensity of the Awareness Policy Importance Scale numerically increases—indicating a greater portion of the fixed budget is allocated toward awareness activities). Each of these policies is discussed in greater detail in the next section.

To compare the effectiveness of an intervention listed in Table 2, we track eight system-level metrics, as described in Table 3.

5. Results

This section represents the simulation results of various scenarios to gain insights into the potential impact of changes in a policy parameter on forced labor in the fishing industry.

5.1. Baseline scenario

To focus the discussion, we examine each of the policy interventions in Table 2 and plot the simulated results for select metrics in Table 3. These results are directly dependent on the values chosen for a particular intervention. To emphasize, the values displayed on the graphs presented are not intended to be in any way accurate or predictive. Instead, the emphasis should be on the differences between the policies and on how the dynamics change after adjusting various parameters from one scenario to the next. A comparison of all the policies is made at the end of this section.

We first set our model to equilibrium to use as a reference against which the results from proposed interventions can be compared and assessed. We disturb the equilibrium state to illustrate behavior dynamics by assuming a 5% increase in consumer demand—a trend in line with global estimates [6].

Fig. 5 reflects the trajectory of the Thailand fishing industry prior to policy implementations—the status quo. Without specific interventions targeting vulnerable populations, trafficker apprehension, and consumers, this baseline scenario indicates that forced labor increases while the fish population significantly decreases, assuming unchanged external conditions. Such observed behavior illustrates insufficient control and inspection of illegal activities and maintenance of the fish population. One possible measure would be for a government to increase inspections and significantly raise penalty fines for forced labor and unlicensed ships. The result of these actions is shown in Fig. 6, in which fish populations are maintained, and forced labor decreases; however, industry profits fall substantially. Notably, projections provided by these

Table 2

Brief overview of policy interventions considered in a model of the Thai fishing industry.

Sector	Policy	Description	Scale
Vulnerable Populations	Awareness	Prevention policy aimed at raising awareness of the risks of exploitation and trafficking among vulnerable migrant populations	1 (low intensity) – 9 (high intensity)
	Rehabilitation	Policy targeting survivors of forced labor exploitation and trafficking, socioeconomic programs such as skills training	1 (low intensity) – 9 (high intensity)
Law Enforcement	Inspection	Policy dealing with vessel inspection for signs of illegal activity. The higher the intensity, the more inspections occur	1 (low intensity) – 9 (high intensity)
	Unlicensed Vessel Fine	Financial penalty imposed on owner of unlicensed or unregistered vessel	1000–10,000 USD
	Exploited Laborer Fine	Financial penalty imposed on vessel owner for violations of labor and anti-trafficking law	100–2000 USD
Consumer	Producer Tax Rate	Tax on seafood producers used to fund anti-exploitation efforts	0–0.25
	Consumer Tax Rate	Excise tax on consumer products, tax used to fund anti-exploitation efforts	0–0.25

Table 3

System metrics for the simulation model.

Output	Description
Fish	Remaining fish population
Total Catch	Total caught fish annually
Fish Price	Market price of fish
Exploited Labor	The number of individuals in situations of forced labor. Note that a fisher employing exploited labor has a reduced vessel operating cost
Legal Labor	The legal labor force—those individuals who receive a fair wage and work in safe conditions
Total Ships	Represents the number of ships fishing in Thai waters, including both unlicensed ships and licensed ships
Profit	Annual industry profit in U.S. dollars
Vulnerable People	Represents vulnerable populations who are susceptible to exploitation

scenarios are not considered to be predictions but rather projected consequences of the system and its policy regime. Figs. 5 and 6 suggest that a combination of policies is needed to protect fish stocks, maintain industry profits, and decrease exploited forced labor.

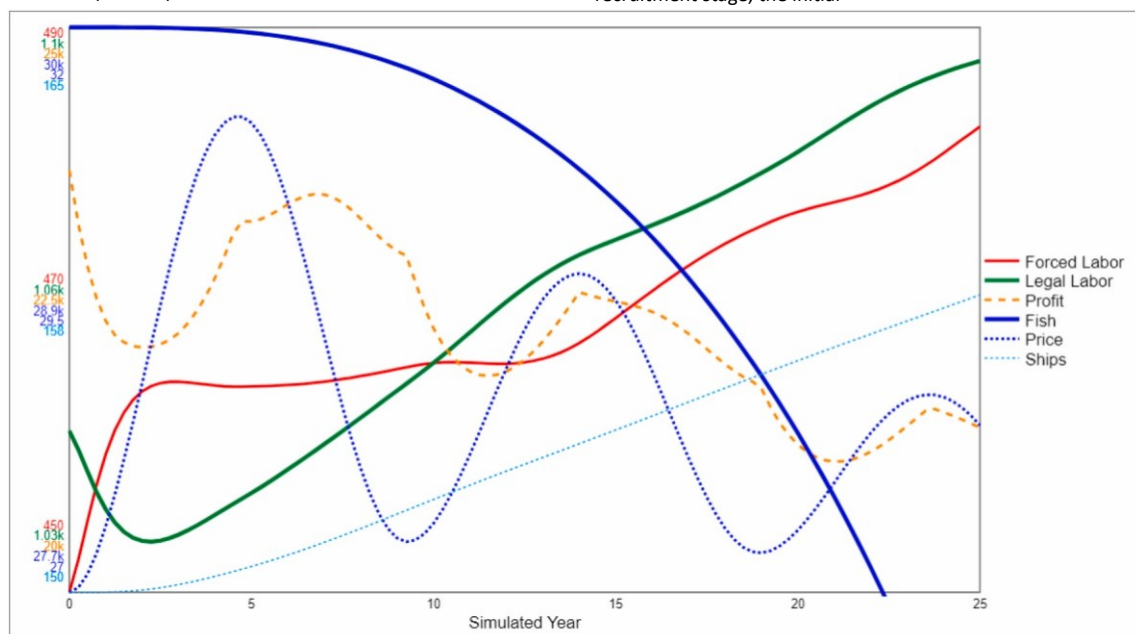
We then reflect on various alternative interventions in the fishing industry. We simulate the performance of the fishing industry by examining policies (i) implemented or considered by the Thai government—the first five interventions listed in Table 2—and (ii) proposed in academic and grey literatures—the last two policies presented in Table 2.

