Foreign Fishing Vessel (FFV) Impact Analysis

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ABSTRACT

This study examined illegal fishing activity by Foreign Fishing Vessels (FFVs), which occurs to an unknown degree and with an unknown frequency. A discrete event simulation, coded in VBA within Excel for ease of use and distribution, was used to model FFV movements and behavior, Coast Guard presence, and probability of detection to estimate the likelihood of FFV discovery. Since system arrivals are a primary output in this case, instead of the standard input, we linked this likelihood of discovery through historically documented performance to estimate the number of system arrivals, or incursions, in a given year. Model data was derived from historical mission analysis, subject matter expertise, and recent academic studies. The resulting analysis regarding the extent of FFV incursions and the overall impact of this activity on both the fish population and the U.S. and foreign economies provided the first rigorous, quantitative estimates on the extent of this problem.

ABOUT THE AUTHORS

LT Elizabeth A. Denicola is currently working as an Operations Research Analyst for Coast Guard Atlantic Area (LANT-7). She received her B.S. in Operations Research and Computer Analysis from the Coast Guard Academy in 2009, and her M.S. in Operations Research from George Mason University in 2012. Prior to attending graduate school, she was stationed on CGC BERTHOLF (WMSL-750) from 2009-2011. She has been assisting with studies and conducting research related to illegal fishing since she reported to LANT-7.

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BACKGROUND

Fisheries are important to the overall economic health of a nation. However, if left unregulated, there is a very real danger to the species as a result of overfishing. To prevent overfishing and preserve the health of these species, laws are put in place to promote sustainable fisheries. As part of these laws, and as an issue of national sovereignty, Foreign Fishing Vessels are not permitted to fish in U.S. waters without express authorization. However, many FFVs still fish illegally in the U.S. Exclusive Economic Zone (EEZ), taking advantage of the better fishing conditions found in U.S. waters. The U.S. Coast Guard, in conjunction with partner agencies, works to defend U.S. fisheries by detecting and interdicting FFVs.

This study focuses on red snapper species, a non-migratory species that is a frequent target of illegal fishing. FFVs fishing illegally for red snapper are often wood or fiberglass vessels between 20-30 feet long, with the ability to transit at 20+ knots (nautical miles per hour), depending on the size of their engine. They utilize a variety of gear types, including longline gear and gillnets. This gear is deployed and can be left unattended for up to 6 hours. Gillnets in particular are very dangerous to a multitude of species, due to their indiscriminate nature; a deployed gillnet, when abandoned, will continue to kill large volumes of marine life. The FFVs in question often make several fishing stops during one fishing trip, collecting as much catch as possible before departing U.S. waters.

PROBLEM STATEMENT

Due to budget and resource constraints, the U.S. Coast Guard does not have the ability to maintain 100% coverage of the U.S. EEZ to detect all illegal activity. As a result, the total number of FFV incursions per year and the impact these FFVs are having on the red snapper population and the U.S. economy are unknown. Without an understanding of this impact, the sustainability of the targeted species (in this case red snapper) is at risk. This study is an effort to estimate the number of incursions and the impact through modeling and simulation. A discrete event simulation was determined to be the best approach to model this unknown impact due to the stochastic nature of this problem. The interarrival times, however, are not known, nor can they be reliably estimated. The simulation, therefore, seeks to estimate this parameter, and therefore the total number of incursions, by modeling interactions of Coast Guard assets and the illegal fishing vessels and tuning the parameters to match the model outputs with observed data.

DEFINITIONS

The following terms are included throughout this paper and may cause confusion if not defined explicitly in the context of this analysis.

Arrival/Incursion:

FFV initial border crossing into the U.S. EEZ. This is the point within the simulation model where the FFV begins its transit and becomes subject to detection by law enforcement.

Detection:

A FFV is sighted but remains uninfluenced by law enforcement. In reality, this number includes sightings of abandoned gear (such as nets left by FFVs that may have departed the EEZ). The simulation does not directly model gear detection.

Interception:
A FFV is sighted and compelled out of the U.S. EEZ by law enforcement.

Interdiction:
A FFV, and all catch onboard, is seized by law enforcement.

