Supplementary information

Table of content

FIBE Model description

Description of the FIBE model following the ODD+D protocol (Müller et al, 2013, Grimm et al. 2010, 2006).

Outline		Guiding questions	
I) Overview	I.i Purpose	I.i.a What is the purpose of the study?	**Study purpose:** To advance the incorporation and understanding of human behaviour (diversity) in fisheries research and management. In particular focusing on insights from social (fishery) science of fisher behaviour. **Model target:** to represent diversity of fisher behaviours as observed following fisher style descriptions reflecting the trawlers, coastal and archipelago fishing styles that differentiates why when and how they fish (Boonstra & Hentati-Sundberg 2016).
		I.ii.b For whom is the model designed?	Researchers involved in fisheries, social-ecological systems and/or policy designers that are interested in human behaviour in natural resource management.
	I.ii Entities, state variables, and scales	I.ii.a What kinds of entities are in the model?	<u>Environment (fish & sea)</u>: fish populations, location-based resource. <u>Agents</u>: fishers (the resource users).

		I.ii.b By what attributes (i.e. state variables and parameters) are these entities characterized?	Environment: fish-stock, carrying-capacity, growth-rate. Agents: myStyle, memory (of goodSpots, profit, catch), catch-ability, cost (existence, equipment, travel), regionPref, catch, profit, goals, satisfaction, colleagues. Agent attributes are reflected through their (fishing) style. It affects if they fish, what region(s) they fish in, how able they are to find the fish, the amount they can fish given their gear and vessel; the cost and sources of income they have. See Figure 2 in the paper.
		I.ii.c What are the exogenous factors / drivers of the model?	Weather, fuel-subsidy
		I.ii.d If applicable, how is space included in the model?	The **sea** reflects a space with various fishing grounds that differ in terms of fish abundance and remoteness. The sea is represented as a grid (50x56), where each grid cell, i.e. patch, represents a fish stock (see also B2 Calibration).
		I.ii.e What are the temporal and spatial resolutions and extents of the model?	Temporal: *daily* timesteps – agents decide and behave every tick; the fish follows a *yearly* reproduction cycle. Spatial: The patches are grouped into four regions (A, B, C, D), representing the distances from the home port of the fishers. Region A is close to the coast, region B is further away and regions C and D are far offshore. (See Fig B2)
	I.iii Process overview and scheduling	I.iii.a What entity does what, and in what order?	Each time step: · **Decide:** fisher agents decide whether to go fishing 'decide-fishOrNot'; those that will fish decide where to fish 'decide-fishSpot' · **Execute-decision**: fisher agents execute to 'go-fish' or do nothing. The individual catch and stock on patches are directly adapted

			· **Update:** fisher's memory. Every year: · The fish stocks in each patch grow. 'update-stock'. See Fig B1
II) **Design Concepts**	**II.i Theoretical and Empirical Background**	II.i.a Which general concepts, theories or hypotheses are underlying the model's design at the system level or at the level(s) of the submodel**(s) (apart from the decision model)?** What is the link to complexity and the purpose of the model?	Population dynamics & harvesting (Verhulst 1935, Clark, 2006a; Schaefer, 1954) Common pool resource theory Fishery as a social-ecological system Design is empirically based – see Table B1b on the formalisation a for details.
		II.i.b On what assumptions is/are the agents' decision model(s) based?	The model reflects the a) theoretical optimal reasoning assumption, b) assumptions of falling the fishing styles narratives, assuming this classification
		II.i.c Why is a/are certain decision model(s) chosen?	Based on an empirical study of fishing styles in the Swedish Baltic cod fishery (Boonstra & Hentati-Sundberg, 2016)
		II.i.d If the model / a submodel (e.g. the decision model) is based on empirical data, where does the data come from?	Indirect on the data collected to support the fishing styles categorisation published in Boonstra & Hentati-Sundberg, 2016)
		II.i.e At which level of	Group and individual level.

		aggregation were the data available?	
	II.ii Individual Decision Making	**II.ii.a What are the subjects and objects of decision-making? On which level of aggregation is decision-making modeled? Are multiple levels of decision making included?**	Subjects of decision-making are the agent fishers. Object are two choices that fisher agents make: 1) the whether the go fishing or not and 2) where to fish. Decision making is modelled at the level of the individual, however may be influenced by multiple levels (i.e. the fish stock (perception), seeing where other fish)
		II.ii.b What is the basic rationality behind agents' decision-making in the model? Do agents pursue an explicit objective or have other success criteria?	Depending on the fishing style the fishers pursue and the choice at hand: 1. Whether to fish: • Maximising Growth (profit) - *Trawler* • Maximising Growth (profit) and home time - *Coastal* • Satisficing the amount they fish with what they need and avoiding scarcity – *Archipelago* 2. Where to fish: based on one's own knowledge (individual) or on what others do (social)
		II.ii.c How do agents make their decisions?	See table B3 for the decision trees. In words: A) **Decision 1: To fish or not** · A *trawler fisher* agent only goes fishing if it expects an economic gain. The expected catch >= cost. · A *coastal fisher* agent decides to fish when it expects a profit and its current satisfaction with being home is higher than the satisfaction of growth (profit). · An *archipelago fisher* agent goes fishing when it needs to, i.e. when it has not caught enough in the last week or has negative capital. If it thinks the fish is scarce it can decide against fishing and instead reduce living expenses.

			For both the archipelago and coastal they cannot go out when the weather is bad. B) **Decision 2: Where to fish**: Fishing location is based on where the agents think the fish is. They make use of their knowledge (memory) of good spots (random) and for both the *trawler* and the *coastal* fisher agents make use of their colleagues' whereabouts to infer where good spots are.
		II.ii.d Do the agents adapt their behavior to changing endogenous and exogenous state variables? And if yes, how?	Yes, they change due to both exogenous and endogenous variables. <u>Exogenously</u>, when the weather is bad both coastals and archipelagos do not go out fishing. Based on the fuel-subsidy scenario they might choose to stop/continue fishing. <u>Endogenously</u>, based on the satisfaction level of their goals they decide when to go fishing and when not, also the location depends on their memory of good spots that is updated every time a good spot has been visited as well as due to seeing others which depends where most other experts are (group influence – meso level).
		II.ii.e Do social norms or cultural values play a role in the decision-making process?	Only for the value rational where its conservation value could be considered a cultural value. Deciding where to fish based on what (most) others do can be considered a social norm, however the agents have no internal representation of norms.
		II.ii.f Do spatial aspects play a role in the decision process?	No – indirectly in terms of what they remember being a good fishing spot (good catch or profit in the past).
		II.ii.g Do temporal aspects play a role in the decision process?	No – indirectly, their memory allows them to include experiences from the past in their decision.

		II.ii.h To which extent and how is uncertainty included in the agents' decision rules?	There is always a probability that they go to a fishing spot near the spot from their memory.
	II.iii Learning	II.iii.a Is individual learning included in the decision process? How do individuals change their decision rules over time as consequence of their experience?	Learning takes place in the form of adding experiences to memory, which in turn affect the future choices of whether to fish (memory of catch/profit) or where to fish (memory of good spots). The decision rules themselves stay the same.
		II.iii.b Is collective learning implemented in the model?	No.
	II.iv Individual Sensing	II.iv.a What **endogenous** and **exogenous** state variables are individuals assumed to sense and consider in their decisions? **Is the sensing process erroneous?**	Agent only obtain knowledge from their direct interaction with their environment, either local perception, in which the reach of perception is increased with help of technology if they have that. Only exception is for the decision where to fish that involves social influence – expert, this assumes that all agents know the fish-finding expertise of each other.
		II.iv.b What state variables of which other individuals can an individual perceive? **Is the sensing process erroneous?**	No.

		II.iv.c What is the spatial scale of sensing?	Patch the agent is on. For the trawler due to the technology this is also includes the 8 neighbouring patches.
		II.iv.d Are the mechanisms by which agents obtain information modeled explicitly, or are individuals simply assumed to know these variables?	No.
		II.iv.e Are costs for cognition and costs for gathering information included in the model?	No.
	II.v Individual Prediction	**II.v.a Which data uses the agent to predict future conditions?**	They do not really predict, they just make 'implicit expectations' based on past experiences.
		II.v.b What internal models are agents assumed to use to estimate future conditions or consequences of their decisions?	They implicitly assume that future catch/profit can be expected from past catch/profit. This affects their decision making.
		II.v.c Might agents be erroneous in the prediction process, and how is it implemented?	Yes, the past is not a necessarily a predictor of the future.
	II.vi Interaction	II.vi.a Are interactions	The direct interaction is between the fisher agents and the fish at a certain

		among agents and entities assumed as direct or indirect?	location. Implicit interaction is when observing the location of other fishers to decide where to fish (coastal, trawler)
		II.vi.b On what do the interactions depend?	Choices of the agents (if they decide not to go fishing there is not fisher-fish interaction, if a fisher agent decides to fish at spot x, this determines where there will be an interaction.
		II.vi.c If the interactions involve communication, how are such communications represented?	No (verbal) communication.
		II.vi.d If a coordination network exists, how does it affect the agent behaviour? Is the structure of the network imposed or emergent?	-
	II.vii Collectives	II.vii.a Do the individuals form or belong to aggregations that affect, and are affected by, the individuals? Are these aggregations imposed by the modeller or do they emerge during the simulation?	-
		II.vii.b How are collectives represented?	-

	II.viii Heterogeneity	**II.viii.a Are the agents heterogeneous? If yes, which state variables and/or processes differ between the agents?**	The agent are heterogenous mainly due to: myStyle {archipelago, coastal, trawler}, see Fig 2 in the paper As it affects the settings of multiple attributes. Within a style they just differ slightly: · InitialKnowledge distribution {low, medium,high} initialisation of the memory and making some more attractive to follow than others when deciding on f fishing spot. · Memory is unique for each agent – updated during the simulation
		II.viii.b Are the agents heterogeneous in their decision-making? If yes, which decision models or decision objects differ between the agents?	The decision processes differ for the agents with different fishing styles. Within a style the decision-making rules are the same.
	II.ix Stochasticity	II.ix.a What processes (including initialization) are modeled by assuming they are random or partly random?	There are various sources of stochasticity in the model. In the initialisation of agent attributes and knowledge: · **init-knowledge-distr** - Represents a range that can is considered high, medium, medium-high · **init-memory-goodSpots** - which good fishing locations are part of the knowledge of the agent initially · memory_length During the run: · **bad_weather_probabilty:** whether there is bad weather and archipelago and coastal fishers cannot go out fishing (percentage) - *small and constant stochastic role -* · Region preference (coastal and trawler) in the first month of each year is random (**optimise-lifestyle-and-growth** - coastal; **optimise-growth** - trawler) - big but restricted

			in time stochastic role. · **decide-fishSpot** - for the coastal and trawler who are mainly determining their fishing location based on where other fish (social influence) there is always a small change (20%) to follow ones own knowledge · **get-fishSpot-knowledge -** when deciding on a fish spot based on knowledge the fisher will pick a random spot in the preferred region of fishing (always for the archipelago, 20% or the first fisher of the coastal and trawler fishers). Furthermore, there is always a 50% chance to go to one of the neighbouring spots of the fish spot in mind - *large stochastic role for the archipelago, small for the coastal and trawler* · **go-fish** (for coastal) - coastal fishes over 2 patches, the 'other patch' is randomly picked from the neighbouring patches of the targeted patch · **get-fishSpot-expertise** (coastal & trawler) goes to one-of the fishers with that are considered expert
	II.x Observation	II.x.a What data are collected from the ABM for testing, understanding, and analyzing it, and how and when are they collected?	See Table B5 – main outcome variables For understanding why, looking under the hood (meso, micro): · To be able to explain the reasons why fishers do not go out fishing at certain moment we kept track of every time step the number of agents: notFishing, numLayingLow, numThinkFishIsScarce, numSatisfied, numLowCapital, badWeather, numExpectNoProfit, numWantToBeHome · To be able to assess whether the fisher agents were able to find the right spots to fish: numFishersWgoodSpot and percFishersWgoodSpot
		II.x.b What key results, outputs	See results paper.

