Deltares

Beaver behaviour during high water regarding burrows in levees

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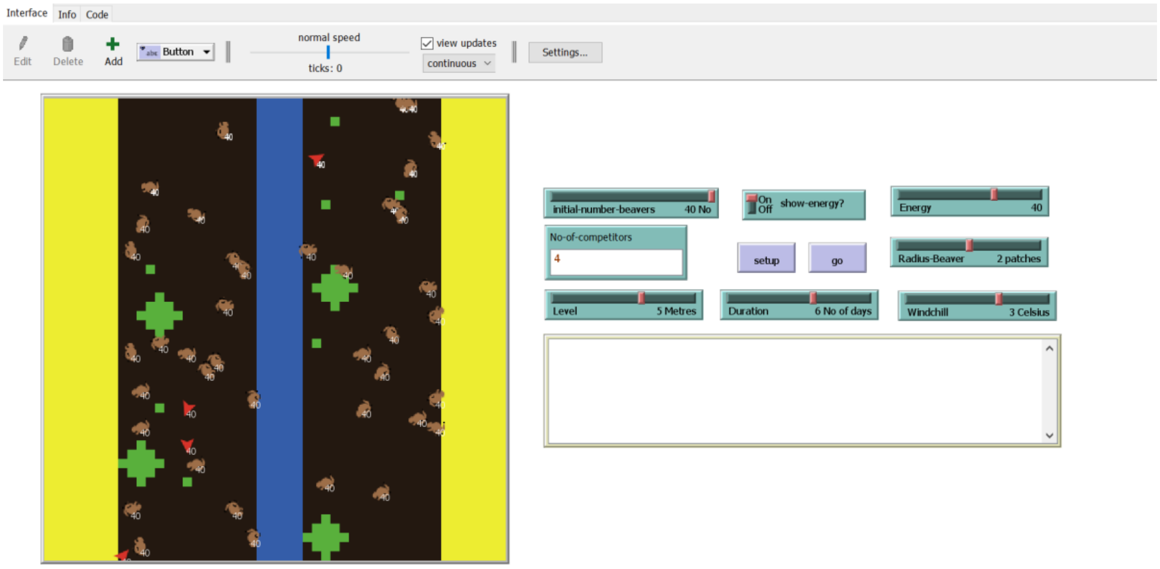
Abstract

The beaver population has grown exponentially since its reintroduction in the Netherlands. The beaver digs their burrows in soil structures, including levees. This weakens the levees and causes them to lose their strength, endangering the safety of the levee. The beaver digs into the levee, especially when the water in the river rises rapidly. Various measures are being taken to prevent the beaver from digging into the levee. To determine effective measures to prevent the beaver from digging into the levee, it is necessary to know the behaviour of the beaver during high water. This case study uses an agent-based model to study this behaviour of the beaver.

The used conditions (variables) in this case study are windchill, duration of the high water, level of high water, and competitors as other beavers/ badgers (the red arrows as shown in the image below). The variables mentioned can be manipulated, changed or turned off. Once the model is run, by pressing ‘go’ (as seen in the image below), the beavers move around the model world until they find a target location or get worn out of energy. Following this, the probability of digging is calculated based on the number of beavers that have dug into their choice of a safe place during high water divided by the total number of beavers in the study.



This case study shows that it is possible to create an agent-based model with the assumed conditions to predict the behaviour of beavers during high water. We believe that agent-based modelling is useful in accounting for real-time decision-making amongst the beaver families, incorporating independent behaviour traits, and also testing out several combinations of parameters. We have also provided some recommendations for improving the model such as greater complexity in the landscape features such as vegetation, natural inundations or wooded areas, variability in beavers—age, lonely beaver, family sizes, more emphasis on territory and their ability to dig underwater that a future version can use as a starting point. This starting point for more complex agent-based models can provide more insight into their behaviour and provide way for better measures for averting them from digging into levees.

Contents

1 Introduction

1.1 Problem statement

1.1.1 Introduction of the beaver

In 1988, the beaver (Castor fiber) was re-introduced in the Biesbosch in the Netherlands, after the last beaver was killed by a fisherman in 1826. Their population growth has been steady until after 2011 when it began growing rapidly to 3.500 in 2019 (Dijkstra, 2019). Today, across the Dutch landscape, they are present in almost all provinces in the country and their population is estimated at 7000 according to the different water authorities. The beaver is a protected animal and acts as a key animal for many florae and fauna. Given its ability to physically alter landscapes, the beavers are regarded as having a positive impact on local biodiversity in areas across Europe where they were reintroduced (Nica et al., 2022). For example, the beaver makes dams, which form slow-moving ponds that reduce stream erosion and provide brand-new habitats for small fish and other aquatic wildlife.

1.1.2 Beaver burrows during high-water

Recently it has become apparent that the beaver increasingly digs into the levee, especially at high water levels. Examples of this behaviour are known at various water authorities in The Netherlands[1].The beaver digs its burrow mainly in levees and other soil structures and thus poses a risk to the safety of the flood defences. Because the beaver has its entrance underwater, it is also difficult to detect them, especially during flood conditions when the water contains a lot of sediment and debris. Summarized, at high water level of the river, the beavers will look for higher places and, sometimes, will dig into the levee, which is a major risk to the safety of the levee. See Figure 1.1.