Likelihood of Discovery:
This is the overall likelihood that this type of FFV is detected at some point while fishing in the U.S. EEZ. Intuitively, the number of incursions multiplied by the computed likelihood of discovery yields the number of detections.

Probability of Detection (POD):
POD is the probability, at a given time, that a Coast Guard asset will detect a FFV, given the FFV's proximity to the asset. This probability is based on mathematics derived from Coast Guard Search and Rescue (SAR) theory. We have further extended this calculation, using Monte Carlo simulation, to encompass the POD given that a FFV and an asset are both present in the same 10x10 nautical mile (nm) grid block within the model.

SYSTEM DESCRIPTION

The system models the behaviors of FFVs while in the U.S. EEZ, including movements and fishing activities, and the interaction between the FFVs and U.S. law enforcement assets. The FFVs modeled in this study use two types of fishing gear: longline and gillnets. The type of gear used directly affects the behavior of that FFV within the system. The model assumes that FFVs using longline gear cross into U.S. waters in the morning, while FFVs using gillnets cross in the evening. The model further assumes that FFVs tend to leave and fish in groups, an assumption that is corroborated by numerous Coast Guard observations.

Once in the U.S. EEZ, the FFV proceeds to its first desired fishing location and begins to fish. FFVs using longline gear are assumed to make between one and three fishing stops per trip; gillnets, just one. A longline stop is assumed to take three hours, while a gillnet stop is assumed to take six. Once a fishing stop is complete, the FFV will transit to the next stop, or, if it has completed its trip, transit directly out of U.S. waters. The preference for certain fishing locations over others is a primary modeling consideration that will be discussed further in the "Data" section.

While a FFV is in the U.S. EEZ, it faces discovery by U.S. law enforcement assets. This model incorporates only Coast Guard assets. At any given time, given the FFVs location and the presence of Coast Guard assets, there is an associated POD. Therefore, each time period (30 minutes) within the model functions as a Bernoulli trial with a fluctuating probability p. The overall likelihood that a FFV completes its trip undetected can be represented as a combination of these trials, where p_t is 1 – POD at time t. If a FFV is detected, there is a small chance that it will continue its fishing trip. More likely, it will either be pursued and forced to exit the EEZ (abandoning the remainder of its trip), or it will be pursued and interdicted. If a FFV is not detected during a given time period, it proceeds with its trip as planned. The percentage of FFVs that are detected by Coast Guard assets equates to the overall probability that a FFV is detected while in the U.S. EEZ. We call this the *likelihood of discovery*.

The likelihood of discovery is a driving factor within the simulation model and is a key to understanding how the observed impact of FFV incursions relates to the actual impact. If the likelihood of discovery were 100%, then the observed number of incursions would equal the actual (documented) number of incursions. This is represented by the red dashed line in Figure 1 to the right. However, the likelihood of discovery is safely assumed to be below 100%. The blue and purple dashed lines in Figure 1 represent two hypothetical projections given different likelihoods of discovery. The true likelihood of discovery and the true impact are both unknown. The known within the equation is the

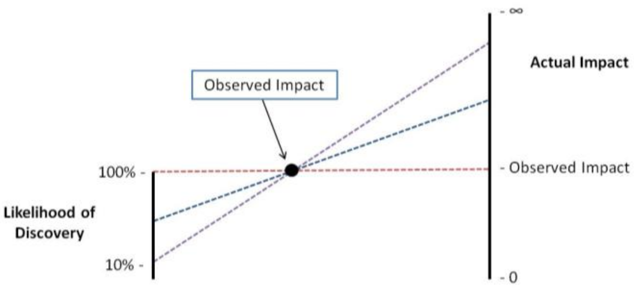


Figure 1. Likelihood of Discovery vs. Impact.

observed (documented) number of incursions, which acts as a fulcrum between the likelihood of discovery and the true impact. The simulation model aims to provide insight into the two unknown quantities, based on the known.