		or characteristics of the model are emerging from the individuals? (Emergence)	
III) Details	**II.i Implementation Details**	**III.i.a How has the model been implemented?**	NetLogo 6.0.3
		III.i.b Is the model accessible and if so where?	The model will be made publicly available on COMSES on acceptance (www.comses.org).
	III.ii Initialization	III.ii.a What is the initial state of the model world, i.e. at time t=0 of a simulation run?	Stock is at half carrying capacity. The indicated number of fisher agents created and initialised according to their fishing style and non-style related variables: memory-length and population of their memory of good spots.
		III.ii.b Is initialization always the same, or is it allowed to vary among simulations?	Some variables are the same, the fish population variables - carrying capacity and growth rate -and the agent variables related to costs and the maximum fish they are able to given their gear (see B2. calibration) Other variables are initialised based on the experimental design, these included the fishing styles and the fuel subsidy levels where varied.
		III.ii.c Are the initial values chosen arbitrarily or based on data?	The choice for the values is based on our theoretical research questions. The calibration aimed to reflected the empirical based relations, e.g. cost for trawler is X times higher than archipelago.
	III.iii Input Data	III.iii.a Does the model use input from external sources such as data files or other models to represent processes that change over	No.

		time?	
	III.iv Submodels	III.iv.a What, in detail, are the submodels that represent the processes listed in 'Process overview and scheduling'?	See table B4.
		III.iv.b What are the model parameters, their dimensions and reference values?	Table B2 and section B2 calibration.
		III.iv.c How were submodels designed or chosen, and how were they parameterized and then tested?	Fish stock dynamics is a simple, but spatial explicit logistic growth function. It is a standard fish dynamics function made spatial to be able to see the influence of spatiality, but also in future to explore spatial regulations, e.g. MPAs. See section B2 Calibration for details. Fishing styles: *the choice* to embed empirical social science-based insights on fisher behavioural (assumptions) this general description allows for exploring the question 'what the role of behavioural assumptions are. (Boonstra & Hentati-Sundberg 2016). *The design* was informed by the paper of the fishing styles as well as interactions with the creators of the fishing styles (co-authors of the paper). The testing was done based using a Pattern oriented approach (POM), see section B3 - Verification & Validation
Boonstra, W. J., & Hentati-Sundberg, J. (2016). Classifying fishers' behaviour. An invitation to fishing styles. *Fish and Fisheries*, *17*(1), 78-100.			

Table B1b. Overview of main variables used in FIBE.

	Name	Definition	Value range

Agent	**myStyle**	represents the style the fisher is displaying in the initialisation it supports setup, during the simulation it characterises the settings	{trawler, coastal, archipelago }
	Region	The region(s) a fishing agent can fish in determined by myStyle.	{A,B,C,D}
	Memory	Memory-of-goodSpots knowledge of good spots to fish Memory-catch: memory of catches, profit and goodSpots. All memories are limited by memory-length	Array with patches
	Knowledge	Representing the initial level of knowledge of good fishing grounds in memory of good spots.	{low, medium, high}
	Catchability	The maximum or ability of a fisher agent to catch a certain amount of fish when fishing at a good spot, given its gear (and implicitly the time it spends). Note this is not following the definition of catchability coefficient in fishery biology.	{low, medium, high}
	Cost	The cost a fisher agent has representing the sum existence, travel and equipment cost.	0.0-1.0
	Technology	Boolean indicating the fisher has technology (e.g. radar) to scan for fish in its vicinity, i.e. enables to find fish	True/False
	Colleagues	Boolean indicating the fisher has colleagues that it can observe.	True/False
	Partner	Boolean indicating the fisher has a partner it can rely on for income	True/False
Sea - patches	**Fish-stock**	Indicates the number of fish present in this patch	[0-CARCAP/numPatches]
	Density	Indicates how much fish a patch can provide for (region depended), see calibration for more details.	{low, medium,high}
	Growth-rate	Fish growth on this patch	1
Global	**badWeather**	Boolean to indicate bad weather (archipelago and coastal cannot go out)	True/False

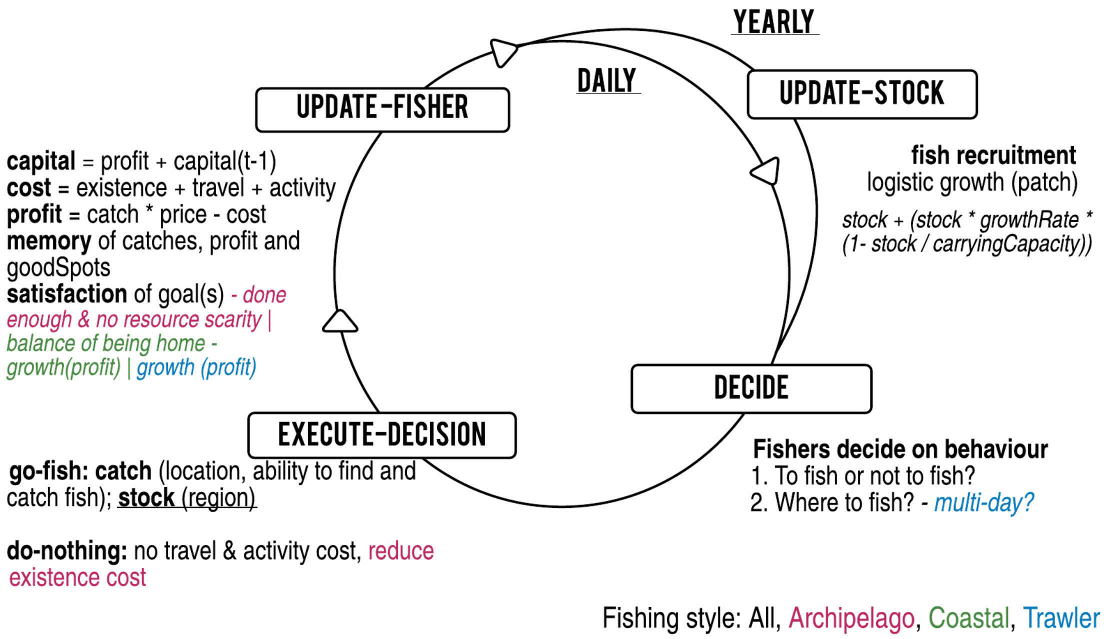
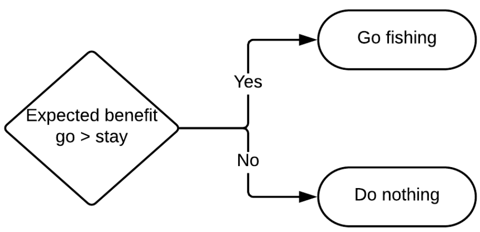


Figure B1b. Process diagram FIBE. The colours reflect specifics for each fishing style.

Table B1c: Decision trees representing each choice specification for the fisher agents, i.e. decision models.

Decision I: To fish or not?

Trawler
Bounded rational-profit-maximiser

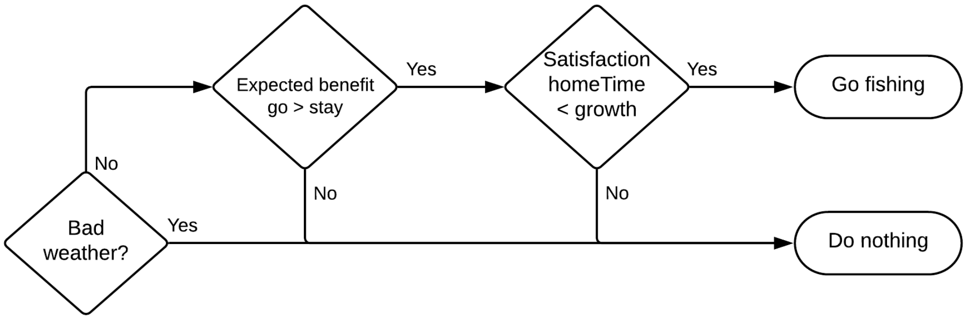


Perceptions:

Expected benefit (go) = (expected catch * price) - expected-cost
Expected cost (go) = existence (+ travel + equipment)
Expected catch } = catchability *at the beginning of the season*
= max (past catch * of each region) *rest of the time*

Expected benefit (stay) = expected-cost
Expected cost (stay) = existence

Coastal
Bounded rational-values-maximiser



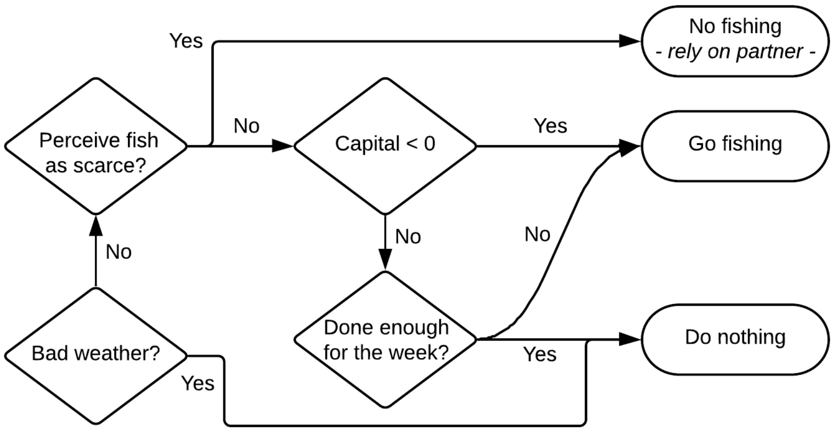
Perceptions:

Expected benefit (go) = (expected catch * price) - expected-cost
Expected cost (go) = existence (+ travel + equipment)
Expected catch } = catchability *at the beginning of the season*
= max (past catch of each region) *rest of the time*
Expected benefit (stay) = expected-cost
Expected cost (stay) = existence

Need satisfaction:

Home-time =f(time-away-from-home)
Profit growth = f(capital (t-1,t0))

Archipelago
Bounded rational-values-satisficer



Perceptions:

Fish scarcity } Scarce: lowCatchCount > 75% #goodspots in memory AND no catch for a year
Not scarce beginning of the season or lowCatchCount < 75%

Done enough? } Profit-current-week > cost-5day-workweek

Note: No fishing means that one relies on income from a partner or other livelihoods.

Decision II: Where to fish?

