

RBM model description

The Relation-Based Model (RBM) purpose is to operationalise (a form of) process-relational (PR) thinking to serve as a thinking tool for process-relational thinking among social-ecological system (SES) researchers. The development of this model itself has been a 'Proof of concept'- exercise to see whether we actually represent process-relational thinking in a methodology that is entity-based (ABM). What aspects can we represent? Is it useful (did we learn anything new /different, if yes, what)? Together - a team of SES and PR scholars (Maja Schlüter, Tilman Hertz, Anja Klein, Nanda Wijermans and later on Jineth Berrio-Martinez) - we went on this journey together.

The target of the agent-based model is to show the emergence, change and disappearance of fishing assemblages (focusing on processes of self-organisation) in a Mexican fishery using a process-relational view.

Fishery in Process-Relational frame.

A fishery is an assemblage in which fishing can be enabled, fishing can occur, and fish can be bought/sold. These core *doings* - or sub-assemblages or capacities - maintain the assemblage. Each (sub)assemblage reflects different actualisations of constellations of **relations** and **elements** (buyers, fishers, fuel, permits, vessels and wind). The RBM reflects an artificial fishery in which agents (elements) and their links (relations) engage in (enabling) fishing, buying/selling.

What does the model do? | Process Description

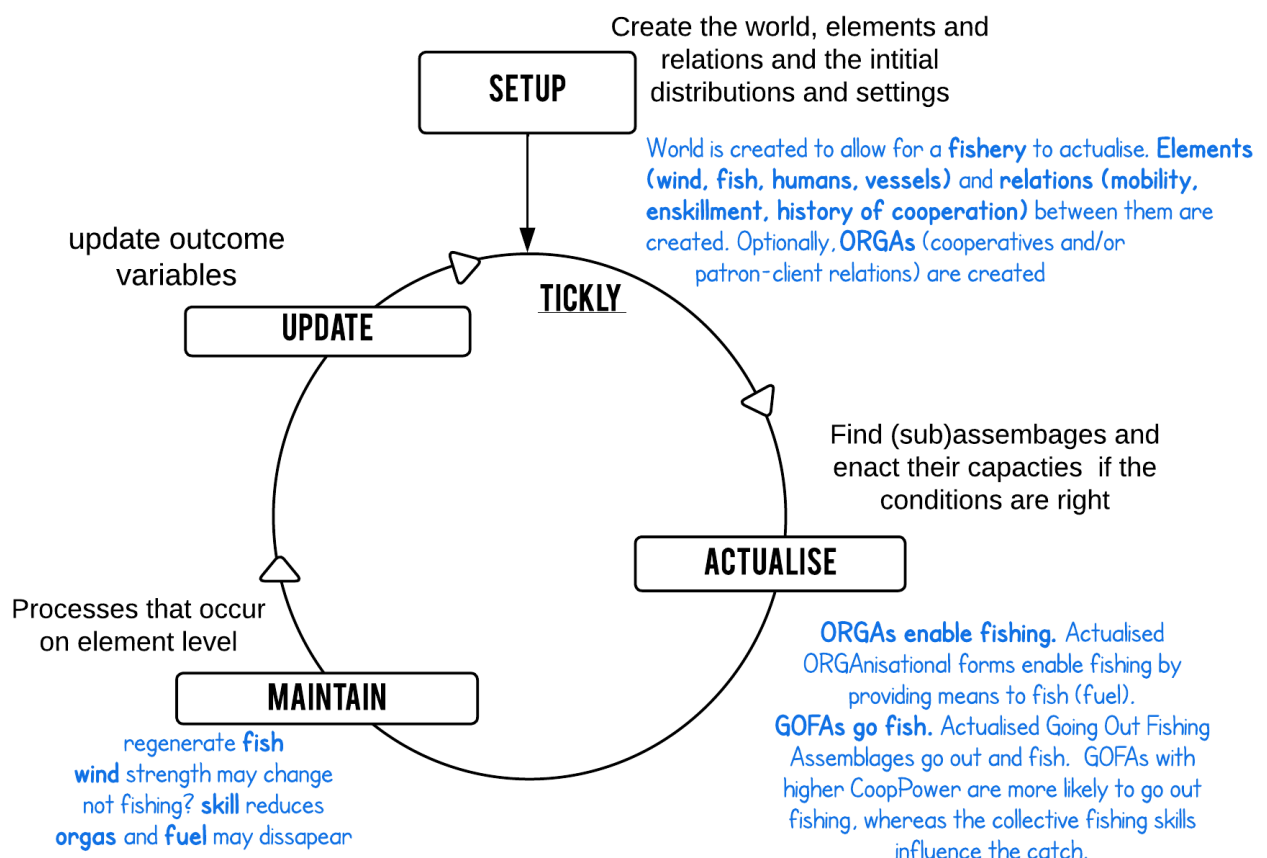


Fig. Overall processes in the RBM inspired by the Mexican Fisheries. Displays what happens generally and more specifically (in blue).

Table. Overview core processes in BeeCome

RB Process	sub-processes	Description
	setup	World is created to allow for a fishery to actualise. Elements (wind, fish, humans, vessels) and relations (mobility, enskillment, history of cooperation) between them are created. Optionally, ORGAs (cooperatives and/or patron-client relations) are created