When estimating the number of incursions from interaction data, there is a compelling case to be made for the effect of deterrence. Certainly one would expect more incursions if there were no Coast Guard presence and therefore no fear of being caught on the part of the FFV. One would similarly expect fewer incursions with greater Coast Guard presence and increased fear of being caught. There are ongoing efforts on the part of the Coast Guard, working with university partners, to understand the effects of deterrence on this illegal fishing issue (Haskell, Kar, Fang, Tambe, Cheung, Denicola. 2014). However, this study specifically did not consider these effects and instead considered the data from each year as a comprehensive input. That is to say that any deterrent effect based on Coast Guard asset presence was already captured in the number of FFVs detected, intercepted, and interdicted in that year and therefore does not need to be explicitly considered in estimating the number of incursions.

MODEL

This simulation model is built in Microsoft Excel and coded in Visual Basic for Applications (VBA). Excel was chosen over specialized discrete event simulation software due to its ubiquity throughout the Coast Guard, which offers district and field level users the ability to run and modify the model in the future. The same is not true of a model built in other languages such as Rockwell Software's Arena.

The model simulates the actions of FFVs and their interactions with law enforcement as described above. The model replication simulates this system over the course of one year. It steps through the year at 30 minute intervals. There is no warm-up period built into this model due to the short duration of FFV trips—the model is already in steady state when it begins. The flow of the simulation model is depicted below in Figure 2.

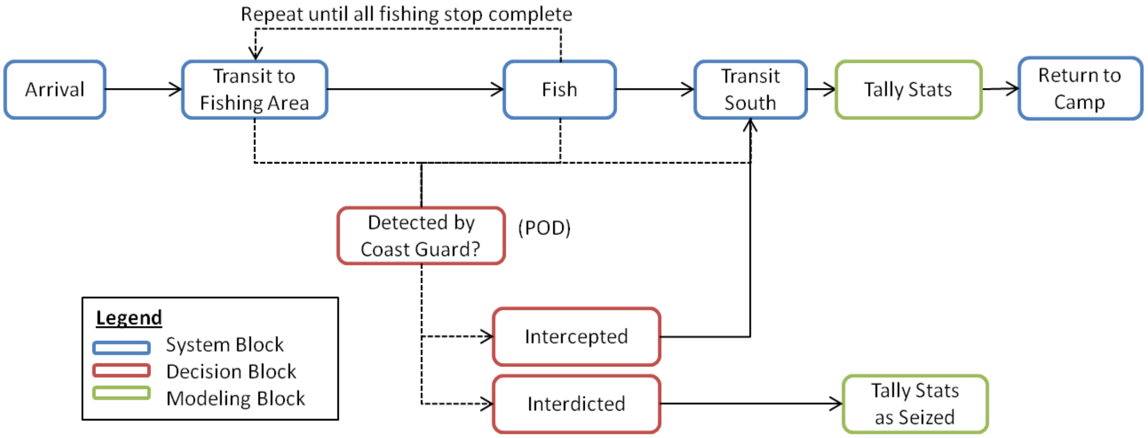


Figure 2. FFV System and Model Diagram

Within VBA, an array is used to track FFV attributes. Each FFV is assigned an underway status (0 if no, 1 if yes), gear type (1 for longline, 2 for gillnet), current catch, total catch, time remaining to fish (0 if not fishing), number of fishing stops remaining, and total number of fishing stops. When a FFV in the model crosses into the U.S. EEZ, it is immediately assigned the applicable initial values (underway status, gear type, total catch for the upcoming trip, and intended number of fishing stops for the upcoming trip).

FFV Arrivals

FFV arrivals are a key driver of the model, as they are of any discrete event simulation. For modeling purposes, an "arrival" is the FFV crossing into the U.S. EEZ. The Coast Guard does not have complete visibility of FFV border crossings, and as a result, is unsure of their exact frequency. Interarrival time is left as an input which is adjusted by the user to tune the model outputs to observations for that year. FFV arrivals were assumed to be independent events following a Poisson process.

One of the characteristics of a Poisson process with mean μ = λ is that the interarrival times are exponentially distributed with mean $\mu = \frac{1}{\lambda}$. These were calculated via inverse transform random variate generation according to the inverse cumulative distribution function (Equation 1), where x is the time (in days) between arrivals and y is uniformly distributed between 0 and 1 (Banks, Carson, Nelson, Nicol, 2001).

$$x = \frac{1}{\lambda}\ln(1-y) = \mu * \ln(1-y) \qquad (1)$$

In order to use Excel to generate these interarrival times, Equation 2 below was used.