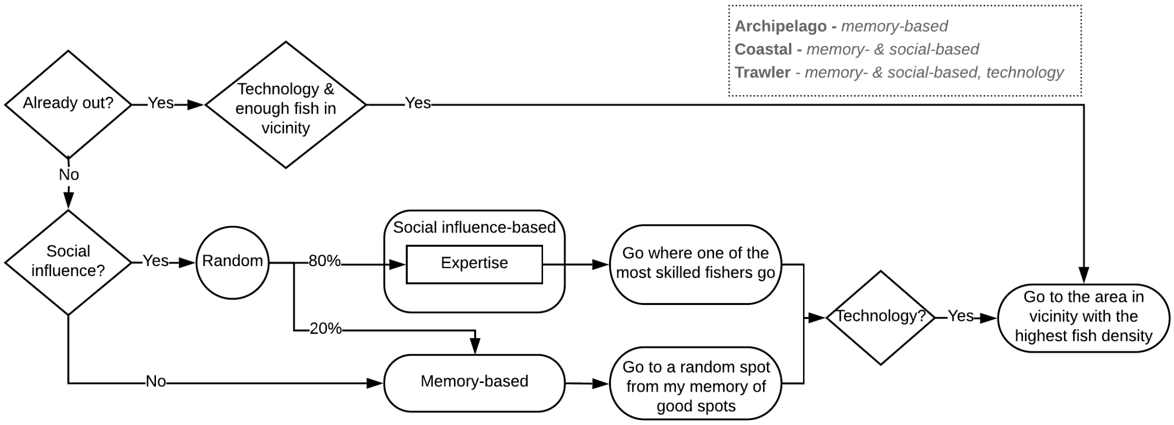

Archipelago - memory-based
Coastal - memory- & social-based
Trawler - memory- & social-based, technology
Already out?
Yes
Technology & enough fish in vicinity
Yes
No
Social influence?
Yes
Random
80%
20%
Social influence-based
Expertise
Go where one of the most skilled fishers go
No
Memory-based
Go to a random spot from my memory of good spots
Technology?
Yes
Go to the area in vicinity with the highest fish density

Table B1d. Details of the Implementation of the model processes.

Process	Variables involved	Description	Formalisation
A. Decide ***- 1. whether - 2. where***	catch profit capital satisfaction badWeather goodSpotsMemory	**Decide-fishOrNot()** A *trawler fisher* agent only goes fishing if it expects an economic return. This means that the expected catch should at least cover the operating costs for the trawler fisher agent to decide to go out and fish. At sea, it bases its catch expectation on the fish it can perceive nearby (e.g. using sonar technology in the real-world). A *coastal fisher* agent decides to go fishing when the trade-off between expected profit and time not spent at home is not too big. This means that if a coastal fisher agent has satisfied its preference for staying home and expects a profit, it will go out fishing. Coastal fisher agents stay at home when staying home preference is not satisfied or they expect no profit. An *archipelago fisher* agent goes out fishing when it needs to, i.e. when it has not caught enough in the previous week or in the situation of having negative capital. In addition, if the archipelago fisher thinks the fish is scarce, it can decide against fishing and instead reduce living expenses **Decide-fishSpot()** The second choice 'where to fish?' is influenced by where the fisher expects the fish to be within their reach. Fishers use their memory of good spots to help them decide where to go. In addition, both *trawler* and *coastal* fisher agents use their colleagues' whereabouts to inform their target location choice. The functional representation of the choice where to fish is rule-based (heuristic), the fisher will go either informed by its own good experiences (memory of good spots) or by what others do (social influence).	See decision trees in Table B1c.
B. Execute	Stock catch capital	The fisher agents execute to 'go-fish' or do nothing. The individual catch and stock on patches are directly adapted. (See Fig B1c and Movie B1 for examples of this fishing activity in space)	Stock = stock – catch Profit = catch * fish-price - cost

C. Update-Fisher	goodSpotsMemory
	catch
		If the fisher agent went fishing, it updates it's memory by evaluating how good or bad the fishing spot was based on the catch. Depending on this evaluation the spot is added or removed from memory.	If (catch < catchability)
			THEN
			remove from memory
			ELSE
			Add to memory + shuffle memory

D. Update-stock	Fish-stock	Once a year the fish stock is updated. The population growth is represented by a standard discrete logistic growth model with growth rate and carrying capacity.	FOR each patch [regenAmount = round(fish-stock * growth-rate * (1 - (fish-stock / PATCH-CARRYING-CAPACITY))) fish-stock = fish-stock + regenAmount

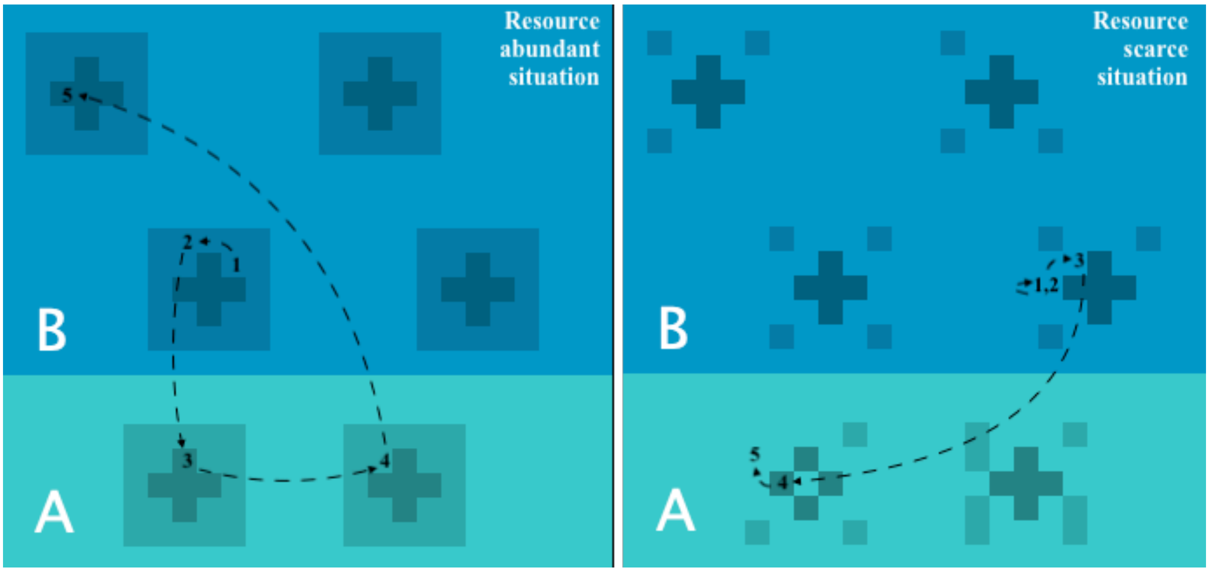
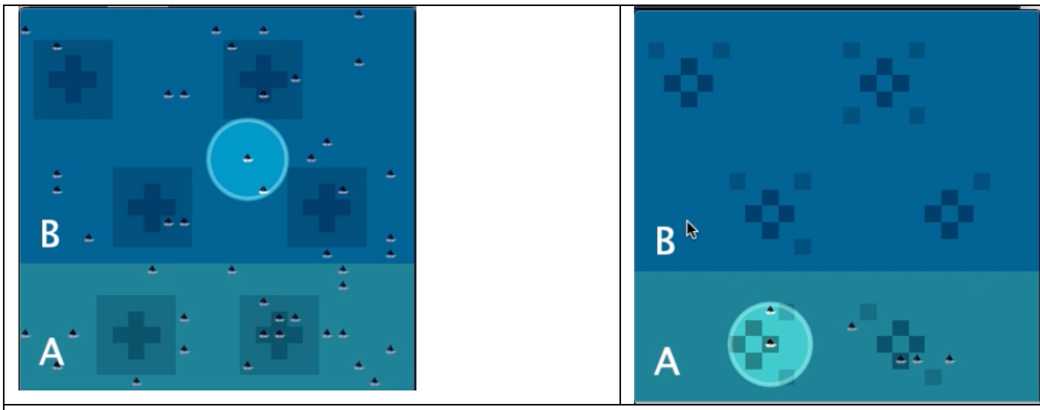


Figure B1c. Example of a coastal fisher fishing for 5 timesteps in space in a resource abundant (left) and scarce (right situation)



Movies B1. Overtime example of fishing activity in space for coastal fisher agents while being in a resource abundant situation (<u>Left,</u> 5 years) and later in a resource scarce situation (<u>Right</u>, 20 years).

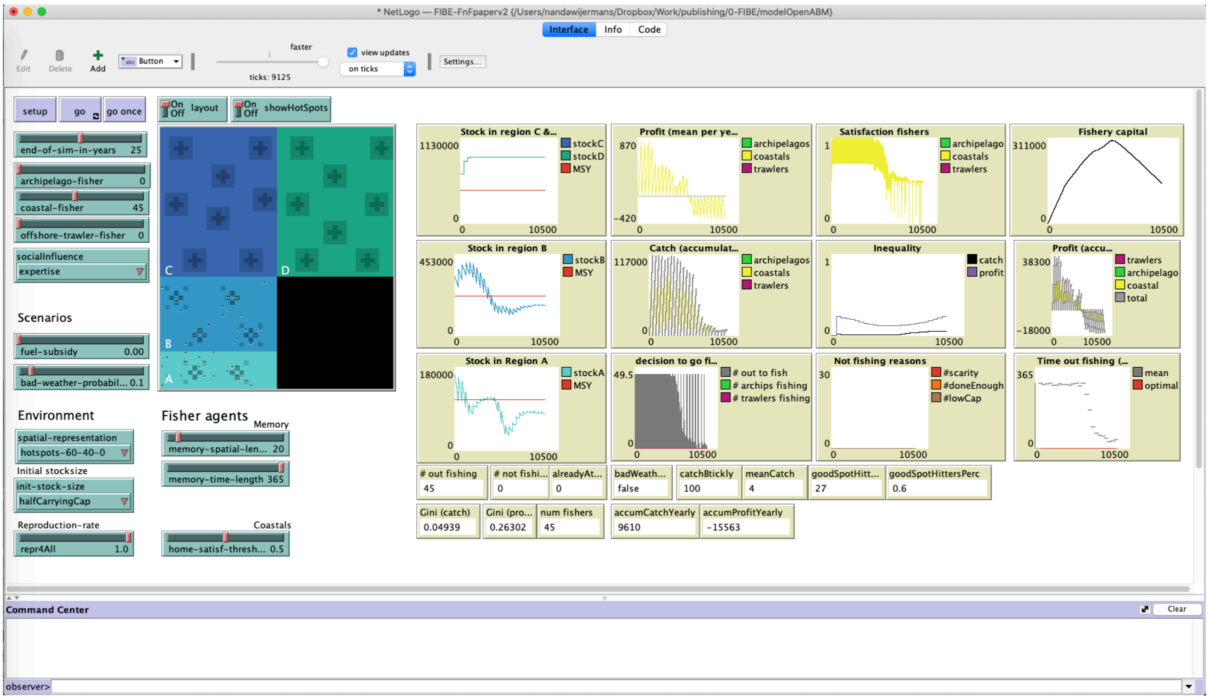


Figure B1d. Screenshot of FIBE (agent-based model in NetLogo)