actualise	go-enable-fishing	ORGAs enable fishing. Actualised ORGAnisational forms enable fishing by providing means to fish (fuel).
	go-out-and-fish	GOFAs go fish. Actualised Going Out Fishing Assemblages go out and fish. GOFAs with higher CoopPower are more likely to go out fishing, whereas the collective fishing skills influence the catch.
	go-sell	GOFAs and ORGAs sell and buy fish. The earning gets distributed among the crew (GOFA) and enter the ORGA
maintain		regenerate fish wind strength may change not fishing? skill reduces orgas and fuel may disappear
update		Update outcome variables

BeeCome (the RBM) aims to reflect a fishery assemblage. For a fishery assemblage to exist, several capacities need to actualise. In the RBM model we focus on the following 2 capacities:

- Enable fishing (~loan, access to market/sell fish, fuel, etc).
- Going out fishing

These capacities emerge from the sub-assemblages: ORGAs and GOFAs. That reflect doings that enable fishing (ORGA) and doings that go out and fish (GOFA). We will detail for each how the sub-assemblage is formalised and how their capacities come to be from the possibility space.

ORGA

The doing that enables fishing (fuel capacity) and provides for GOFAs to go out is visualised below.

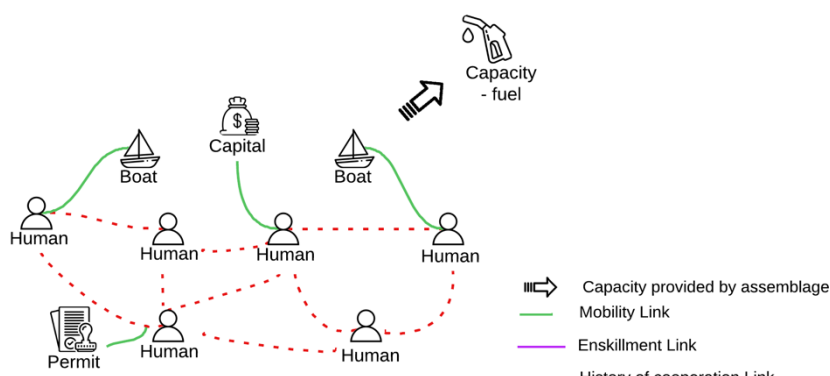


Figure 1. ORGA elements and relations. An organisational form can take different shapes. However it always needs to have multiple humans, capital and a permit for fishing. Some boats can be in reach, but is not a requirement for an ORGA to exist.

GOFA - Going Out Fishing Assemblage

A GOFA reflects an assemblage that can go out and catch fish. Figure 1 shows the elements and types of relations required to actually form a GOFA. Figure 2 shows the process from possible GOFAs to actualised GOFAs.