The simulation model assumes that a centralized decision-maker has a fixed budget for addressing labor exploitation and associated labor trafficking activities; it is run for 15 years, capturing the metrics listed in Table 3. Initially, we consider seven simulations that each emphasize a specific policy. We first describe each policy, illustrate system behavior when that policy is the main budgetary focus, and then compare the seven policies. We implement the policy under study in year 1 to depict the equilibrium just before policy implementation.

5.2. Interventions targeting vulnerable populations

5.2.1. Interventions 1: awareness campaigns

Ongoing trafficking recruitment calls for more targeted intervention strategies for individuals and communities at risk [72,73]. Awareness campaigns, arguably the most common form of trafficking prevention activities, alert individuals to the tactics used by traffickers and provide them with practical strategies to avoid deception and exploitation. This strategy largely focuses on the dissemination of information and the launching of public information campaigns targeting foreign (typically migrant) laborers and the general public. Such campaigns aim to promote workers' understanding and awareness of labor laws and regulations, workers' rights, and how to stay safe from trafficking [74]. These campaigns are directed at individuals in the recruitment stage, the initial

**Fig. 5.** Trajectory of Thai fishing industry prior to policy implementation, assuming an increase in consumer demand.

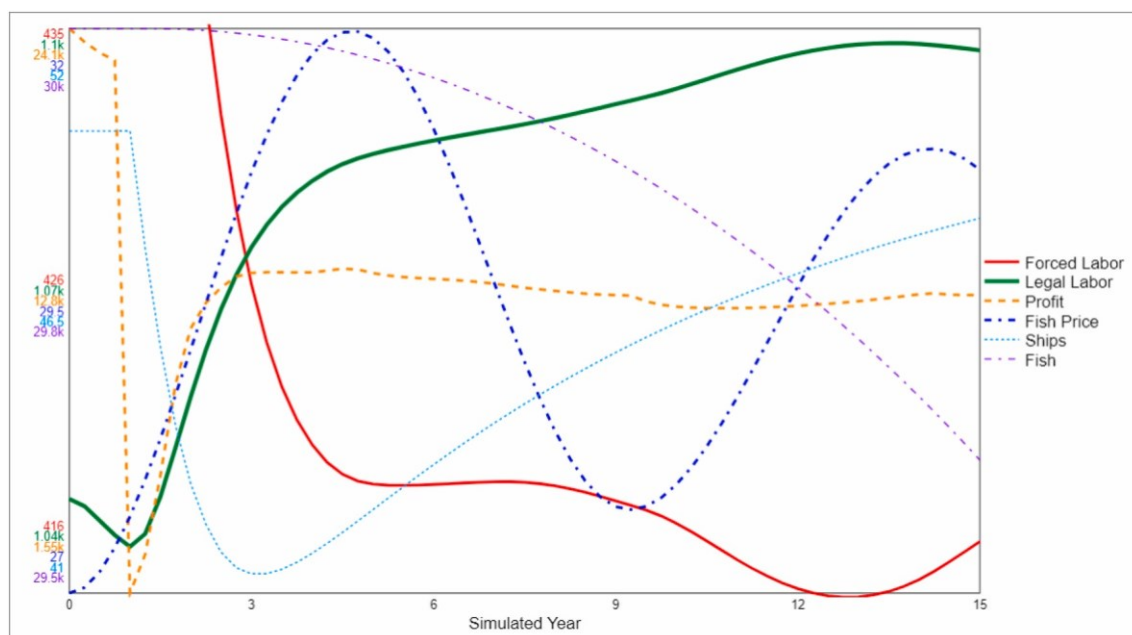


Fig. 6. Simulated result of policies that can be implemented: increasing fines for unlicensed ships and forced labor (Assumption: Fines for unlicensed ships increased from 1500 to 3000 and for forced labor from 300 to 400 in Year 1).

period of the trafficking process [75], when individuals are vulnerable to deceptive offers to migrate for work or promises of a better life [76, 77]. When implemented effectively, awareness campaigns can play an indispensable role in combating human trafficking (for instance, see Ref. [78]). In the SD model, the portion of the budget that is allocated toward awareness determines the outreach that reaches vulnerable populations.

After disturbing the equilibrium by increasing the intensity of the Awareness Policy Importance Scale (indicating that a greater portion of the fixed budget is allocated toward awareness activities), exploited forced labor and vulnerable workers counterintuitively increase over time. As illustrated Fig. 7, an increase in awareness campaigns results in an initial, slight drop in forced labor; however, this number quickly rises.

Because funds are allocated to awareness campaigns, less funding is allocated towards trafficker apprehension activities thus decreasing their effectiveness. Furthermore, the demand for forced labor is driven by falling profits—one way for fishers to offset this decrease is to adopt more forced

(lower cost) labor. Despite the best intentions of awareness campaigns, vulnerable individuals continue to seek employment and are unwillingly recruited into exploitative and trafficking situations [79, 80]. There may be some individuals who resist a particular belief change (e.g., believe that they will not fall into an exploitive situation), or there may be marginalized individuals who are not reached by a particular campaign. Thus, focusing solely on funding awareness campaigns is unlikely to reduce the number of exploited individuals.

5.2.2. Intervention 2: rehabilitation for survivors of trafficking and exploitation

The spectrum of anti-human trafficking efforts also includes initiatives that address individuals' vulnerability. Such initiatives provide job training, skills improvement, or even socioeconomic development. They are designed as a means of prevention, or rehabilitation, to reduce the risk of an individual being exploited or re-trafficked by teaching a set of skills to make an individual employable in a trade [67]. In this model, we consider a rehabilitation approach, which is in line with Thailand's Ministry of Social Development and Human Security, which is responsible for managing rehabilitation efforts and looking after the welfare of trafficking victims [81].

In our model, increased spending for this intervention effectively removes individuals from the vulnerable stock. If the focus of anti-trafficking efforts is concentrated on rehabilitation policies (Fig. 8), the system behaves similarly to the results of the awareness campaign (see Fig. 7). Initially, forced labor slightly decreases as the vulnerable population drops. Forced labor eventually rises, as was the case in the awareness campaigns—with decreased funding targeting trafficker interventions, vessels can evade monitoring, and the rate of labor exploitation rises. Notably, falling profits drive increased forced labor.