Table B1. Outcome variables used in FIBE experiments

Outcome variable	Description	Variable (in NetLogo / R)	Formalised description (in NetLogo / R)	Levels (measured) System scale	Time scale
stockRatioMSY	Relative difference of stock with msy stock allowing for comparing the different fishing styles outcomes with each other.	stockRatioOM	stock / msy_stock_Fstyle	Fishery level	yearly
msyStock	Benchmark stock to compare the outcome stock of the fishing styles fishing. Reflects the fishing stock being at half carrying capacity (K/2), i.e. the stock size that has the highest reproductive rate, i.e. where the catch is theoretically the highest.	MSY_STOCK_ARCHIP	(sum [carcap] of region A) / 2 = 109500	Fishery level	yearly
		MSY_STOCK_COASTAL	(sum [carcap] of region A + B) / 2 = 328500		
		MSY_STOCK_TRAWLER	(sum [carcap] of region B+ C + D) / 2 =1095000		
Stock	The stock size for each fishing style, which corresponds to the region(s) in which each style fishes. Archipelago – stock in A Coastal – stock in A, B Trawler – stock in B, C, D	stock (archipelago)	sum [fish-stock] of regionA	Fishery level	Tickly & yearly
		stock (coastal)	sum [fish-stock] of (regionB + regionC)		
		stock (trawler)	sum [fish-stock] of (regionB + regionC + regionD)		
ProfitRatioMSY	Relative difference of profit with MSY profit, allowing for comparing the different fishing styles outcomes with each other	profitRatioMSY	profit / msyProfit	Fishery level	yearly
msyProfit	Benchmark profit to compare the profit of fishing style fishing, i.e. the income under MSY circumstances. Based on a yearly fishing pressure generated by the # fishers a fishery at MSY sustain (30 Archipelagos, 45 Coastals, 36	MSY_PROFIT_ARCHIP MSY_PROFIT_COASTAL MSY_PROFIT_TRAWLER	msyCatch * price –cost ={54750, 164250, 547500}	Fishery level	yearly

	Trawlers) – fishing every day - reduced by the cost of going out fishing. (price =1)				
msyCatch	Catch when at the MSY stock, i.e. the newly produced stock, by reproduction given a stock that is at half carrying capacity. catch = msyStock * growth-rate * (1- (msyStock / carcap))	MSY_CATCH_ARCHIP MSY_CATCH_COASTAL MSY_CATCH_TRAWLER	msyStock*1*(1- 0.5) = ½ msyStock_fishingStyle ={547500, 164250, 54750}	Fishery level	
Profit	The income of the fisher (catch*price – cost) Price plays no role is thus set to 1,	accumProfitYearly	sum [accumProfitThisYear] of fishers	Fishery level	Yearly
Catch	The catch of fishers related to a particular fishing style (A,C,T)	accumCatchYearly	sum [accumCatchThisYear] of fishers	Fishery level	Yearly
Satisfaction	The satisfaction of the fishers (depending on each style this is related to different goals)	fisherSatisfactionMean	mean [satisfaction] of fishers	Fishery level	Yearly
Under the hood….					
goodSpots	# and % of fishers that are out fishing manage to find a good fishing spot (= medium or high dense patch - as predefined, not dynamically measured)	numFishersWgoodSpot	sum [goodSpotToday] of fishingFishers	Fishery level	Tickly
numExpectNoProfitRatio numWantToBeHomeRatio badWeatherRatio	Tracing the reasons for not fishing for each agent (style dependent).	notFishing badWeather numExpectNoProfit numWantToBeHome	numX / numFishers	Fishery level	Tickly
ratioAtGoodSpot	Proportion of the fishers that are actually at a good fishing spot.	percFishersWgoodSpot	mean (percFishersWgoodSpot)	Fishery level	Tickly

B2. Calibration

FIBE is an abstract representation of a typical fishery, reflecting a space in which different kinds of artificial fishers operate. This is embodied by the relative connection of distance and size of fishing regions; the relative representation the amount and of fish within each region; the relative costs accompanied for fishers etc. They are all relatively connected following the empirical narrative of the fishing styles. Hence, they form the base of the model, the syntactic space in which the agents reside. This calibration thus involved making some base decisions from which the values for the environment (`carrying-capacity` of each patch) and the fishing agents of each style (the `costs`: travel, existence and equipment) were deducted/reasoned.

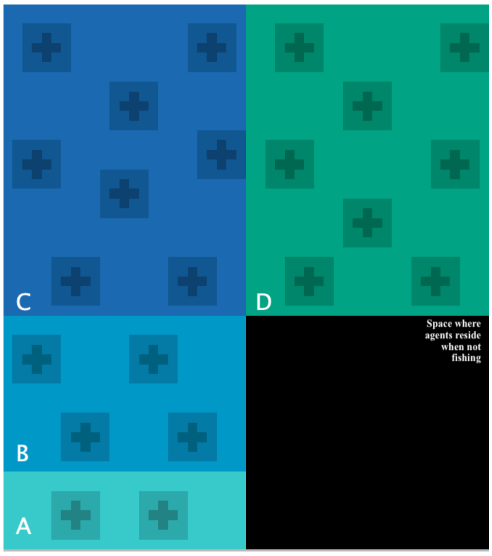


Figure B2a. Space in FIBE. Four fishing regions (spatial) and hotspots reflecting heterogenous fish density, one space for agents when not fishing (symbolic).

Table B2a provides an overview of the anchor decision with their type of reasoning. We attempted to follow the reasoning of the empirical fishery case as much as possible, this concerns mainly the relative degree in which the fishers differ in terms of costs, gains, and means to get gains, e.g. vessel, technology, gear, etc. However, there are also choices that are arbitrary or chosen to keep this version of the model simple on that particular aspect. Arbitrary choices are reflected by the number of fishers 'theoretically' can be sustained given a certain fish population. We could have chosen any other number, it wouldn't have made a difference apart from losing its meaning when there are too few fishers. A choice for simplification is for instance the fish price, something we intend to explore in future versions, but for now does not play a role.

TABLE B2a: Overview of calibrated parameters with their reasoning and when applicable source/underlying assumptions

	Calibration		**Reasoning** *(checked with the fishing style experts)*	**Source / Assumption**
Fisher agents	Catch ability[1] {trawler, coastal, archipelago} = *max income*	{50,10, 5}	<u>Empirical logic (reasoning).</u> Overall reasoning is that the fishing styles operate on different scales that are made consistently relative in terms of the trawler's catches are five times more of that of the coastal and 10 times more of the archipelago's catch, i.e. the coastal can catch double of what the archipelago can catch -> 1:2: 100 (archip:coastal:trawlers)	*Fishing style narrative - conversations with fishing style experts (Boonstra & Hentati-Sundberg 2016).* The trawler, coastal and archipelago fisher span a continuum in terms of high gains, high costs on the one end (trawler) and low gains, low cost on the other (archipelago). The coastal seems to be in between.
	Costs: ● Existence ● Equipment ● Travel	{5, 1, 0.5} {5, 1,	<u>Empirical logic (reasoning)</u> The cost are made relative to the max income, which is catchability * price. - Trawler: profit of 50% per trip.	

[1] Our used of catchability can be a bit different from what is traditionally denotes. Here it reflects the max amount a fisher would catch given the gear and a day's effort when finding a spot with plenty of fish.

	{trawler, coastal, archipelago}	0.5} {15, 5,2.5}	- Coastal: Allows for a profit of 40% of each trip - Archipelago: profit of 30% per trip Existence and equipment cost: 1/10th of the income	Trawler. *high gains, high costs. Trawlers can survive by fishing just a part of the year. Goes further out - deep sea, even to different seas. Access to more fish* Coastal. *In-between, medium gains, medium cost. Wants to go out further at the same time also want to spend time home.* Archipelago. *low profit, low costs.*
Global	Fish price	1	Value that makes price not play a role as the role of price dynamics are not in focus on the current version of the model.	-
Fish & Sea	Growth-rate	1	Simplistic representation.	
	Carrying capacity patches in for each region: Low-CARCAP Medium-CARCAP High -CARCAP	4 3276 8736	Empirical logic (reasoning). Reflects the max fish population that can reside in this particular location. Allows for representing heterogeneous patches (see hotspots)	
	Fish regions A B C D	{A, B, C, D} 200 patches 400 patches 800 patches 800 patches	Empirical logic (reasoning). Regions (A-D) represent distance from coast and increasing space. 1: 2: 4 : 4 (A: B: C:D).	
	# Hotspots A B C D	2 4 8 8	Simplistic representation of heterogeneity fish abundance represented by hotspots: 1: 2 : 4 : 4 (A: B: C:D). Reflects 40% of all patches to be high and medium density, and 60% on low*. One hotspot consists of: 5 high density patches and 20 medium density patches	Hotspot assumption. Fish predominantly the fish resides in the hotspots. Arbitrary fishing pressure choice. The carrying capacity is calculated based on a theoretical

B2.1 Calibration - calculation patch-carrying capacity

All patches have the same carrying capacity, just the regions have different sizes and number of hotspots, making the regional carrying capacity. For the calculation of the baseline value for the carrying capacity we make use of region A and the archipelagos. We calibrate the patch carrying capacity on region A being able to sustain 30 fishers. From this value we derive the total carrying capacity of the other regions (and can derive the number of fishers that that fishery can theoretically sustain).

REGION A - archipelago & coastal

The catchability of the archipelago fisher is 5. We calibrate the fish population size to allow for 30 archipelagos to be able to sustain in terms of fish availability. The archipelago fisher, when catching at their max, fish 150 (5 x 30) per tick = 54750 per year. From this we calculate the total carryingCapacity of regionA (which is of course an estimate, i.e. patch based not region-based dynamics):

Stock update function: *newStock = stock + stock * growthRate * (1-(stock/carCap))* *Given:* x = 0.5 CarCap y = newStock z = maxCatch30Fishers = 5 * 30 * 365 = 54750 growthRate = 1	These two equations hold: *y <= x + z* *y = x + x(1-(x/(2x)) = x + x (1- (0.5)) = 1.5x* Making: x = z / 0.5 = 54750 / 0.5 = 109500 **carCap** = 2*x =**219000**

Region A has 200 patches: 10 (2x5) high density patches and 40 (20x2) medium density patches, and the remaining 150 low density patches. Where I defined that the high-density patches capture 40% of all fish and medium density patches 60%:
making the carrying capacity of each:

- low density patch = 4 (< catchability of archipelago)
- medium density patch: (219000-600= 218400) x 0.6 / 40 = 131040/40 =**3276**
- high density patch: (219000-600= 218400) x 0.4 / 10 = 87360 / 10 = **8736**

carCapA = 219000

REGION B - coastal & trawler
Here we adopt the same carrying capacity as calculated in region A for the low, medium and high density patches.

The regional 'theoretical' carrying capacity is then:
Region B has 400 patches: 20 (4x5) high density patches and 80 (4x20) medium density patches and the remaining 300 patches low density. I defined that the high-density patches capture 40% of all fish and medium density patches 60%:

- high density patches: **8736** * 20 = 174720
- medium density patches: **3276** * 80 = 262080
- low density patches: 300 * **4** = 1200

carCapB = 174720 + 262080 + 1200 = **438000**

REGION C & D - trawler
Here we adopt the same carrying capacity as calculated in region A for the low, medium and high density patches.