Interarrival Time (in days) = -μ**LOG(1-(RAND())* (2)

Once these interarrival times are generated, they are rounded to the next morning or evening predetermined launch time (morning is 1100, evening is 1930). The interarrival time parameter is an input variable in the model and is adjusted by the user until the model output matches with observed calendar year data points (detections, interdictions and interceptions). The predetermined launch times for FFVs were chosen based on subject matter expert input.

FFVs are divided into two categories based on their gear type. Up to five longline FFVs can arrive at once, and up to three gillnet FFVs can arrive at once. The group size is uniformly distributed. Equations 3 and 4 represent the number of longline and gillnet FFVs in each "group" arrival.

$$\text{Longline Arrivals: } P(x) = \frac{1}{5}; x = 1,2,\ldots,5 \qquad (3)$$

$$\text{Gillnet Arrivals: } P(x) = \frac{1}{3}; x = 1,2,3 \qquad (4)$$

When a FFV arrives, it is assigned a "total catch target," which is the total amount of fish it will catch over the entirety of its fishing trip, unless it is intercepted or interdicted. The target catch is a random variable from a discrete uniform distribution ranging between a specified lower and upper bound. The FFV will catch less than its total catch target if it is intercepted or interdicted prior to completing the final stop of its fishing trip. The catch type assigned to a FFV using longline gear is Red Snapper, and "other" is assigned to gillnet FFVs. This is due to the assumption that longline is best for targeting reef fish, specifically red snapper in the geographic region of interest, based on subject matter expert input.

A FFV using longline gear is also assigned one, two, or three fishing areas, representing the fact that they often make multiple stops in a single fishing trip. Each option is equally likely. FFVs using gillnets only make one stop.

Setting Gear

Any FFVs underway in the model will have the opportunity to set gear at each time step, unless they are already fishing. A FFV will only set gear if it is in one of its pre-assigned fishing locations. These locations are selected by FFVs based on the utility grid, or how desirable each location is in respect to the other locations. Additionally, the model sorts these fishing locations to ensure the route taken by the FFV through the water is reasonable given the geography of the locations. The catch per stop is evenly distributed across all fishing stops based on the total assigned catch. For example, if a FFV has two fishing stops in one trip, and has been assigned 900lbs total catch, it will catch 450lbs at the first stop, and 450lbs at the second stop.

The model simulates fish being brought on board throughout the fishing stop. When a FFV first arrives at a stop and sets its gear, the model immediately tallies half of the current stop's catch. It tallies the second half at the conclusion of the stop. Returning to the previous example, if a FFV is supposed to catch 450lbs at one fishing stop, immediately after it sets its gear the model records 225lbs onboard that FFV. By modeling the catch in this fashion, if law enforcement interdicts a FFV partway through a fishing trip, the model captures that there is some catch on board. When the example FFV finishes fishing, the remaining 225lbs is tallied, resulting in 450lbs caught for that one fishing stop.

The progression of the FFV through their fishing stops is conducted to minimize initial and final transit times. FFVs in the model visit the fishing stops closest to the border first. Those using longline gear cross the border directly in line with their first fishing area. The FFVs using gillnets fish where they cross the border, as their typical behavior is to remain close to the border. It is currently unknown, and unmodeled, if FFVs using gillnets set gear and depart the scene, presumably to wait just across the border, and finally return to haul their nets and catch. This behavior would affect the POD for that vessel as the gear itself is considerably more difficult to detect than is the FFV.

Fishing stop durations, currently modeled at three hours for a longline stop and six hours for a gillnet stop, are key drivers of the model. As such, they may be easily adjusted by the user from the primary model interface sheet. A decrease in stop duration would lower the FFVs time in system, which would lower the exposure to detection and thus lower the overall likelihood of discovery. This would lead the model to underestimate the number of incursions and actual impact. An increase in stop duration would have the opposite effects.

Law Enforcement Interaction

The model next simulates possible interaction with law enforcement. The probability that a FFV detection occurs incorporates both the probability that a particular asset (small boat, patrol boat, or aircraft) is present in the FFVs current 10x10nm grid box and also the probability of detection for the various Coast Guard assets. The probability of detection is based on the asset type (detection capability) and historical presence of the assets in that area for that month. An in depth discussion of how POD is calculated is included below.