5.3. Interventions targeting Fishers

5.3.1. Intervention 3: inspection policy

The inspection policy addresses vessel inspection, an initiative used by governments to address illegal, unreported, and unregulated (IUU) fishing and improve migrant fishers' access to legal status [82]. Specifically in Thailand, in 2015, the Thai military government embarked on a comprehensive fisheries

5.3.2. Interventions 4 and 5: financial penalties

The next efforts center on strengthening criminal and civil penalties for violations of trafficking and illegal fishing regulations. Under the Palermo Protocol, Thailand is required to create anti-trafficking legislation, take action to penalize trafficking, protect victims of trafficking, and grant victims temporary or permanent residence in their countries of destination [84]. In response, the Thai government created policies requiring vessel registration and the issuance of permits to use vessels or permits to use fishery tools [68]. Fishers who are found using migrant labor onboard their fishing vessels without work authorization are fined a penalty of 10,000–100,000 Baht for each laborer. Repeated offenses lead to imprisonment for no more than one year or a fine of 50,000–200,000 Baht [85].

We consider two financial penalties that could be imposed on shipping vessels: (i) Fine per Exploited Laborer, representing a fine should illegal or forced labor be found on a vessel, and (ii) Fine per Unlicensed Vessel, a penalty amount should a vessel be found to be unlicensed. As illustrated in Fig. 10, increasing the policy Fine per Exploited Labor dramatically reduces forced labor and yields a steady rise in legal labor on vessels.

Interestingly, increasing the penalty costs in year 1 for unlicensed vessels leads to an equally dramatic drop in forced labor (see Fig. 11). As intended by the policy, the number of unlicensed ships decreases, although to offset profit losses, gradually the number of unlicensed ships increases.

Notably, for both these policies, we were unable to run the simulation model for higher values listed in Table 2 before industry profits fell to levels that would cause the industry to collapse.

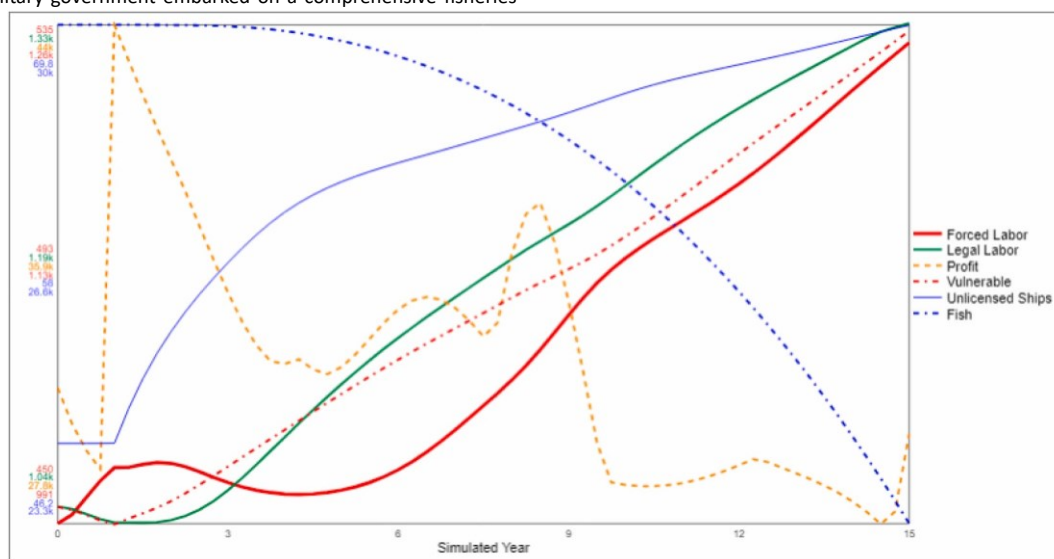


Fig. 7. Effect of allocating the majority of the budget toward awareness campaigns (Assumption: Awareness Campaign increased from a level of 2–9 in Year 1).

reform in part to strengthen anti-trafficking legislation [83]. One of the most notable changes are port-in, port-out (PIPO) inspection centers operated by the Thai Navy. PIPOs are located at every major port and inspect all vessels over 30 gross tons entering and exiting the pier to ensure that workers are registered and working conditions meet legal requirements. Moreover, as part of the 2015 reforms, the Thai government intensified at-sea inspections.

Pertaining to our model, we examine the scenario in which the inspection policies are intensified to monitor unlicensed and licensed fishing vessels. We assume that the effectiveness of licensed vessel inspection is two times the effectiveness of unlicensed ship inspection, as unlicensed ships are more likely to try to evade inspection.

As illustrated in Fig. 9 increasing the intensity of inspection is effective in initially decreasing forced labor. To offset the upkeep of legal labor, over time, vessel owners resort to illegal labor and the number of unlicensed ships entering the industry increases.

5.4. Interventions targeting consumers

5.4.1. Intervention 6: producer tax

Lastly, we consider policies aimed at the producers and consumers to explore their impact on forced labor. Industry buyers, such as Thai Union and Nestle, are actively monitoring their supply chain transparency and support policies to support anti-trafficking and anti-labor exploitation. Similarly, some supermarket chains and other seafood buyers are establishing programs to ensure that their supply chains are free of slave-associated products [83].

Thus, we introduce a policy of a producer tax placed on vessels bringing their catch to port, and the additional tax revenue is then redirected toward anti-trafficking policies such as awareness campaigns and rehabilitation. As shown in Fig. 12, by introducing a producer tax,