The regional 'theoretical' carrying capacity is then:
Region C and D have each 800 patches: 40 (8x5) high density patches and 160 (8x20) medium density patches and the remaining 600 patches are low density. I defined that the high density patches capture 40% of all fish and medium density patches 60%:

- high density patches: **8736** * 40 = 349440
- medium density patches: **3276** * 160 = 524160
- low density patches: 600 * **4** = 2400

carCapC and carCapD each = 349440 + 524160 + 2400 = **876000**

B3. Verification & Validation

Any model is a simplification of a real-world phenomenon. Before a model is convincing scientifically and used to answer research questions, it needs to be *verified* and *validated* according to the model's purpose. Verification involves ensuring that the model is correctly implemented and working as intended, whereas validation involves ensuring that the behaviour of the model correspond to the behaviour of the model target (Balci, 2010; Gilbert, 2008; David 2017).

For verification, the FIBE code (written by Nanda Wijermans) was checked for bugs and correct representation of the fishing styles conceptual model. The code checking was performed by a) in-code test methods to check whether the function and/or values are in the correct ranges, and b) the most important functions (in 'go') were checked independently by (Kirill Orach). The conceptual checking was done in interaction with the conceivers of the fishing styles categorisation (Wijnand Boonstra and Jonas Hentati-Sundberg). Both checking procedures, code and conceptual checking, were executed iteratively until the code was considered sufficiently representative without any obvious bugs.

For validation, the FIBE model was tested to be able to reproduce a set of empirical patterns of fish stock dynamics and fishing style related fishing dynamics, listed in Table B7. Note that in our model validation and verification are not that far apart as the model's purpose is to reflect an empirical description and results into a macro level verification test. This approach follows the idea of pattern-oriented modelling, where the model's credibility/goodness is assessed based on the ability to reproduce multiple patterns {Grimm:2005ei}. Patterns are considered "defining characteristics of a system and often, therefore, indicators of essential underlying processes and structures". By targeting multiple patterns, model structure and parameter uncertainty is reduced. Furthermore, it allows us to test the diversity of behaviours on fleet level as well as the stock dynamics on fishery system level.

Table B3a. Empirical patterns specified to test the FIBE model

		Empirical/Theoretical patterns (to be compared with emergent patterns in the model)	**Source** {Expertise, data, paper}	**Level**
Fish		Dynamics: yearly regeneration, carrying capacity	(Beverton & Holt, 1957)	Fishery (macro)
		Density: spatially variable	(Aro, 1989)	
Fishers	all	Frequency: they are not always out fishing, parts of the year there is no/less fishing (can be seasonal)	(Boonstra & Hentati-Sundberg, 2014; Hentati-Sundberg, Hjelm, Boonstra, & Österblom, 2015; Morgan et al. 2014 Coulthard and Britton 2015; Salmi 2015; Cinner and Bodin 2010)	
		Location: Fishers tend to fish on the same locations (as others and past locations). Some spots go unnoticed.	(Branch et al., 2006; Hilborn, 1985; Begossi 2006)	
		Catch: Catch is heterogeneous. Finding the right fish spots is insecure.	(Branch et al., 2006; Hilborn, 1985; Marchal et al 2006; Palsson and Durrenberger 1990; Wilson 1990)	

Archi pelago	Frequency: most of the time, daily basis - quite the same overall. Under low stock size is difficult to assess - can be different things: more, do something else, or just fish as usual. When stock size is high, does not make them fish more.	(Hentati-Sundberg et al., 2015; Salmi 2005	Group (meso) fleet
	Location: Fish on different locations, however similar spots that they fished in the past (not random). Fishing location is situation dependent (e.g. weather, season | not socially)	(Boonstra & Hentati-Sundberg, 2016, Beuving 2015))	
	Catch: catch can be quite different	(Boonstra & Hentati-Sundberg, 2016)	
	Capital: low earnings, low cost, effect is related to state of stock size, but only when state of stock size is bad for a very long time.	(Boonstra & Hentati-Sundberg, 2014)	
Coastal	Frequency: go out a lot for longer durations of time, but also have some periods of breaks. When stock size is low (like archipelago) can be different things: more fishing, do something else (rely on partner/other income/lay low), or just fish as usual.	(Hentati-Sundberg et al., 2015)	
	Location: Fishers tend to fish on the same locations as others	(Bastardie et al., 2015)	
	Catch: diversity of catches, more diverse than the trawler, less than archipelago (in between archipelago and trawler).	(Boonstra & Hentati-Sundberg, 2016; Hentati-Sundberg et al., 2015)	
	Capital: medium earnings, low cost, effect is related to state of stock size, but only when state of stock size is bad long time.	(Boonstra & Hentati-Sundberg, 2016)	
trawler	Frequency: if the stock is low, they are out least, when high the most.	Expert communications.	
	Location: Fish 'together' (at the same spot, but also coordinated on different spots)	(Hentati-Sundberg et al., 2015), unpublished Vessel Monitoring System (VMS) data	
	Catch: can be quite diverse	(Hentati-Sundberg et al., 2015; Hentati-Sundberg, Hjelm, & Österblom, 2014)	
	Capital: does the best/worst when stock size is high/low	(Boonstra & Hentati-Sundberg, 2016; Clark, 2010; Hentati-Sundberg et al., 2014)	
Comparison	Frequency / Time spent fishing: Archipelago (less variable), coastal (in between) than trawler (abundance = most high, and vise versa)	(Boonstra & Hentati-Sundberg, 2016)	Fishery (inter-user groups)
	Catch: Archipelago is more equal, Trawler is more variable, coastal in between.	Expert communications, (Hentati-Sundberg et al., 2015)	
	Capital: trawler (highest or lowest/neg), coastal (medium-negative), archipelago (low-negative)	(Boonstra & Hentati-Sundberg, 2016)	

Validation synthetic fishing styles

To validate, we test whether the model is able to reproduce the empirical patterns of frequency, catch and location of fishing. Therefore, we conducted several experiments and describe the validation process for each fishing style implemented in the model as follows:

Table B3b. Experimental design for validation.

Key variables	Experiment 1: ***Frequency***	Experiment 2: ***Catch***	Experiment 3: ***Location***	**Reason for the experiment settings for each experiment**
Fishing styles	archipelago; coastal; trawler			
# of fishers	45; 65 (coastal)	45; 65 (coastal)	45	Number of fishers which can sustain optimal yields under the ½ carrying capacity fish population and standard environmental settings for the model.
Starting fish stock(s)	At 1/2 and 1/10 carrying capacity	At 1/10 carrying capacity		½ carrying capacity represents high initial fish population, while 1/10 represents low population. The different initial conditions in Experiment 1 were necessary to check how frequency pattern is different under high versus low fish stock.
Simulation time	2 years	50 days (beginning and end of year)	1 month	Frequency patterns in Experiment 1 were tested under long-term scenarios (2 years) to better capture dynamics under high and low fish stock size. Since we found that catch diversity can also be different, depending on stock size, we ran Experiment 2 under conditions of low and high fish stock, although under smaller resolution (50 days) to allow for better visualization. In Experiment 3 we also focused on a short-term scenario (1 month) as it was sufficient to demonstrate the fishing location pattern and allowed better visualization of results.
# of repetitions	100	1	1	While it was possible to compare mean frequency of fishing under 100 repetitions, we chose to use single runs in Experiment 2 and 3 to clearly show the pattern which otherwise would have been diluted by aggregation.

Pattern	**Outcome variable** (name, description)	**Operationalised** (measured by/at….)
Frequency	*%fishing* Percentage of fishers fishing	daily
Catch	*catch* Individual catch of fishers	daily
Location	*return-visitors* Repeated patch visits by fishers *fishing-together* # fishers not currently fishing alone	daily

Archipelago fishing style

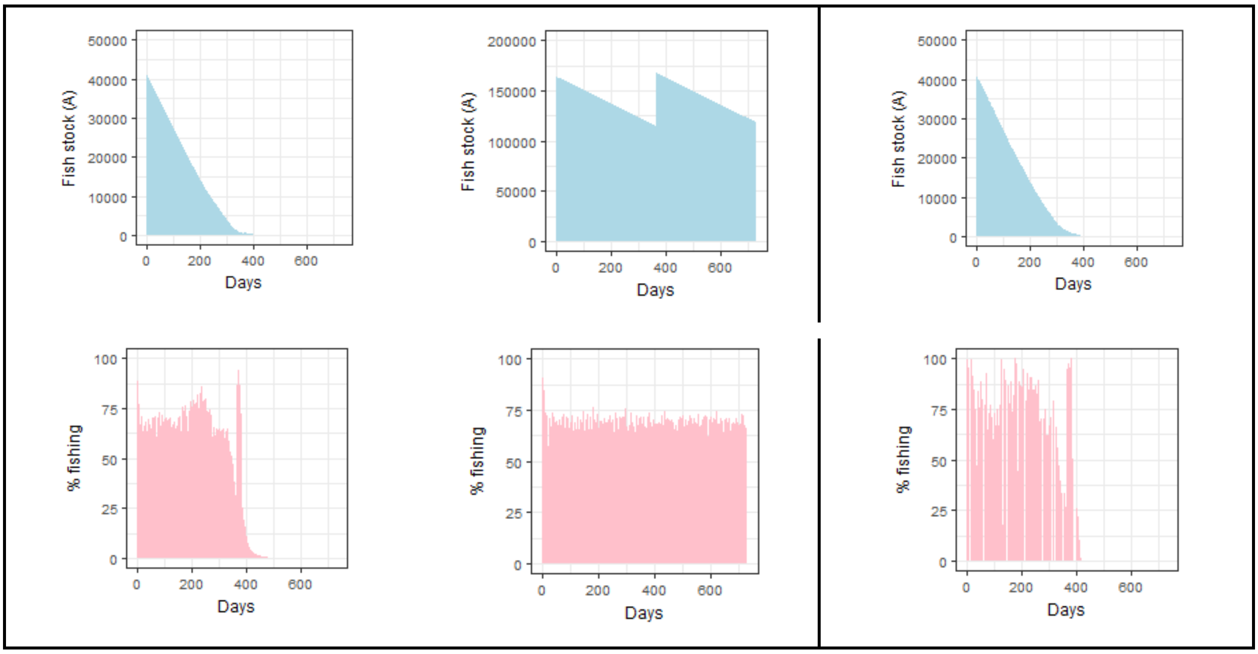
Pattern	Description	Reproduced in model?
Frequency	Go fishing most of the time, on the daily basis - quite the same overall. Under low stock size can fish less or as usual. When stock size is high, do not fish more.	Somewhat
Catch	Diverse catches	Somewhat/No
Location	Fish on different locations, however similar spots that they fished in the past (not random).	Yes

We find that the archipelago fishers tend to go out at relatively the same level of frequency, at least before the fish population reaches a low level. This is consistent with the empirical pattern that argues that archipelago fishers tend to maintain their fishing activity relatively the same, without taking long breaks. As the fish stock decreases, archipelago fishers in the model rapidly decrease their activity and stop fishing when the fish population has collapsed. The empirical pattern relating to stock size is however ambiguous, stating that archipelagos can fish less or as usual when the fish stock goes down. In the model we do not reproduce the "fish as usual" pattern, although archipelago fishers responded to stock decline rather late, only when the stock is nearing collapse. Single runs of Experiment 1 with archipelago fishers however show that the fishers tend to show some variability in frequency of their fishing, which is independent from the state of fish population. Their fishing frequency is thus relatively consistent, although variable at times, which only partially confirms the empirical frequency pattern for this fishing style.