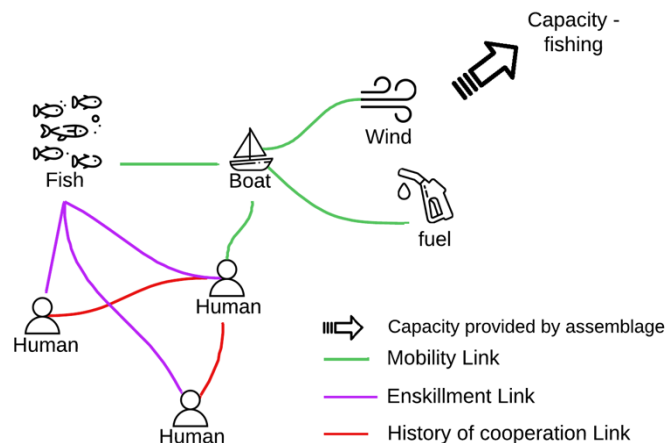


Figure 2. GOFA necessary elements and relations

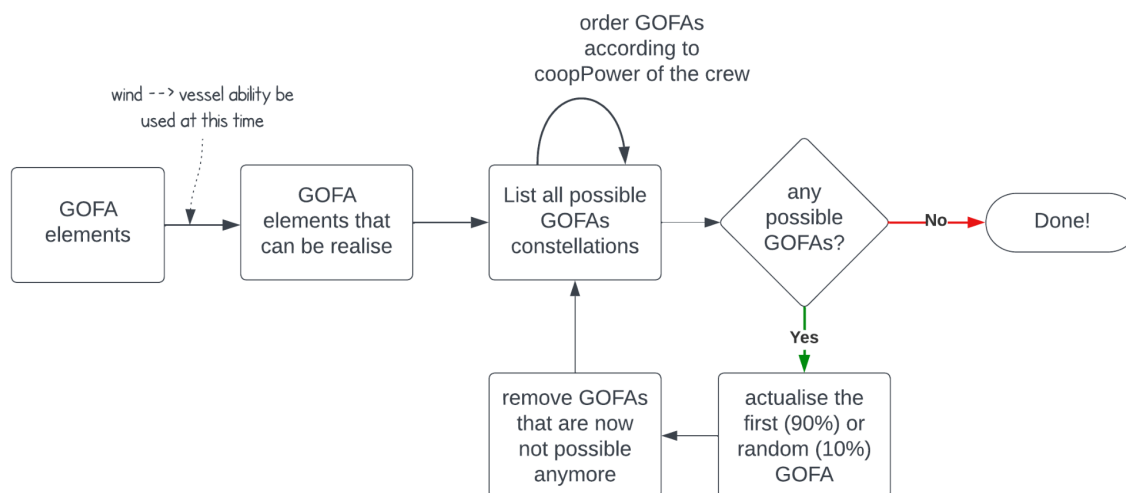


Figure 3. GOFA actualisation process. How the possibility space is changing (influence wind, ongoing actualising GOFAs) and how that over time leads to the realisation of some possible GOFAs.