The model first considers surface asset interaction (as opposed to air) for multiple reasons. Even though aircraft will sometimes detect a FFV and subsequently vector in a surface asset, aircraft assets alone cannot interdict FFVs. Additionally, the majority of surface asset patrols are unsupported by air assets. Finally, the surface asset data obtained does not differentiate between vessels on routine patrol and vessels underway because of an aircraft sighting—it just captures all vessel activity. Therefore, vessels vectored in by aircraft are already captured by the surface asset data, and other aircraft interaction with FFVs should be considered separately. The surface asset interaction happens with an averaged probability of detection for the given month and grid block. If a FFV is detected, a subsequent interception or interdiction happens based on the observed probabilities for that year. Because the simulation is attempting to accurately represent the calendar year of interest and is not trying to forecast future scenarios, input data was limited to data for that calendar year. If the FFV is not detected by a surface asset, the model then shifts to potential detection by air asset. This probability of detection is taken from the aircraft grid. The only possible interactions with law enforcement in this case are detection or interception. The probability that an aircraft intercepts a FFV given that it was detected is also taken from historical data for the calendar year being modeled. FFV detections, interceptions, and interdictions are tallied throughout each replication of the model, and averaged over the total number of model replications. If a FFV is detected, it does not impact the FFVs behavior within the model. If a FFV is intercepted, it is assumed that the FFV escapes across the border with the current amount of catch onboard, which is tallied. If the FFV is interdicted, the model assumes the catch onboard was seized by law enforcement and this catch is tallied as seized catch.

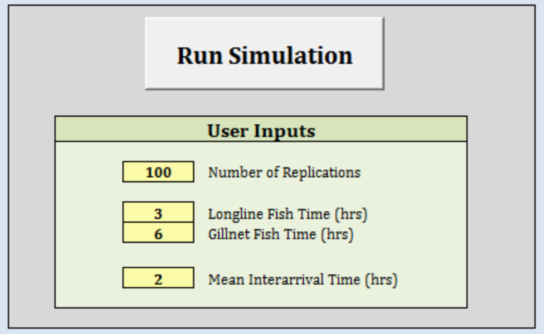
It is important to note that in the model, Coast Guard assets are not “tied up” while pursuing or interdicting a FFV. That is, a second FFV in a given area is subject to the same POD and probability of interception or interdiction even if a first FFV is being interdicted. Since such subsequent FFVs are still recorded as detections by CG assets, this is not a source of error in the model. Additionally, Coast Guard asset presence is modeled as static through the month, which does not account for pulse op work. Because of the lack of data regarding FFV arrival surges, it is not currently appropriate to model surges in CG assets. The default assumption is that, probabilistically, the two cancel out and can be thought of as static and/or random

FFV Transit

If the FFV is not intercepted or interdicted, it continues its transit as planned. The next step for the model is to simulate this transit (unless the FFV is currently engaged in fishing). If the FFV is transiting to a fishing area, it moves one grid block east/west and one grid block north/south each time period towards the next assigned fishing area. If the FFV is transiting toward the border at the end of its fishing trip, the model assumes that it transits straight towards and perpendicular to the border, as this is the most direct and fastest route back across the border. When the FFV crosses the EEZ border, the catch onboard is tallied, as is the undetected FFV. The FFV is still subject to detection while transiting.

DATA

The model uses Coast Guard asset locations and FFV location preferences in grid format as data inputs. This FFV Utility Grid, explained in greater detail in its own subsection below, represents how desirable different fishing locations are to a FFV. Additionally, the user enters the number of model replications, duration of a longline and a gillnet fishing stop in hours, and the interarrival parameter. These user inputs are depicted below in Figure 3.



User Inputs

100 Number of Replications

3 Longline Fish Time (hrs)
6 Gillnet Fish Time (hrs)

2 Mean Interarrival Time (hrs)

Figure 3. Model User Inputs

Coast Guard Asset Probabilities of Detection

Coast Guard assets (cutters, boats, and aircraft) were considered separately by the model because they have different probabilities of detection. Because the grid sizes in the model are 10x10nm, and needed to remain so to ensure the accuracy of FFV transit speeds, detection probabilities needed to be calculated for each asset type in a 10x10nm box.