In terms of catch, archipelago fishers in the model do not show a great diversity, as under conditions of high or low fish population, they tend to either predominantly catch the maximum amount they can carry in a day or nothing. The difference between two most frequent outcomes can be explained by the "hotspot"-finding behaviour of fishers. Archipelagos with less advanced knowledge of the region can in some cases fail to find a hotspot and catch nothing. While if an archipelago fisher will succeed in finding a hotspot, they will most likely catch their fill, unless the fish in that spot has already been fished before. The "all or nothing" outcome also results from our implementation of fish stock distribution - where the fish population is centred around the hotspots, while it is unlikely (when fish population is high) for fishers to fish the same hotspot so that the second fisher would not be able to catch their fill. The empirical pattern observed in archipelago fishing style argues about diversity of their catches. Under current implementation of fish stock distribution, it is difficult to confirm the catch diversity pattern for archipelagos, although we do observe that their catches are not all the same.

Finally, Experiment 3 allows us to confirm the location pattern for the archipelago fisher. We find that archipelagos tend to fish consistently in different areas within hotspots, which is demonstrated by repeated visits by the same fishers to the same spots. This shows that their behaviour is not random and that their fishing is mostly focused on different locations where they had success in the past.

Figure V1.1 1/10 and ½ Carrying capacity	**Figure V1.2** 1/10 carrying capacity - **Single run**


Fish stock (A)
Days
Fish stock (A)
Days
Fish stock (A)
Days
% fishing
Days
% fishing
Days
% fishing
Days

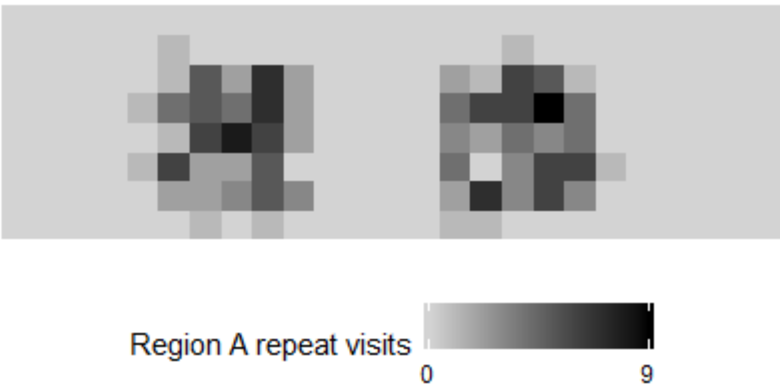

Region A repeat visits
0
9

Figure V2.1
1/10 carrying capacity - **Single run**
Beginning (0-50)

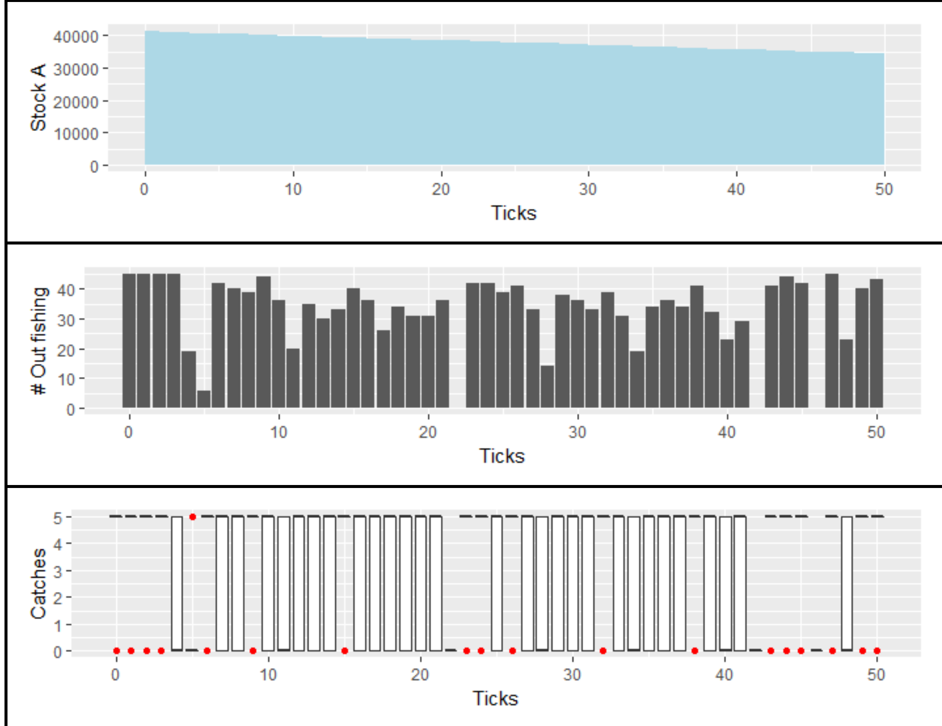
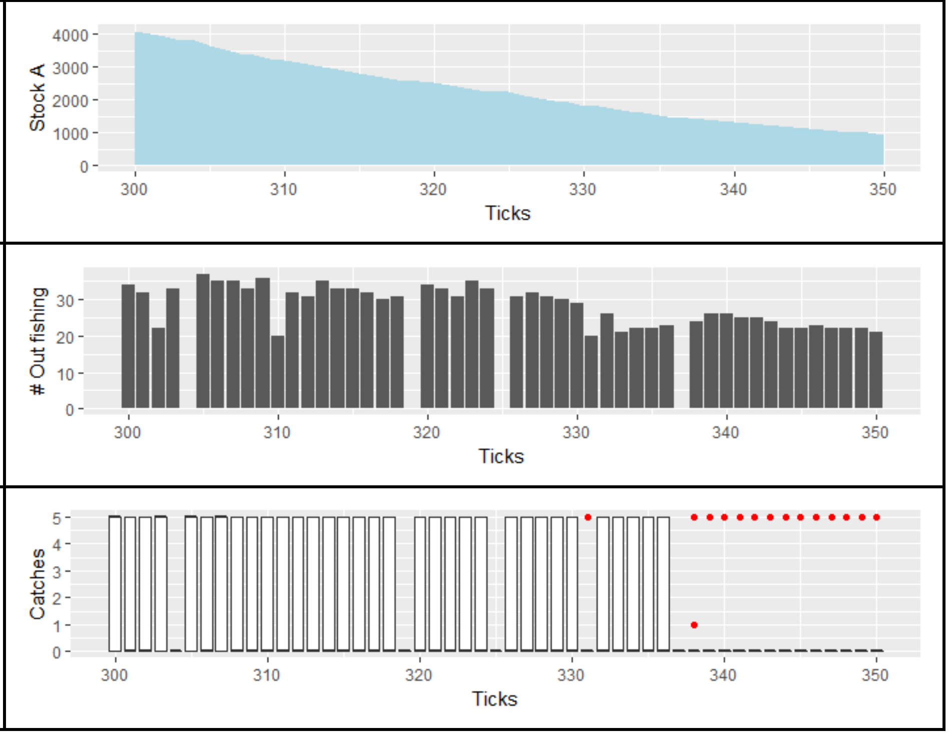


Figure V2.2
1/10 carrying capacity - **Single run**
End (300-350)



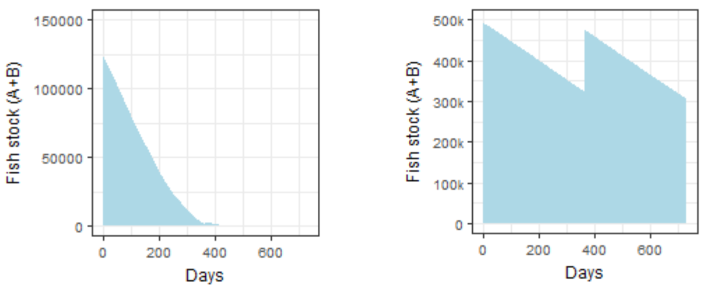
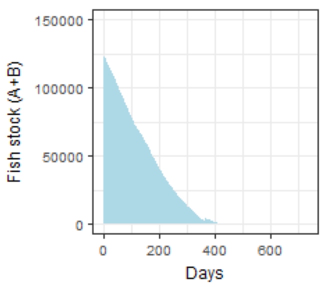
Coastal fishing style

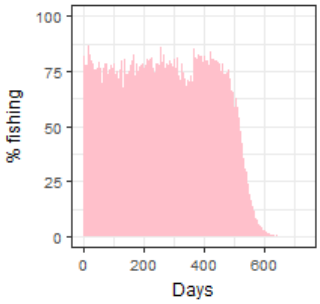
Pattern	Description	Reproduced in model?
Frequency	Go fishing for longer durations of time with some breaks. When stock size is low can fish less (rely on partner/other income/lay low) or as usual.	Yes
Catch	Diverse catches	No/Somewhat
Location	Fishers tend to fish on the same locations as others	Yes

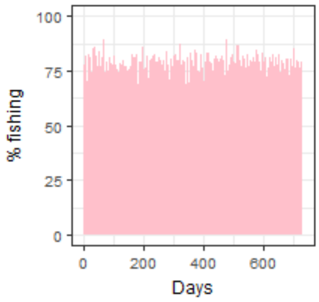
Experiment 1 confirms the frequency pattern for the coastal fishing style. The aggregate runs show a relatively stable pattern of fishing during high fish population and a delayed response to fish population decline. When examining a single run of the frequency experiment, we can see that coastals tend to have periods of continuous fishing followed by short breaks, which they most often take simultaneously. As stock declines, some fishers choose to take a longer break or do something else, which is reflected in the figure through a decline in the percentage of fishers fishing continuously. The consistent breaks taken by fishers simultaneously are a result from a homogeneity in implementing coastal fishers in the model, as all coastals spend the same amount of days at sea before wanting to return home. The frequency pattern thus results from hard-coded individual behaviour in the model, but is reproduced in the experiment nonetheless.

Like the archipelago fishers, coastals display different yet not very diverse catches in Experiment 2. Particularly, in the beginning, when fish population is still high, coastal fishers mostly catch the maximum amount, with a few outliers who do catch less or nothing due to lack of success in finding good fishing spots. Diversity of catches increases towards the end of the simulation, when fish population is declining and finding a good fishing spot is more difficult. Just as in other fishing styles, the empirical catch pattern is not sufficiently reproduced by the coastal fishers due to the way fish population is distributed across patches.

Empirical pattern for fishing location in coastal fishers can be confirmed, as the results of Experiment 3 show that during most days the majority of coastals fished at the same patches as other fishers. Since the fishing area for the coastal fishers is quite large, it is unlikely that the pattern observed in the experiment occurs due to randomness.