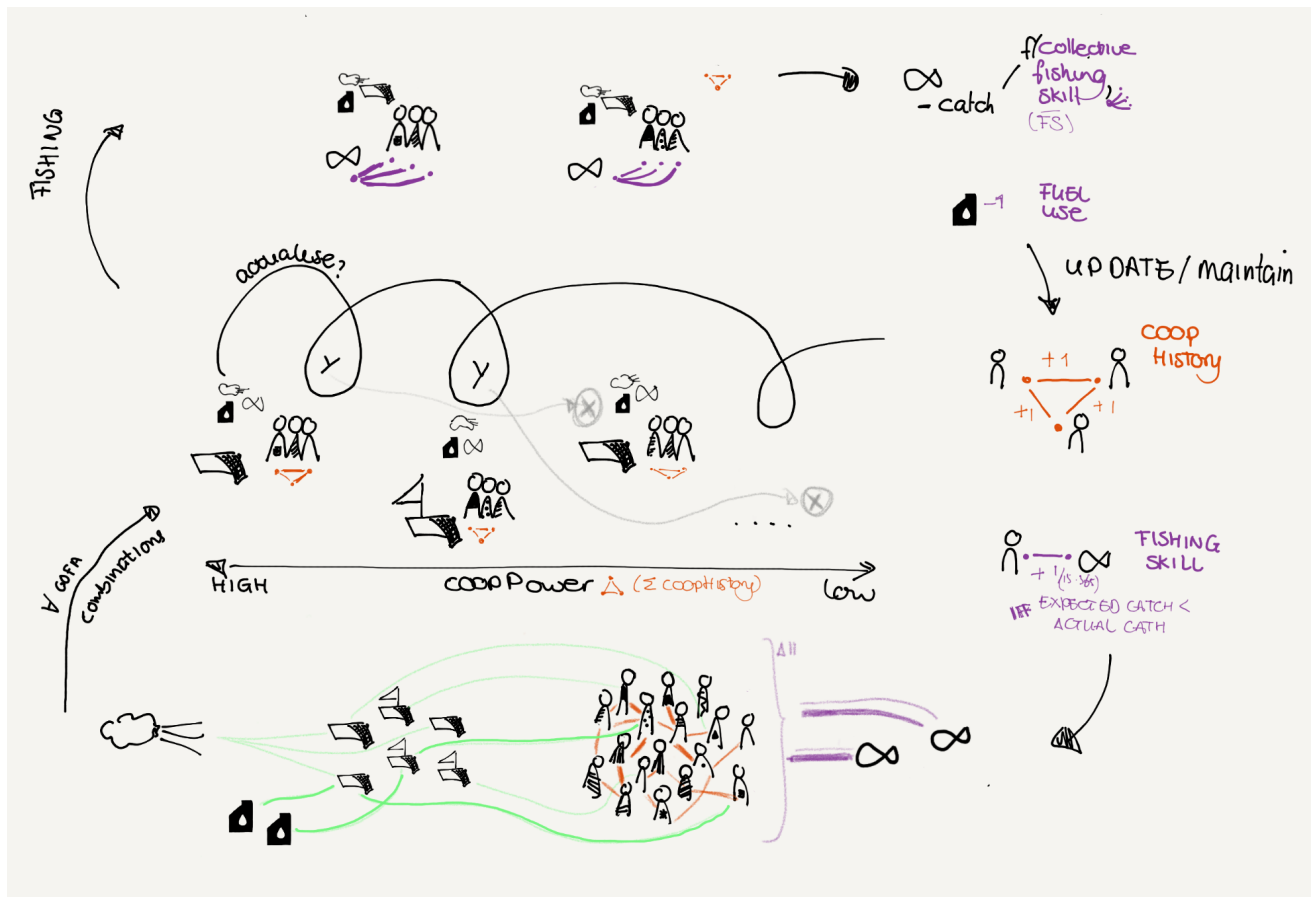


Fig. Going out fishing. what assemblage goes out fishing and the core processes underlying in influencing which assemblages in the possibility space get more to the foreground (cooperationHistory → coopPower)

Calibration Fishs stock

The fish stock purpose in the model is to reflect two fish stocks that regrow depending on how many fish there are. The actual amount of the stock nor how much is fished are in focus, however, we want to reflect the mechanisms. For this, we make use of the Gordon-Schaefer model¹ to reflect fish stock changes due to harvesting. We use amounts chosen or derived to follow a logical story: *We want to create a fishery that can sustain 10 vessels (5 small, 5 large) are present, while they continuously fish while having average fishing skills. Additionally, large vessels catch twice the amount as small vessels.*

Gordon-Schaefer Model

$$stock_{t+1} = stock_t \cdot growthRate \cdot stock_t(1 - stock_t / carcap) - harvesting$$

$$harvesting = (fskills \cdot effort \cdot stock_t)$$

(in bio economical fishery modelling jargon: $S_{t+1} = S_t r S_t(1 - S_t / K) - qES_t$)

Where the new fish stock ($stock_{t+1}$), is s function of the former fish stock ($stock_t$), fish growth rate ($growthRate$), fishing skills ($fskills$) and effort ($effort$).

With this formula one can determine the maximum sustainable yield (MSY), which is theoretically the largest yield that can be taken from a species' stock over an indefinite period. The MSY can be determined given the carrying capacity of an environment - the maximum population size of a biological species that can be sustained by that specific environment.

$$catch_msy = carcap \cdot growthRate / 4$$

(In fishery modelling jargon: $H_{msy} = K \cdot r / 4$).

$$stock_msy = carcap / 2$$

Deriving effort for large and small vessels

The effort - *time spent at sea* - for vessels is determined based on a theoretical number of vessels we set as the amount that should be able to sustainability fish. To be able to derive this amount, we made use of the Gordon-Schaefer logistic growth function and some anchor choices/assumptions:

```
CARCAP = 100 000      # carrying capacity of one stock
msyStock = CARCAP / 2 = 50 000      # msy stock
growthRate = 0.4
```

To derive the effort per vessel per day, we first calculate the total catch/harvest a year at MSY:

```
yearlyMSYcatch = CARCAP * growthRate / 4 = 100 000 * 0.4 / 4 = 10 000
dailyMSYcatch = yearlyMSYcatch / fishingDaysInAYear = 10 000 / 365 = 27.397
```