Probability of Detection, within the model, is closely related to theories governing Coast Guard search and rescue operations (Soza and U.S. Coast Guard, 1996). The probability of success (POS) of a search is defined as the probability of containment (POC) multiplied by the cumulative POD. The POC is the probability that the search object is in the area being searched. Since the model already has the location of the lancha, the POC for the model is always 1. The POD is a function of the size and visibility of the search object (the FFVs for this model), the Coast Guard search asset including its speed and height of eye or altitude, and the distance between the two objects. The relationship between the asset and the object is called sweep width. The formula that relates the probability of detection to the distance between the objects is given below in (5), where x is the distance between the Coast Guard search asset and the FFV and W is the predefined sweep width between those two objects.

$$p(x) = 1 - e^{\frac{-W^2}{4\pi x^2}} \qquad (5)$$

Probabilities of detection for each asset type within a 10x10nm box were calculated using a Monte Carlo simulation run 30,000 times (30 x 1,000). The simulation generated random FFV positions within a 10x10nm box, as well as uniformly distributed north/south asset tracks within the box. It then calculated the distance between the FFV position and the asset position, storing this value, and the probability of detection based on equation (5). It then determined if a detection occurred by generating a random number between (0, 1) and comparing it to the probability of detection. The simulation tallied all detections to determine the overall probability

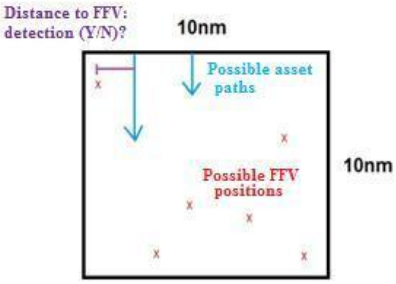


Figure 4. Simulation to Determine POD

of an asset detecting a FFV within the grid. This methodology is illustrated in Figure 4. (Note: Visual probabilities of detection are lower at night. This may lead the model to overestimate the likelihood of discovery for FFVs fishing between sundown and sunup which would lead to a slight underestimation of the number of incursions and the actual impact.)

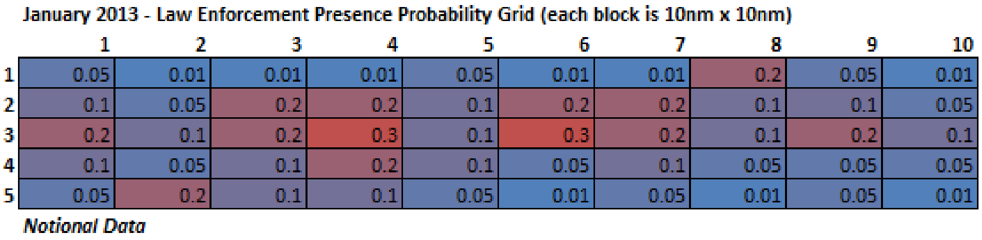
The law enforcement probability grids were calculated using Equation 6 below, by month *j*, asset type *i*, and grid location. Surface assets were calculated independently of air assets.

$$P(detection)_j = \%Availability_j * \left(\frac{\sum_i (minsCovered_i * P(detection)_i)}{\sum_i (minsCovered_i)}\right) \qquad (6)$$

Where:

- $\%Availability_j$ represents combined asset period coverage for month *j*
- $minsCovered_i$ represents the minutes covered by asset type *i* in month *j*
- $P(detection)_i$ represents the probability of detection calculated above for asset *i*
- $minsTotal_j$ represents the total number of minutes in month *j*
- The factor on the far right is the weighted, average POD

An example surface grid is shown below in Figure 5.