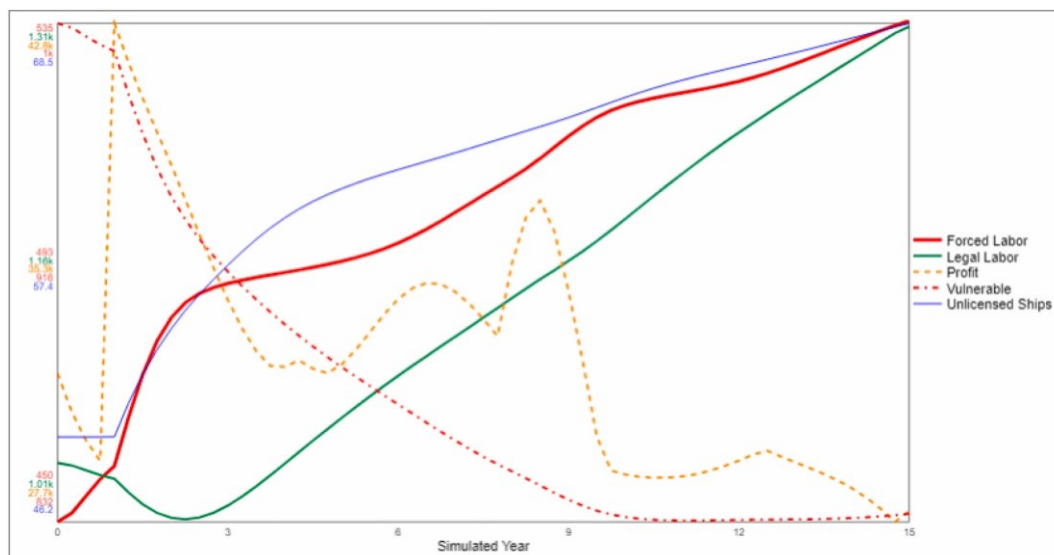


Fig. 8. Effect of allocating the majority of the budget toward rehabilitation efforts (Assumption: Rehabilitation increased from a level of 3–9 in Year 1).

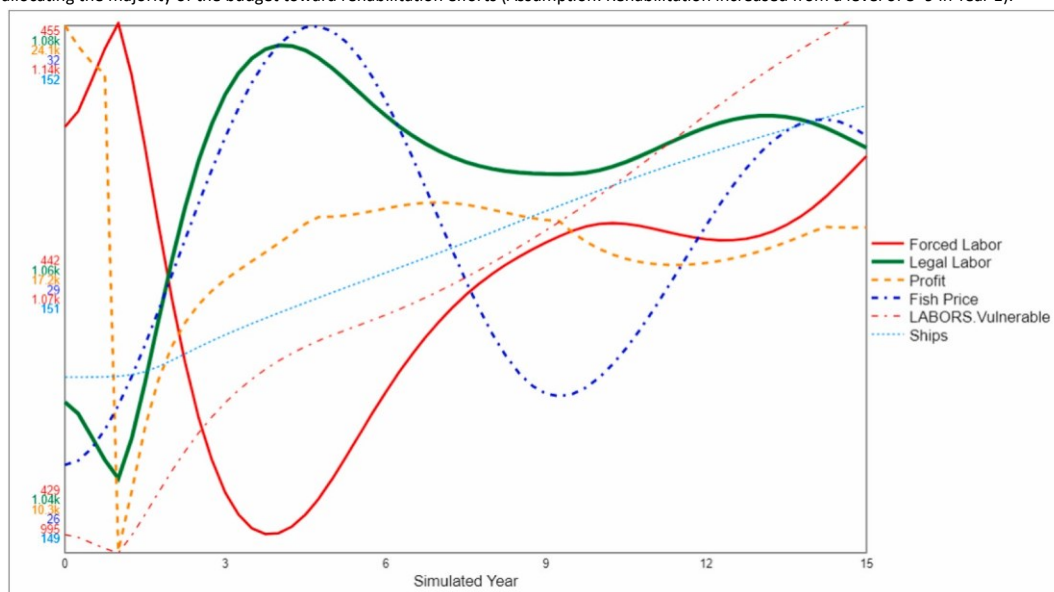


Fig. 9. Effect of allocating the majority of the budget toward vessel inspection (Assumption: Vessel Inspection increased from a level of 5–9 in Year 1).

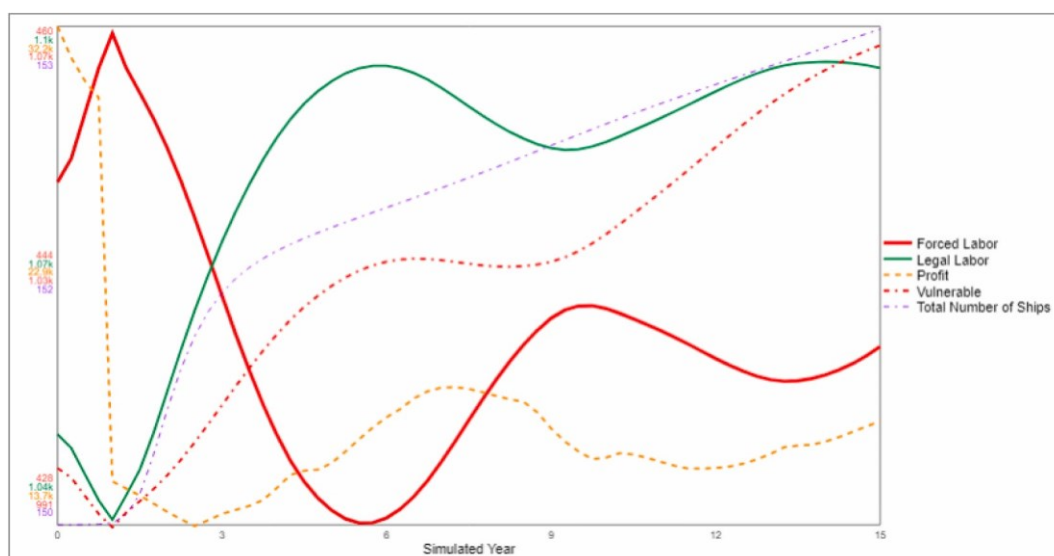


Fig. 10. Effect of increasing penalty costs for forced labor found on ships (Assumption: fine increased from 300 to 2000 in Year 1). profits decrease for two reasons: the price of fish rises, thereby decreasing demand for product, and as anti-trafficking policies receive increased funds, excess supply drives prices down, making the product more favorable to consumers.