Since our fishery has vessels that are large or small, i.e. large ones fish 2x as much AND for the MSY amount we want the fishery (both stocks together) to be able to support 10 vessels (5 small and 5 large vessels). Given that $catch (=harvesting) = effort * fskill * stock$

We can derive the effort to be:

¹ Gordon-Schaefer is a density-dependent population growth function (logistic function)

```
yearlyMSYEffort = yearlyMSYcatch/(skill * msyStock)
                 = 10 000 / (0.5 * 50 000) = 0,4
yearlyMSYEffort = growthrate/(2 * fishing skills)
dailyMSYEffort = yearlyMSYEffort/365 = 0,00109589

dailyEffort = dailyMSYcatch / (skill * msyStock)
             = 27.397 / (0.5 * 50 000) = 0,0010958
```

Since our model has small and large vessels (half-half), of which the large vessels catch twice as much as the small vessels we then derive the daily effort for one small or large vessel as follows:

```
dailymsyEffort = (num-vessels/2 * smallVesselEffort) + 2 * (num-
vessels/2 * smallVesselEffort)
               = 3/2 * num-vessels * smallVesselEffort

smallVesselEffort = dailyEffort / (1.5 * numVessels)
                  = 0,00109589/ (1.5 * 5) = 0.00014612
largeVesselEffort = dailyEffort / (0.75 * numVessels)
                  = 0,00109589 / (0.75 * 5) = 0.00029224
```

Fish stock regeneration

Updates the stock following a logistic growth function - standard discrete population dynamics model (Verhulst 1935 - Schaefer model), mentioned above.

$$stock_{t+1} = stock_t \cdot growthRate \cdot stock_t(1 - stock_t / carcap) - harvesting$$
$$harvesting = (fskills \cdot effort \cdot stock_t)$$

This is implemented as follows, plus a minimum amount of fish necessary to be able to regenerate.

```
to regenerate
  let spawningStock 0.3 * myCARCAP ; minimal stock needed to regenerate
  let yearsCatch myStock_beginOfYear - myStock

  if (myStock > spawningStock) [
    set myStock myStock_beginOfYear + (myStock_beginOfYear * myGrowth-rate *
      (1 - (myStock_beginOfYear / myCARCAP))) - yearsCatch
  ]
end
```

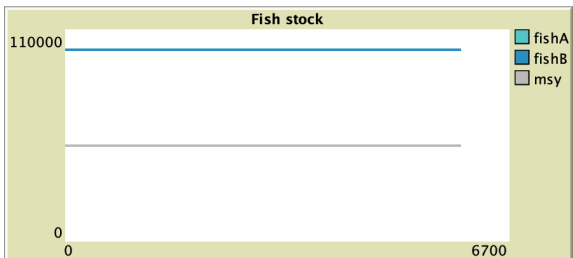
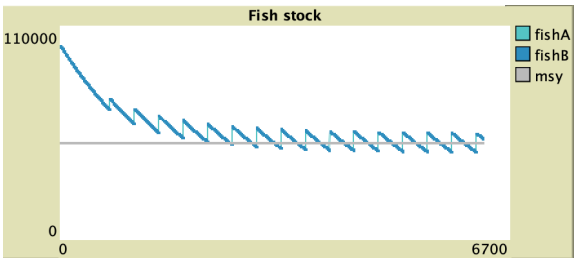
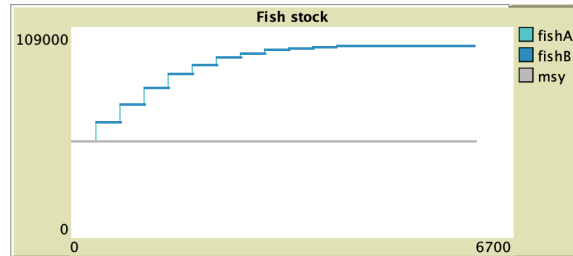
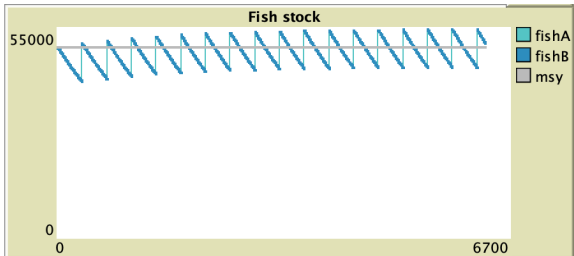
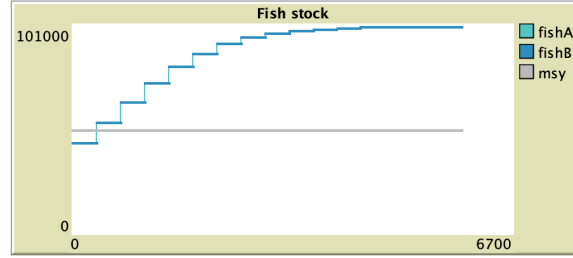
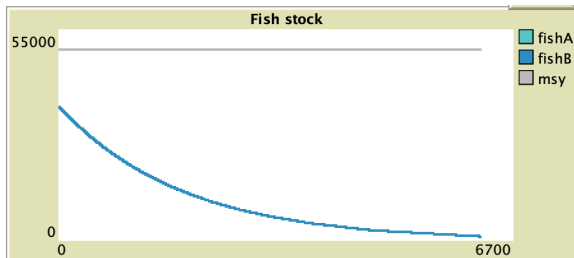
Fish stock verification