January 2013 - Law Enforcement Presence Probability Grid (each block is 10nm x 10nm)

	1	2	3	4	5	6	7	8	9	10
1	0.05	0.01	0.01	0.01	0.05	0.01	0.01	0.2	0.05	0.01
2	0.1	0.05	0.2	0.2	0.1	0.2	0.2	0.1	0.1	0.05
3	0.2	0.1	0.2	0.3	0.1	0.3	0.2	0.1	0.2	0.1
4	0.1	0.05	0.1	0.2	0.1	0.05	0.1	0.05	0.05	0.05
5	0.05	0.2	0.1	0.1	0.05	0.01	0.05	0.01	0.05	0.01

Notional Data

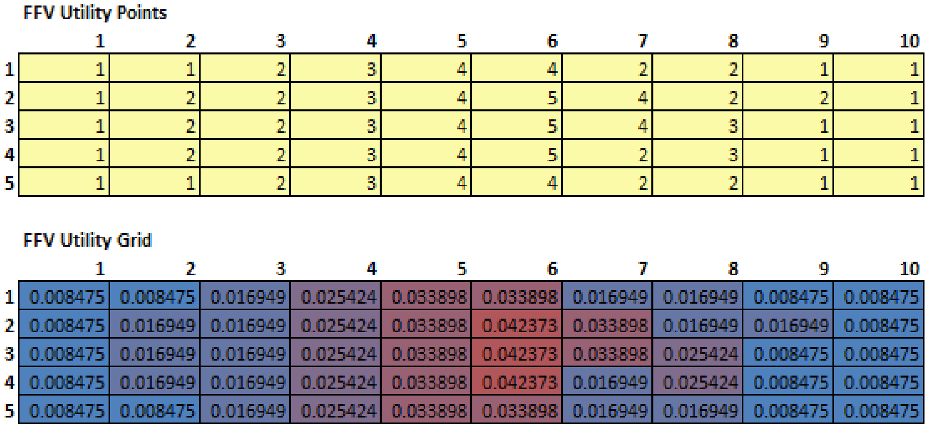
Figure 5. Notional LE Presence Probability Grid

FFV Utility Grid

The Utility Grid is extremely subjective, and can be edited easily by the model user. These probabilities are used in stochastically assigning the fishing locations for the FFVs. The grids work on a relative weighting system, then convert that weight into probabilities. Users should input the relative importance of each grid block, on whatever scale is easiest for the user to work with (for example, a 1-5 scale, or a 1-10 scale). The calculated weights for the grid blocks represents a probability mass function where

$$\sum_{i,j} p_{i,j} = 1 \qquad \forall\, i,j \text{ in the grid} \qquad (6)$$

Figure 5 below shows a notional utility grid and the corresponding points for that grid. The top image in Figure 6 shows weights assigned on a 1-5 scale, and the bottom image shows the utility grid.



FFV Utility Points

	1	2	3	4	5	6	7	8	9	10
1	1	1	2	3	4	4	2	2	1	1
2	1	2	2	3	4	5	4	2	2	1
3	1	2	2	3	4	5	4	3	1	1
4	1	2	2	3	4	5	2	3	1	1
5	1	1	2	3	4	4	2	2	1	1

FFV Utility Grid

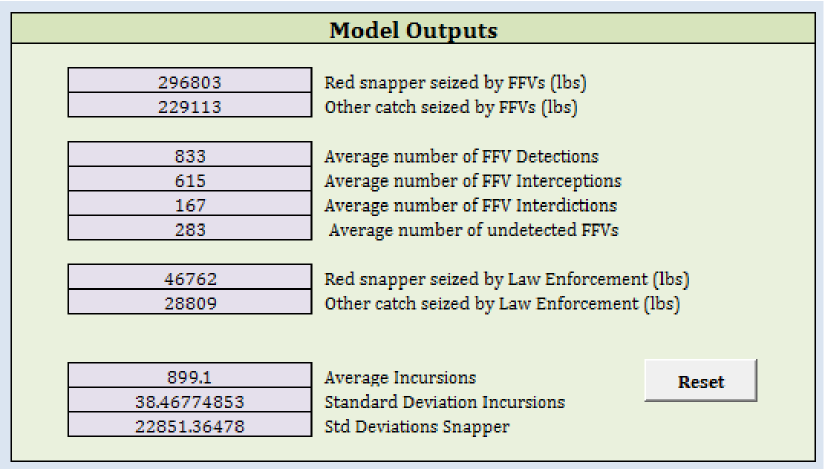
	1	2	3	4	5	6	7	8	9	10
1	0.008475	0.008475	0.016949	0.025424	0.033898	0.033898	0.016949	0.016949	0.008475	0.008475
2	0.008475	0.016949	0.016949	0.025424	0.033898	0.042373	0.033898	0.016949	0.016949	0.008475
3	0.008475	0.016949	0.016949	0.025424	0.033898	0.042373	0.033898	0.025424	0.008475	0.008475
4	0.008475	0.016949	0.016949	0.025424	0.033898	0.042373	0.016949	0.025424	0.008475	0.008475
5	0.008475	0.008475	0.016949	0.025424	0.033898	0.033898	0.016949	0.016949	0.008475	0.008475