Figure V1.3 1/10 and ½ Carrying capacity	**Figure V1.4** 1/10 carrying capacity - **Single run**
	


% fishing
100
75
50
25
0
0
200
400
600
Days


% fishing
100
75
50
25
0
0
200
400
600
Days

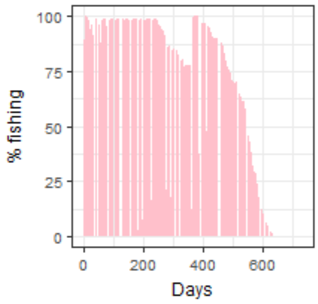
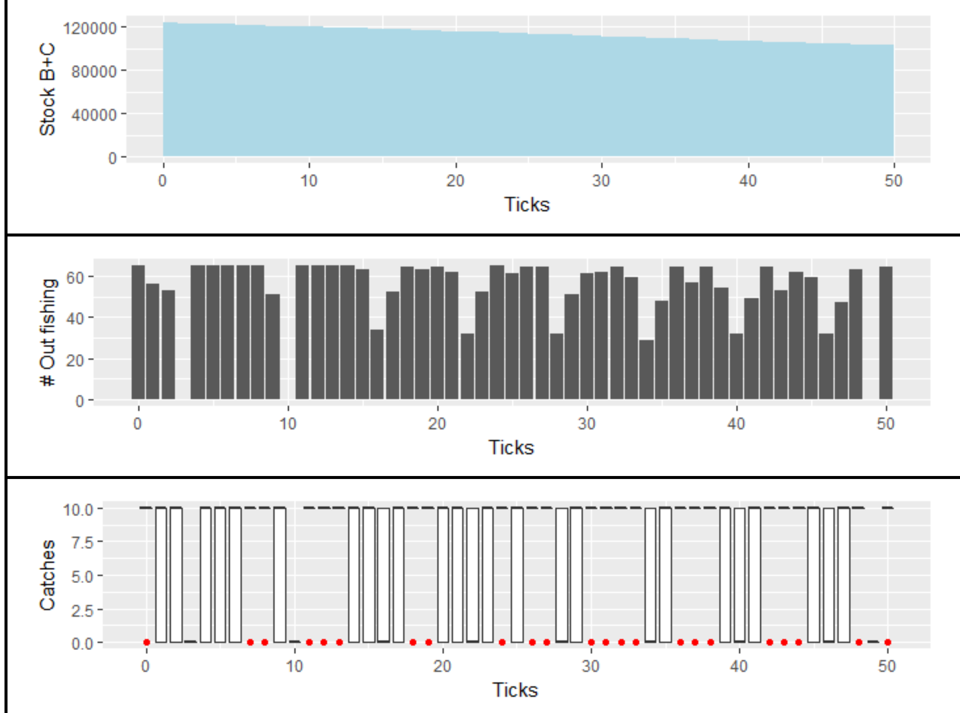
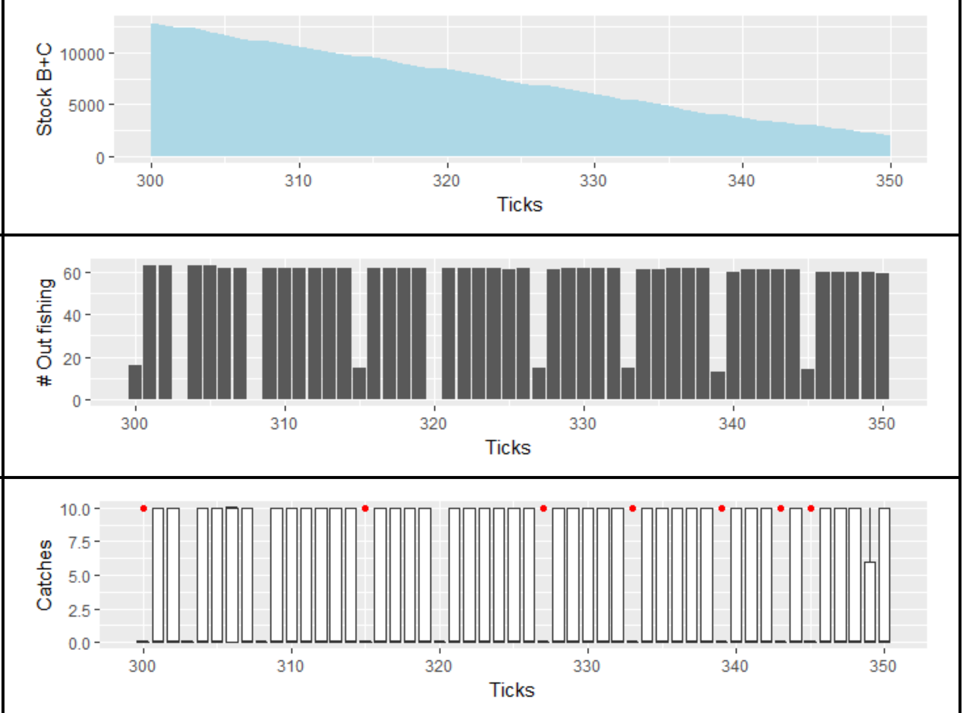
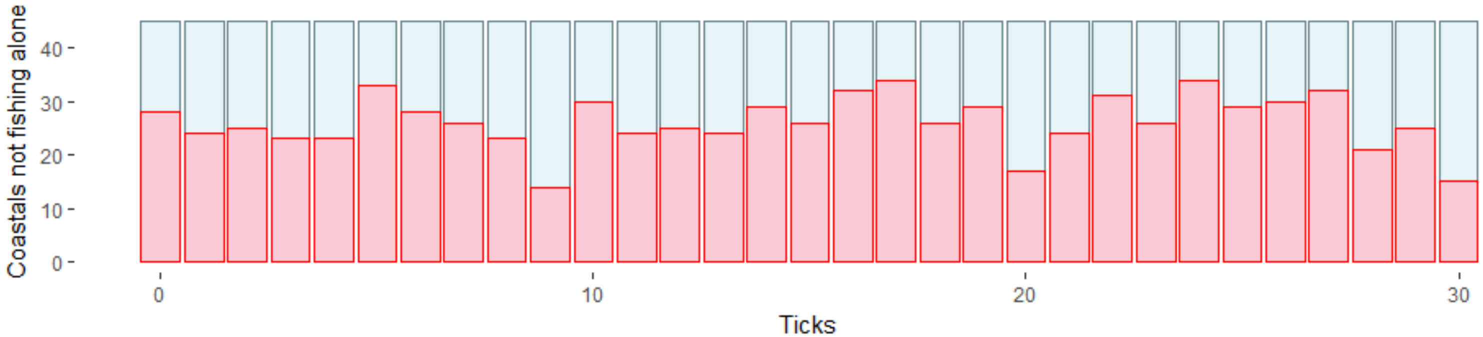

% fishing
100
75
50
25
0
0
200
400
600
Days

Figure V2.3 1/10 carrying capacity - **Single run - Beginning (0-50)**	**Figure V2.4** 1/10 carrying capacity - **Single run - End (300-350)**
	



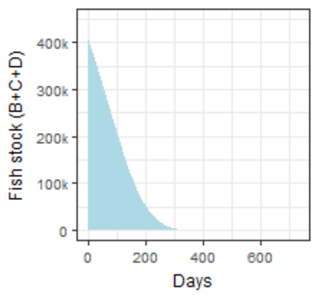
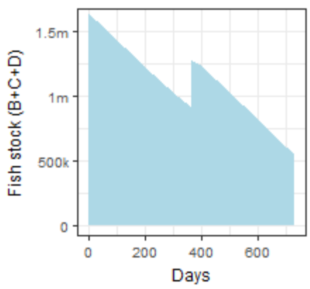
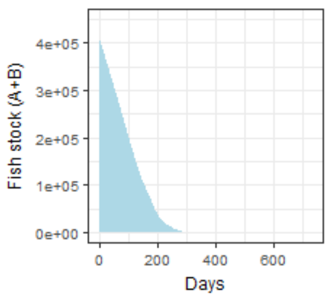
Trawler fishing style

Pattern	Description	Reproduced in model?
Frequency	When the stock is low, they are out least, when high - the most.	Yes
Catch	Diverse catches	No/Somewhat
Location	Fish 'together' (at the same spot, but also coordinated on different spots)	Yes

The empirical pattern for the trawler fishing style points to a relationship between trawler fishing frequency and the state of the fish stock. This pattern can be reproduced in our model, as Experiment 1 shows that under conditions of high fish stock almost all trawlers were out fishing. As the fish stock declined, trawlers were out significantly less, although not all of them stopped fishing. Nonetheless, the results of the experiment show a clear relationship between the percentage of trawlers out fishing and the state of the fish stock.

Diversity pattern is once again, not reproduced to a full extent in the trawler fishing style. In Experiment 2, when fish population is high, the majority of trawlers catch the maximum possible amount, while when the fish is low, most of the trawlers catch nothing. The trawler fishers show the least diversity in their catches in comparison to two other fishing styles represented in the model.

In Experiment 3 we find that trawler fishers in the model fish together on the same or adjacent spots more often than alone. Trawler fishers in the model frequently choose to follow other knowledgeable fishers, however do not necessarily fish on the same spot - their fish-finding technology allows them to locate fish on the nearby patches and move there. Although not all trawlers choose to follow others (e.g. on few days more trawlers were fishing alone than together), overall the expected empirical pattern is reproduced - as most of the time the majority of trawlers coordinated their fishing with some of the other fishers.

<table>
<tr><td colspan="2">Figure V1.5
1/10 and ½ Carrying capacity</td><td>Figure V1.6
1/10 carrying capacity - Single run</td></tr>
<tr><td>
</td><td>
</td><td>
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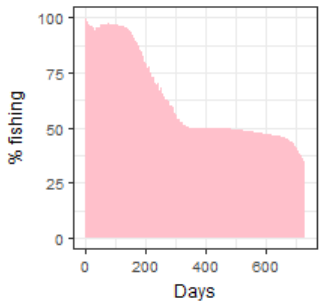
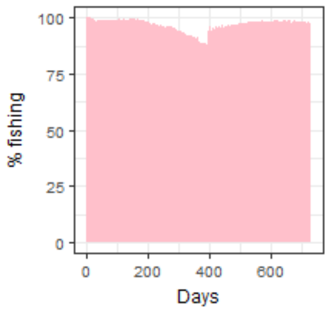

% fishing
100
75
50
25
0
0
200
400
600
Days


% fishing
100
75
50
25
0
0
200
400
600
Days

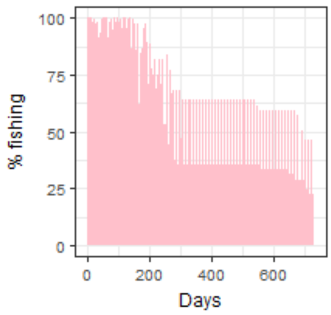
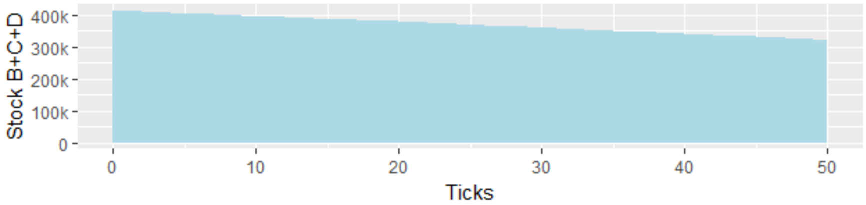
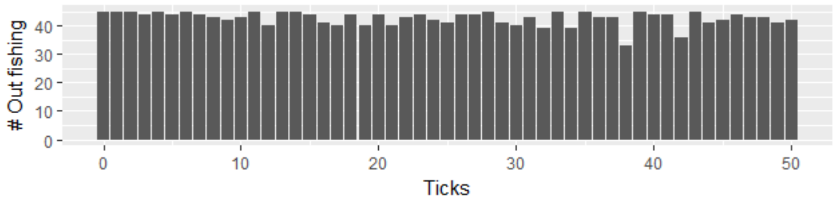