The fish stock behaves as expected when

1. If there is no fishing the stock depending on its initial value stays or moves to the carrying capacity | [VERIFIED \(see table 1 below\)](#).

- When there is msy fishing aligned, the stock should either stabilise around 0.5 CARCAP (msy), or when the initial stock is below MSY, the stock will be depleted **VERIFIED** (see table 1 below).
- A fishery with 10 vessels (fixed skill) yearly harvest amounts to 19775, which is close enough to the theoretical 20 000, given that we have 2 stocks here and which makes the stock-dependent catch slightly different. **VERIFIED**

Table 1. Verification fish stock mechanisms

Verification: NO fishing	Verification MSY fishing
Init Stocksize at CARCAP	
 ... stays at CARCAP	 ... goes down, but stabilised around CARCAP
Init Stocksize at MSY (0.5 CARCAP)	
 ...moves to CARCAP	 ... resides around MSY
Init Stocksize below MSY (0.35 CARCAP)	
 ...moves to CARCAP	 ... crashes the stock

References

Population dynamics & harvesting (Verhulst 1935, Clark, 2006a; Schaefer, 1954)

Calibration Fishing Economy

The Beecome model has a simple economy used to provide for means to fish (capital → fuel) and where earnings can be gained through selling fish (fish → earnings → capital). For the calibration the following choices were made:

- 1:2 in effort and fuel cost between large versus small boat
- 1 day of fishing should be able to provide enough earnings to go out fishing another time with an average catch.
- When an ORGA is accumulating a lot of capital the amount of cost should go up encapsulated in 10% of the income

Calibration process:

- We simplified the scene by fixing fishing skills to 0.5 for everyone (no change over time either).
- Now by running the model a few times one can see that average catch is: ~3 LargeBoat, ~1.5 smallBoat

In general the profit for an ORGA: $\text{profitOrga} = \max(0, \text{catch} * \text{fishPrice} - \text{FUEL-cost}) / 4$

Deriving the fishPrice: we set this to 4.5

Table. Overview constants and functions related to the fishing economy

	Variable	Formalisation / vessel
Boat / GOFA	Catch	$\text{Catch} = \text{collective skill} * \text{effort} * \text{stock}$
	Profit	$\text{earnings} = \text{catch} * \text{fish_price}$ $\text{Profit} = \text{earnings} - \text{FUEL_COST}$
ORGA	earnings capital	$\text{earnings} = \frac{1}{4} \text{profit (gofa/vessel)}$ $\text{Capital} += \text{earnings}$
Fisher	earnings capital	$\text{earnings} = \frac{1}{4} \text{profit}$ $\text{capital} += \text{earnings}$
<i>Constants</i> FUEL_COST {3,6} {S,L} FISH_PRICE 4.5 $\text{maxCatch-smallBoat} = \text{EFFORT-smallBoat} * \text{msyStock} = 7.305936073059359$ $\text{maxCatch-largeBoat} = \text{EFFORT-largeBoat} * \text{msyStock} = 14.611872146118719$		