Figure 6. Notional FFV Utility Grid Calculations

MODEL OUTPUTS

The model steps through one year at 30 minute intervals and tallies the red snapper and other catch seized by FFVs, red snapper and other catch seized by law enforcement, and undetected, detected, intercepted, and interdicted FFVs.

The model completes a user-specified number of replications and outputs the averages of the above values. It then calculates a 95% confidence interval around the average amount of red snapper, the species of interest to this study, impacted (seized either by FFVs or law enforcement). However, the run time is usually slightly under one second per replication (which varies based on the number of FFVs in the system), so large runs can take upwards of 10 minutes. Notional model outputs are displayed below in Figure 7. This model represents the first rigorous, quantitative estimate of the incursion rate and subsequent impact of these FFVs to the red snapper population.



Model Outputs

296803	Red snapper seized by FFVs (lbs)
229113	Other catch seized by FFVs (lbs)
833	Average number of FFV Detections
615	Average number of FFV Interceptions
167	Average number of FFV Interdictions
283	Average number of undetected FFVs
46762	Red snapper seized by Law Enforcement (lbs)
28809	Other catch seized by Law Enforcement (lbs)
899.1	Average Incursions
38.46774853	Standard Deviation Incursions
22851.36478	Std Deviations Snapper

Figure 7. Notional Model Outputs

LIMITATIONS

A model cannot perfectly represent reality; all models are subject to limitations. Listed below are limitations of this simulation model, grouped into several broad categories.

Law Enforcement Assets

This model only includes Coast Guard assets, categorized into three broad categories: cutters, smallboats, and aircraft. Probabilities of detection by law enforcement are generated based on this assumption. Other agency assets do contribute to detections of FFVs, but there was insufficient available data to incorporate these assets into the model.

FFVs

All FFVs are modeled as remaining with their gear when fishing. The model does not account for gear adrift or the potential adverse impact of gear adrift on marine life. There is evidence that FFVs using gillnets may set gear and retreat out of the EEZ to wait before coming back to collect their catch and gear, but there is currently not enough data to incorporate this behavior into the model. The implication of this behavior would be to lower the likelihood of discovery, which would increase the estimated overall number of incursions and impact.

Environmental Considerations

Weather is accounted for in law enforcement data, but not necessarily in modeled FFV decision making. This means that this model represents a best-case scenario for FFV activity (not factoring in severe weather systems or weather events that may influence or limit FFV movement). The nature of the exponential interarrival times does provide short periods with no FFVs and periods of more frequent arrivals, which may mimic a storm moving through and a subsequent surge of arrivals, without doing so directly. This is presumably offset by concurrent surges of Coast Guard assets. As both behaviors are averaged out over the course of the month within the model, this is a minimal cause for concern from a model validity standpoint.

FUTURE RESEARCH

This effort began in 2013 with the goal of estimating the impact these FFVs are having on the red snapper fishery. As this is such a new effort, we plan on continuing to improve and refine the model. Areas for future research include modeling gear adrift independently of the FFVs, modeling additional species (instead of just “red snapper” and “other”), and continuing to collect data to improve other listed model limitations. Another avenue which may be worth pursuing would be tracking where FFV detections, interceptions, and interdictions were occurring within the model and displaying this information as a heat map. This can be examined for trends and compared to the observed detections, interceptions, and interdictions.

Additionally, we intend to conduct an in-depth sensitivity analysis of the model, to explore the influence each of the inputs has on the model outputs of red snapper impacted, estimated incursions, and likelihood of discovery.

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