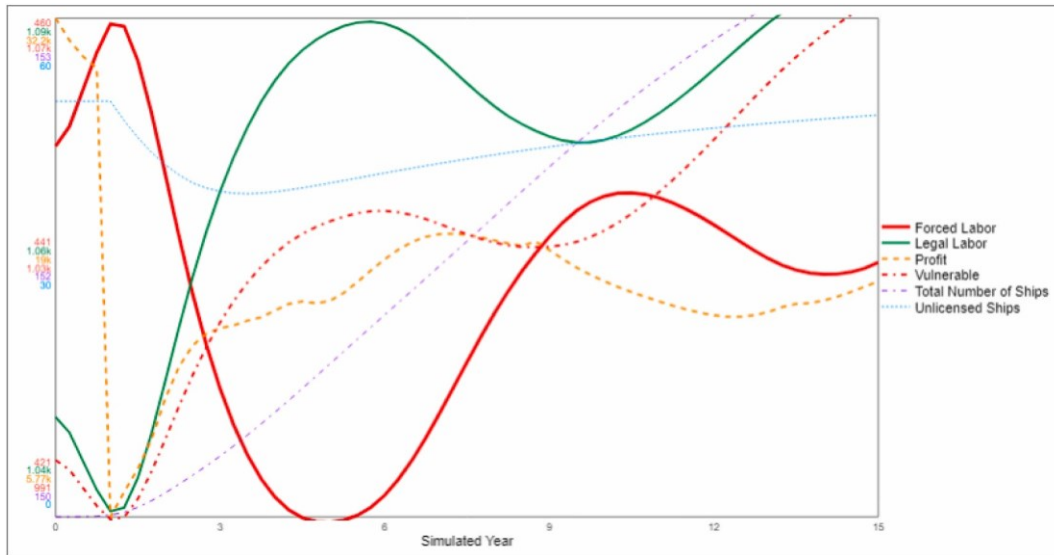


Fig. 11. Effect of increasing penalty costs of unlicensed ships (Assumption: fine increased from 1150 to 5500 in Year 1).

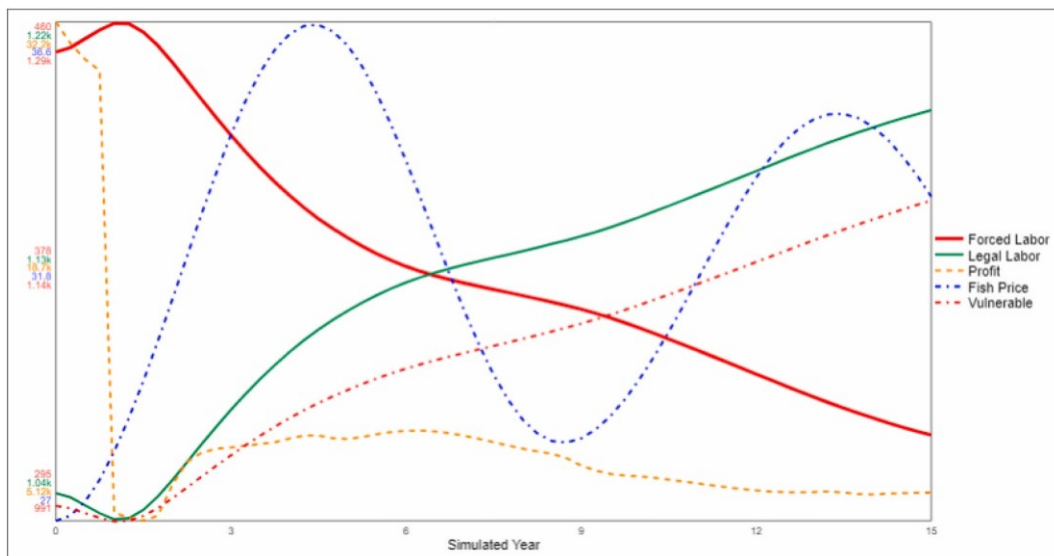


Fig. 12. Effect of producer tax (Assumption: tax rate increased from 0 to 0.25 in Year 1).

the rate of exploitation decreases, requiring vessels owners to pay a fair wage and employ labor legally.

5.4.2. Intervention 7: consumer tax

Finally, we consider a growing social movement of increased consumer responsibility in the use of environmental resources. In recent years, consumer markets have demanded that seafood products must be obtained using more sustainable practices, prompting the introduction of several certification schemes and ecolabels [16,86]. While a few ethical certification programs exist, we introduce a concept of a consumer tax imposed on the consumer to offset the costs of supply chain monitoring systems. We consider such a scenario in the simulation model in which additional tax revenue from products sold is used allocated toward funding anti-trafficking initiatives such as awareness campaigns and rehabilitation initiatives. With such a tax, the product price of a price-sensitive item increases, which in turn affects demand.

From Fig. 13, we observe that forced labor steadily decreases after an initial rise. Profits drastically drop, illustrating consumer price sensitivity, and then oscillate in response to lower consumer demand due to higher prices. In turn,

5.5. Comparison of interventions

The above results reveal that a single intervention listed in Table 2 is unable to decrease forced labor, while maintaining industry profits and fish stocks. For comparative purposes, Fig. 14 shows the impact of introducing a particular policy in year one on the three metrics. Some policies, such as increasing the fines for forced labor, are effective at reducing forced labor, but cannot maintain fish stocks or profits. Other policies, such as awareness campaigns counterintuitively increase forced labor and see a drop in fish stocks.

Such results suggest that a combination of policies is likely to be more effective at reducing forced labor. Moreover, as discussed in Section 3.3, key feedback loops consisting of variables from the Liquidity submodel drive fishers' behavior. Therefore, dynamic implementation of several policies targeting variables in key feedback loops are likely to be effective. Fig. 15 provides one such example in which small increases in fines for unlicensed vessels are introduced, as well as increased inspection. After three years increased funding is allocated for awareness campaigns in the model. To address declining fish stock, a small consumer tax is introduced in year 10 that

in turn is used to fund anti-exploitation efforts. Compared to individual policies, such a combination of interventions is more effective at reducing forced labor while minimizing profit and fish stock decline. A key difference between Fig. 15 and earlier figures is understanding key structural elements and their influence on system behavior. The variables in the Liquidity submodel constitute key feedback loops (Table 1). As such policies like fines for unlicensed vessels and inspection are key behavior drivers. While a systematic search of policy combinations is beyond the scope of this paper, our intent is to demonstrate the value of analyzing simulated results with key structural elements to promote learning and better decision-making. Furthermore, such efforts illustrate the cooperative approach needed to jointly set policies with a systemic understanding of structure-behavior insights.