% fishing
100
75
50
25
0
0
200
400
600
Days

Figure V2.5
1/10 carrying capacity - **Single run |Beginning (0-50)**





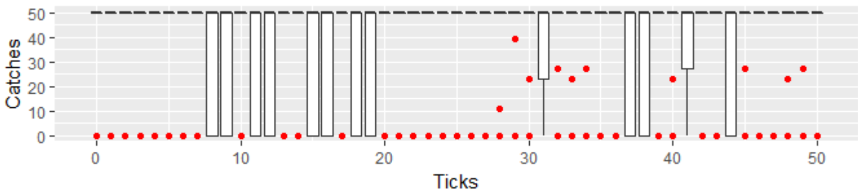
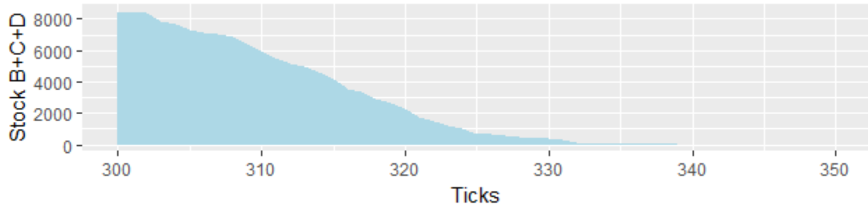
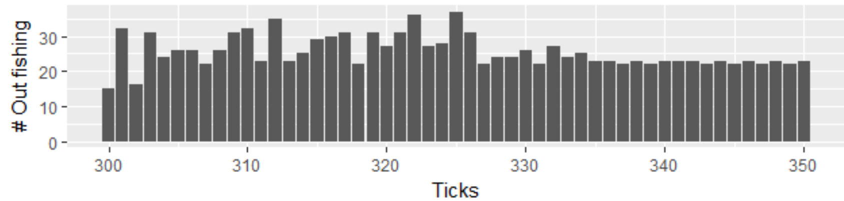
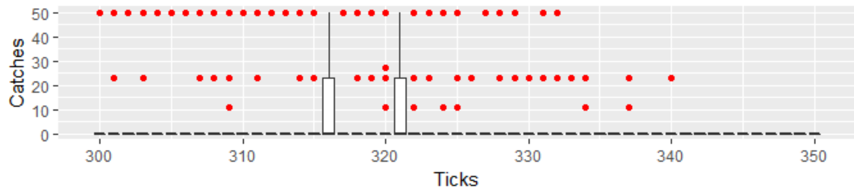
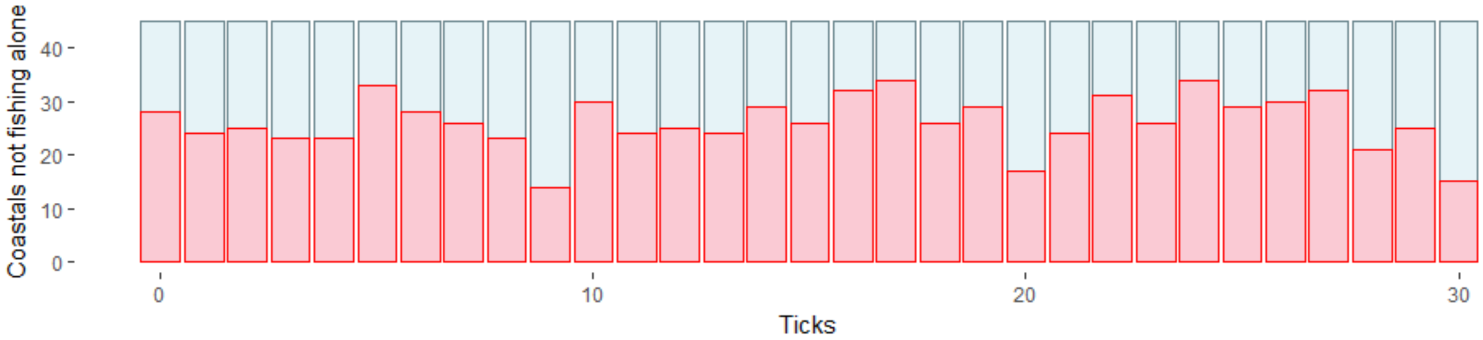


Figure V2.6
1/10 carrying capacity - **Single run | End (300-350)**








Coastals not fishing alone
40
30
20
10
0
0
10
20
30
Ticks

Comparing the patterns between the three fishing styles

Pattern	Description	Reproduced in model?
Frequency	Archipelago (less variable, constant fishing) , coastal (in between), trawler (fish most when fish is abundant, least - when the stock is low)	Yes
Catch	Archipelago is more equal, Trawler is more variable, coastal in between.	No

Examining single runs from each of the fishing styles (Figures) we can see the key difference between archipelago and coastal fishers. Coastal fishers tend to take short breaks more often and on a regular basis. Either most of the coastals are out fishing or none of them are. Archipelago fishers tend to show some variability in their fishing with no clear "break" periods, while in coastal fishers we observe more consistent behaviour due to the homogeneity between fishers in their desire to return home after fishing (all coastal fishers can spend the same amount of days at sea before they want to return home). Due to this, we can argue that coastal fishers display more variable fishing behaviour than archipelago fishers (thus confirming the empirical pattern), however they are not very diverse in their fishing patterns, as they most often take breaks simultaneously. Trawler fishers also show diversity between high frequency of fishing (during high fish stock) and low frequency (during low fish stock), which is consistent with empirical observations.

Comparing the outcomes of Experiment 2 observed in each of the three fishing styles, we find that unlike observed empirically, archipelago fishers have shown the most diversity in catches, particularly during the beginning of the run (when fish population is still high). Catches of coastal fishers have been more diverse than trawlers' who most of the time either predominantly got highest possible catches (high fish population) or predominantly nothing at all (low fish population). As a result, it is not possible to confirm the catch diversity comparison pattern between the fishing styles.

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B4. Model experiments

B4.1 Design of experiments

Table B4a. Overview of the initial settings and their motivation for the simulation experiments with FIBE to illustrate how a model with behavioural diversity can support the understanding of complex behavioural patterns in fisheries.

Name	Type [value range]	Initial settings	Motivation for initial settings
Number of fishers	Integer [0-Inf]	1) **30** Trawler 2) **45** Coastal 3) **30** Archipelago	The initial setting reflects an experiment for each fishing style fishery: 1). Trawler, 2) coastal, 3) archipelago. The settings detail the number of fishers of that particular type of fisher, the other types of fishers are set to zero. The number of fishers for each fishing style reflects the theoretical optimal number of fishers that would allow the fishers to sustain the resource and make the most profit by fishing at MSY. This allows for comparing the different fishing style fisheries (see B4.2 for the benchmark details)
Fuel-subsidy	Float [0-1]	1) 0 2) 0.25 3) 0.5	The demonstrate the role of a policy we created a situation without (0) and with (0.25) the role of a policy (setting 1 and 2). The subsidy level was intended to be substantial but not extremely high, which made ¼ of compensation a simple and reasonable choice. The third setting (0.5) was chosen exaggerate its influence to further explore the role of the subsidy.
duration	Integer [0-Inf]	25 years	The duration of the simulation is based on two factors. 1) should not reflect more than 1 generation of fishing as this would deviate too much from the fishing style description and should then also reflect changes in the styles themselves. 2) This duration allowed for showing the key dynamics and stabilises for each fishing style fishery.
init-stock-size	Integer [0-CarCap]	½ * Carrying capacity	The basic scenario we chose to compare. To reflect a starting point that in theory could be maintained when fishing at MSY. Allowing for showing the differences between the fishing styles in a good way and letting resource scarcity be a result of fisher behaviour not of the initial settings.
home-satisf-threshold	Float [0-1]	0.5	Variable for the coastal fisher agents. They value both being at home and making a profit just as important. Making the role of going for one goal over the other purely based on the satisfaction level of the agents, which is a good baseline version of the coastal fishing style.
memory-spatial-length	Integer [0-Inf]	20	Reflecting the number of good fishing spots a fisher recalls. It was 'arbitrarily' chosen to reflects 10% of the patches. It is a variable that is up for redesign (relative to fishing area size, sensitivity analysis, insights from cognitive science etc). It is an important influencer of behaviour of a fisher when using memory to find a spot to fish.
memory-time-length	Integer [0-Inf]	365	Reflecting that choices are affected by memories (catch and profit) going back one year.
bad-weather-probability	Float [0-1]	0.1	This is based on an expert guess on how often the weather is so bad that archipelago and coastal fishers cannot go out fishing.
fish-price	Integer [0-Inf]	1	To keep the illustration simple, we left out the role of fish price by making the price 1, however making the model easily adaptable for including the role of price.

B4.2 A benchmark for comparing the fishing styles

We compare the outcomes of our simulation experiments to the theoretical benchmark of a regulated fishery in which the number of fishers is restricted through e.g. licences to a level where their aggregate harvest corresponds to Maximum Sustainable Yield (MSY). MSY is a biological measure that indicates the stock size at which the reproductive rate of the population and hence the harvestable surplus, is highest. It is a key indicator used in contemporary fishery management, despite some critique (e.g. Hilborn, 2004; Larkin, 1977). We call this benchmark "theoretical optimum management".

For the benchmark calculations we use a single fish stock and assume that fishers follow an optimum fishing strategy, as commonly assumed in bio-economic fishery models. We calculate the benchmark MSY profit as the total profit that can be made in this fishery assuming fishing style specific costs. This benchmark serves to assess the relative differences in fishery outcomes among the different fishing styles. We assess three types of fishery outcomes: the fish stock size (ecological), the profit (economic), and fishers' goal satisfaction (social). The first two are assessed relative to the stock size and profit of the theoretical optimum management benchmark.

Table 4b. Overview benchmark variables and values

Benchmark variables	Description	Variables in Netlogo/R	Calculation
msyStock	Benchmark stock to compare the outcome stock of the fishing styles fishing. Reflects the fishing stock being at half carrying capacity (K/2), i.e. the stock size that has the highest reproductive rate, i.e. where the catch is theoretically the highest.	MSY_STOCK_ARCHIP	(sum [carcap] of region A) / 2 = 109500
		MSY_STOCK_COASTAL	(sum [carcap] of region A + B) / 2 = 328500
		MSY_STOCK_TRAWLER	(sum [carcap] of region B+ C + D) / 2 =1095000
msyCatch	Catch when at the MSY stock, i.e. the newly produced stock, by reproduction given a stock that is at half carrying capacity. catch = msyStock * growth-rate * (1- (msyStock / carcap))	msyCatch {trawler, coastal, archipelago}	msyStock*1*(1- 0.5) = ½ msyStock_fishingStyle ={547500, 164250, 54750}
number-of-fishers	The theoretical optimal number of fishers that the fishery should be able to sustain in the benchmark scenario: N = MSYcatch /(catchability * 365)	archipelago fisher	= **30** (anchor decision – see B2) (=54750 / (5* 365)
		coastal-fisher	N = 164250 / (10*3650) = **45**
		trawler-fisher	N = 657000 / (50 * 365) = **36**