6. Discussion

Labor trafficking in the fishing industry is a prevalent and global crime. Implementing counter-trafficking policies is an arduous task involving multiple actors and often leading to unintended consequences. Policy interventions targeting labor crimes are implemented in a complex feedback system that can cause policy resistance or amplification. Furthermore, subpopulations of targeted policies often overlap so that the impact of one intervention on the population may affect the effectiveness of another policy, creating positive and negative synergies. These phenomena have two major consequences. First, the effective cost of achieving a particular outcome may differ from what is projected. Second, interactions between policies may shift patterns of expenditure over time for each intervention. Systems dynamics is a method to capture the interdependencies and interactions in such complex systems.

To increase the accessibility and relevance of this model, we created a freely available online game, “Fish-y Banks,” with a user-friendly interface. A game interface enables better decision-making by encouraging users to consider a systemic approach. Furthermore, SD provides structure-behavior insights to explain implications of decisions made. Through a gaming interface players can evaluate the dynamic allocation of funding toward intervention policies. A player is charged with reducing the number of people in forced labor while maintaining fish stocks and profits. To do so, the player can adjust the intensity of policies and interventions at discrete time intervals (e.g., annually). The goal of the game is to minimize the number of forced laborers at the end of the game (e.g., 15 years) while ensuring that fish stocks and industry profits are above a minimum threshold (e.g., 30% of the initial fish population, or annual profit above \$1000 per vessel). If either the fish population or annual profit falls below the minimum threshold, the game is over (Fig. 16).

While calibrated for the general Thai fishing industry, “Fish-y Banks” could be calibrated to focus on a particular species or a particular geographic region. The game illustrates the deep interdependence of systems and the unintended consequences of well-meaning policies; it serves to bring policymakers and decision-makers a means of discussion. “Fish-y Banks” can also be used as a teaching or training tool for students, policymakers, regulators, and law enforcement personnel. A system dynamics approach can help decision-makers harness the high degree of interconnectivity between drivers to better inform policy decisions for conservation, ethical employment, and industry management.

7. Concluding thoughts

This research aimed to investigate Thailand’s fishing industry with a focus

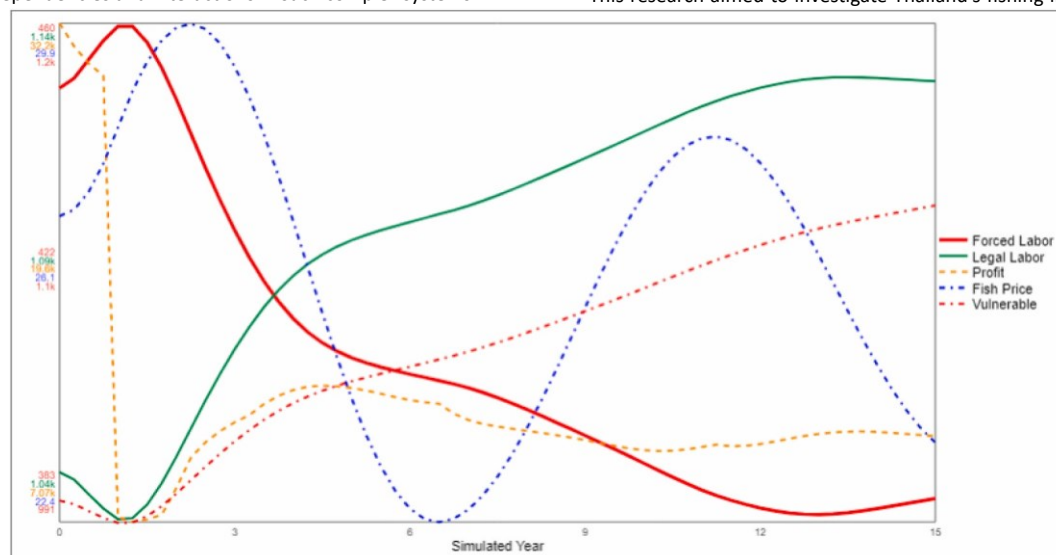


Fig. 13. Effect of introducing a consumer tax (Assumption: tax increased from 0 to 0.25 Year 1).

We developed a simulation model to test current and proposed policies that reduce forced labor in the fishing industry. We concluded that no single policy can effectively reduce forced labor in the fishing industry while respecting sustainability criteria in both the natural sphere (e.g., regeneration capacity of fish populations) and economic sphere (e.g., profits and employment).

Thus, a combination of policies is likely to be more effective at reducing forced labor; a single policy may have unintended consequences, and policies need to be dynamic and robust to a range of circumstances. This observation has implications for how central funding agencies, such as a government or NGO, decide to invest its resources. Effective allocation of resources is an important issue given that funding for anti-trafficking policies is typically limited, and an agency or government must determine how to best use these resources. Therefore, an SD model, such as the one created here, has potential for use in the policymaking arena. Capitalizing on the value of a feedback loop perspective, the study presented here provides a method to understand which model structures are responsible for its behaviors and results.

on trafficked and forced labor to explore the complex interplay of economics and environmental spheres and determine policy intervention strategies that reduce forced labor. We did this by including a system dynamics model with a dual labor substructure that included legal labor as well as forced labor. The results of the model illustrate trends and feedback loops, which allows for more detailed analysis of different potential changes in fishing industry policies.

Models are not a perfect representation of reality; nonetheless, they offer valuable insights into the dynamics of complex systems. Specifically, system dynamics modeling facilitates comparison between scenarios—for example, to investigate the potential effects of policy interventions. Although some dynamics investigated here, such as fish stocks, have been explored before, the incorporation of legal and illegal labor markets makes the exploration much more robust and effective. We assessed the success of these policies on labor, as well as economic and ecological grounds. The simulation model provides insights related to the effects of policies for law enforcement, social, and

behavioral policies on trafficked labor, local economies, and fish stocks—thereby addressing a range of policy questions.

In our investigation, investment in a single policy was unsuccessful at reducing trafficked labor while simultaneously maintaining profit and fish stocks, highlighting the interdependence of these three spheres in the fishing industry. To effectively respect economic and ecological sustainability criteria while addressing labor trafficking, several policies must be dynamically implemented (e.g., see Fig. 15). We created a user-friendly interface, “Fish-y Banks,” to ensure that such comparisons are made more accessible to a wider audience. This open interface enables decision-makers to change parameters with system-wide recalculation of its effects.

This study provides an approach to enable systemic planning and policymaking of initiatives that reduce forced labor while still valuing environmental and economic concerns, including the interplay between legal and illegal labor. The study provides the following unique contributions to literature. First, the study presents a policy evaluation model that considers the interplay between legal and illegal labor while accounting for the nonlinear feedback relationships and accumulation processes in the system. Using this model, the study presents empirical evidence and an explanation of how an emphasis on one policy over another impacts key metrics by providing results that are counterintuitive and highlight the need to consider the whole process. The model can be replicated and applied to policy and scenario analysis and

thus provides a previously unrealized systematic approach to anti-trafficking efforts. Second, the study evaluates the impact of parameter changes compositely on segments of the fishing industry. This allows for an assessment of the impact on the factors of interest (economic, environmental, and social), avoiding the mitigation or exclusion of potential policy impacts, which can fail to yield desired results. The analysis in this study has implications for decision-makers as they assess the impact of their decisions on an industry attempting to counter forced labor. The feedback loops represent the causal relationships of economic, environmental, and external variables in a systematic way. Normally, such systematic approaches are not frequently addressed in anti-trafficking literature.

To date, studies regarding forced labor and more broadly human trafficking have focused on policies solely targeting victims, survivors, or perpetrators. In their recent review of 142 anti-human trafficking studies in the Operations Research and Analytics domains [85], the authors found the vast majority focus prosecution efforts and call for more inclusion of, and collaboration between, the 4 P s (prevention, protection, prosecution, and partnership) of anti-human trafficking. We echo this stance. Rather than focusing analysis solely on a particular set of participants (e.g., perpetrators), or a single policy (e.g., increasing law enforcement), we encourage the broader adoption of systems thinking, specifically a systems dynamic approach when considering policy design, implementation, and evaluation. A systemic view offers insights

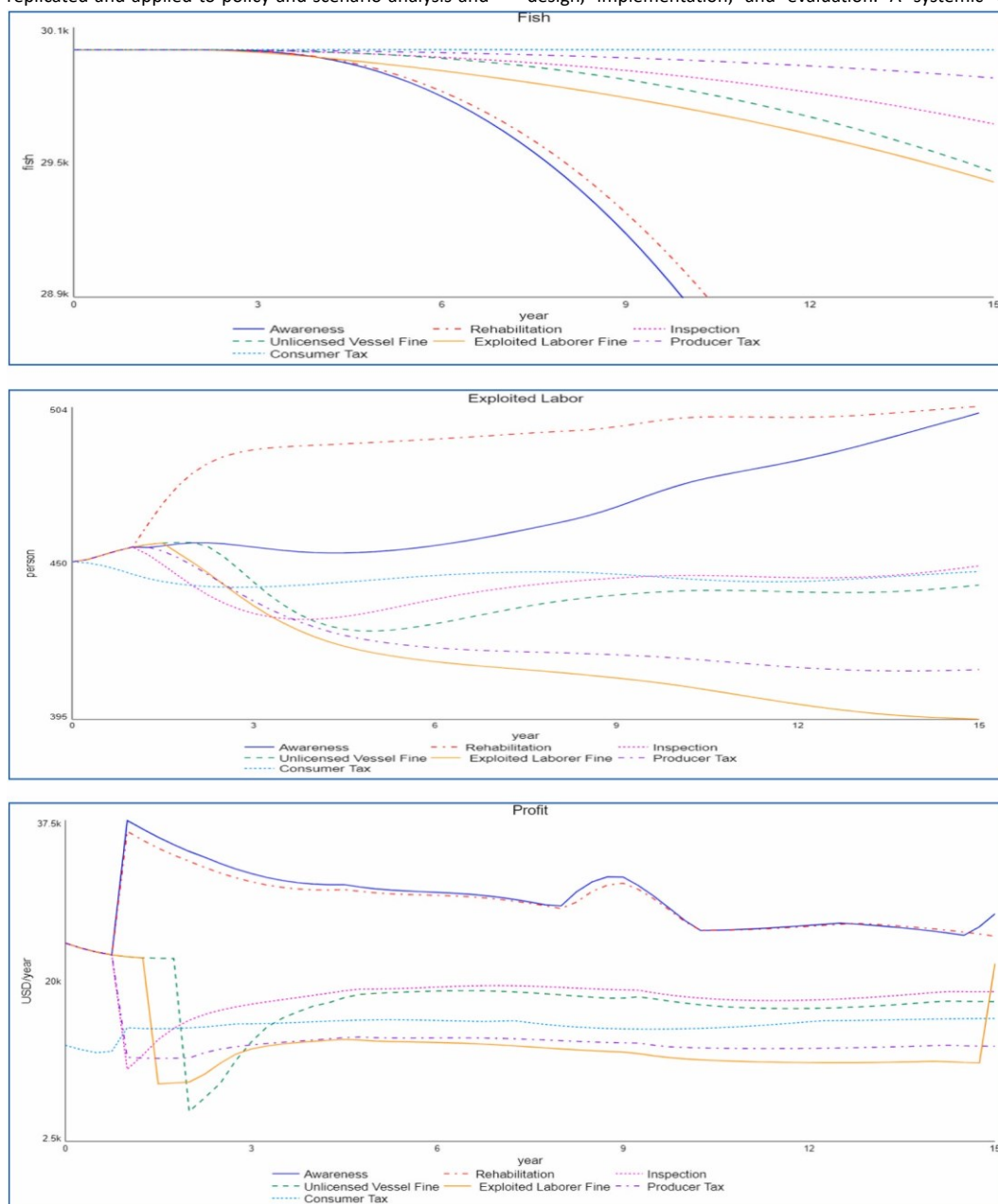


Fig. 14. Comparison of seven policies with respect to fish stocks, forced labor, and profits.

regarding system behavior, particularly if it incorporates the dynamics that exist between ecosystem participants and environmental spheres.

Recognizing the growing body of Operations Research and Analytics (see Ref. [85]) in the anti-human trafficking domain there is potential to use SD to augment optimization and multi-criteria decision-making. For instance, SD could be used iteratively in conjunction with math programming similar to Ref. [86].

While this study tests a connection between fishing and forced labor, it is not without limitations. First, the model is not calibrated for a particular species

populations in the model, would provide richer insights into policies targeting socioeconomic interventions. Third, while this model provides a basic starting point to test anti-exploitation policies, law enforcement agencies, NGOs, and governments may have that differ from the ones investigated with varying rates of effectiveness. We also did not consider the role of corruption in law enforcement [88].

There are several directions for future work. We consider a centralized decision-maker that allocates funds toward policy interventions. In practice, multiple agencies and organizations allocate their budgets with respect to their

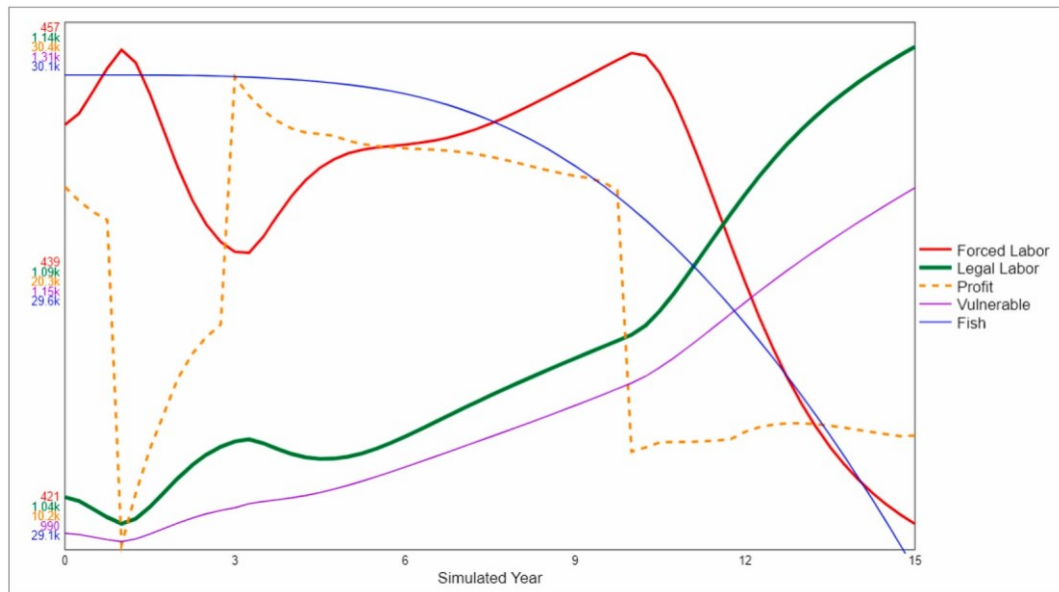


Fig. 15. Combination of policies aimed at reducing forced labor, maintaining fish stocks and profits (Assumption: Unlicensed Vessel Fine increased from 1.5 K to 2 K, and Inspection Policy from 5 to 6 in Year 1; Awareness Campaign increased from 2 to 5 in Year 3; Consumer Tax increased from 0 to 0.125 in Year 10).



Fig. 16. Fish-y Banks" game interface - profit fell below threshold.

of fish, and additional effort is required to match the existing model with data for species of fish and related law enforcement activities. Second, the model did not explore the socioeconomic implications of overfishing and its threat to economic livelihood of artisanal fishers, which increases their vulnerability toward forced labor [87]. Incorporating this connection by including, for example, the provision of alternate sources of income for vulnerable

organizational mandate, often without knowledge of the other's actions. Coordination and the possibility of competition between multiple national and international organizations is a major challenge in fishing but very much needed [67], and our model could be extended to examine the amplification of policies when several funders are addressing a range of potentially conflicting policies. Related to the limitations above, it would be insightful to investigate

economic and ecological thresholds, and at which point multiple agencies must coordinate to respect agreed-upon sustainability criteria. Additionally, sustainable policy development typically requires consideration of multiple criteria. Our model can be extended to address multiple criteria within a decision support system used by policymakers [89–91].

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authorship statement

Conception and design of study: R. Konrad, K. Saeed, and M. Kammer-Kerwick; acquisition of data: P. Busaranuvong and W. Khumwang; analysis and/or interpretation of data: R. Konrad, K. Saeed, M. Kammer-Kerwick, P. Busaranuvong and W. Khumwang. Drafting the manuscript: R. Konrad, K. Saeed, M. Kammer-Kerwick, P. Busaranuvong and W. Khumwang; Revising the manuscript critically for important intellectual content: R. Konrad, K. Saeed, and M. Kammer-Kerwick.

Approval of the version of the manuscript to be published (the names of all authors must be listed): R. Konrad, K. Saeed, M. Kammer-Kerwick, P. Busaranuvong and W. Khumwang.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.seps.2023.101731>.

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Palawat Busaranuvong is a Ph.D. student in Data Science at Worcester Polytechnic Institute, USA. He holds a M.S. in Data Science and a B.S. in Mathematical Science, both from WPI.

Matt Kammer-Kerwick, PhD, is a Senior Research Scientist at the Bureau of Business Research at the IC² Institute, a Research Affiliate of the Population Research Center, and a Lecturer in the Human Dimensions of Organizations program, all at The University of Texas at Austin. He is the principal investigator of the study Collaborative Research: Disrupting Exploitation and Trafficking in Labor Supply Networks: Convergence of Behavioral and Decision Science to Design Interventions (NSF 2039983). Prior to his current appointment, he was a research consultant to industry for over 20 years and was President and Founder of Visionary Research, Inc.

Wai Khumwang is an M.S. student in Computer Science at Worcester Polytechnic Institute, USA. He holds a B.S. in Computer Science, also from WPI.

Renata Konrad, PhD, is an associate professor of industrial engineering at Worcester Polytechnic Institute. Her research is funded by the National Science Foundation, and she served on the U.S. Department of Transportation Advisory Committee on Human Trafficking and on the U.S. Department of Homeland Security–Science and Technology, Human Trafficking Advisory Committee. She is the recipient of a 2021/22 Fulbright Scholar Award to Ukraine. Renata earned a Ph.D. in industrial engineering from Purdue University and her master's degree from the University of Toronto.

Khalid Saeed, PhD, Professor of Economics and System Dynamics at Worcester Polytechnic Institute, USA. His research is on computer modeling and experimental analysis of developmental, organizational, and governance-related issues. His recent writings address sustainable economic development, poverty alleviation, political dynamics, supply chain management, tax reform, and health care. Professor Saeed holds a PhD in system dynamics and economic development from MIT and is a recipient of Jay Wright Forrester Award and a past president of system dynamics society.