Figure 1.1 At high water level the beaver will look for higher places. In the left photo the location of the beavers during normal situation is given. In the right photo the beaver will look for higher places during high water. Because of the new location is unknown a question mark is given (aerial pictures: Tom Hessels).

[1] For example: Waterschap Rivierenland and Waterschap Drents Overijsselse Delta

Under normal circumstances, the beaver will dig its burrow below the water level toward the levee or another earthen structure. The beaver prefers a water depth of at least 50 cm in the foreshore to dig its burrow, which makes the beaver feel safe. When the water rises in the river during a high-water period, the beaver will display the following behaviour (Dijkstra et al., 2022):

1st stage: Water rises in the river:
The beavers lie on their lodges.

2nd stage: Water rises higher:
The beaver will lie on other (higher) structures (earthen structures, floating tree limbs, building etc.), see Figure 1.2.

3rd stage: Water rises even more:
The beaver crosses the levee to the dry area land inward and sometimes they dig into the levee which could lead to a significant effect on the flood safety.

Figure 1.2 Beavers shelter in a treetop during a high-water level (source: Rothengatter, 2023).

Given the risk posed by beavers to the levee and dike structures, research for protection against beavers has largely focused on the possible ‘dig-proofing’ of these structures (Czech, 2005; Kamczyc et al., 2016; Kozłowski & Balawejder, 2017; Pietro, 2017). These measures to protect levees include the use of mesh (netting) or stones to discourage burrowing.

While the levee protection measures have also proven to reduce the digging of not just beavers, but also other burrowing animals, the concern of their diversion into other areas closer to human settlements, as a result, is another risk (Pietro, 2017). Understanding the favourability of levees specifically during high water when burrowing tendencies into levees have shown to rise (Dijkstra et al., 2022) is therefore, required to propose more appropriate protection measures. One way of doing so is with the use of computer simulations.
They prove highly useful to account for many variables and conditions that may encourage digging patterns into levees amongst beavers (Grimm & Railsback, 2006).

1.2 Aim of the study and approach

To take targeted and efficient measures against digging by beavers during high water, it is necessary to investigate why beavers display this behaviour under what circumstances, and what probability. This research shall, therefore, investigate whether it is possible to use agent-based modelling to determine the probability that beavers will dig in the levee under high water conditions. If found feasible, the results from an agent-based model may prove highly insightful in conceptualising better protection measures.

2 Methods

2.1 Introduction

This research uses the agent-based modelling software NetLogo 6.3.0[2]. NetLogo is an open-source software typically used to run individual and agent-based models. The model assumptions are based on a list drawn up in collaboration with a beaver expert, Vilmar Dijkstra (Zoogdierenvereniging), Daan Bos (ecologist and lector at Van Hall Larenstein University of Applied Sciences) and Marc Weeber (Deltares). This list contains possible causes that influence the beaver's behaviour of digging into the levee during a high-water period. The complete list of the various considerations is included in appendix A and forms the basis for the assumptions that feed into the agent-based model.

Not all causes are included in the model. There are several reasons for this:

- No further information on whether the behaviour leads to digging into the levee during a high water period.
- Not modellable at this stage.

This section will provide an overview of the agent-based model before deep-diving into the model built. The model is built using the ODD protocol to ensure standardization amongst agent-based models (Grimm et al., 2010).

2.2 Background of Agent-based modelling

Agent-based models (ABM's) have been popularly used in ecology and mathematics since the 1990s when they gained popularity (Vincenot, 2018). As opposed to other models, analysis of agent behaviour in agent-based models focused on the agent's intended actions. As such, their interactions in a shared model would help in evaluating emerging behavioural patterns within a system due to its reductionism (Sellers et al., 2007). ABM application within the domain of ecology has to a large extent focused on individual behaviour of agents and differences in their behaviours. A result of which, it is often referred to as individual-based models (IBM's). The nuanced difference between ABM and IBM lies in its approach to its application: ABM focuses on adaptive action while IBM focuses on individuality (Vincenot, 2018).

Irrespective of the terminological disparities, agents in both IBM and ABM are considered to have capable behaviour, intentions, memory, and decision-making power (Sellers et al., 2007). Their goal-oriented actions may be manipulated in the way of their adaptive decisions. ABM's have thus been used largely in applied ethology, specifically targeting social animals. Within the research context of beavers, ABM's and IBM's have largely focused on two strands: population dynamics and habitat suitability (Mayer et al., 2017; Natural Heritage, 2015; Smeraldo et al., 2017; South et al., 2000) which specifically targeted reintroduced species. Research available in English on the two strands was also found largely concentrated in Scotland (Natural Heritage, 2015; Smeraldo et al., 2017; South et al., 2000).

Given its large applicability within applied ecology and ethology as well as its flexibility to model adaptive behaviour, ABM's can prove to be highly insightful in gaining more knowledge on beaver-digging tendencies. This is especially for circumstances where agents need to adapt to unique circumstances, which in turn impact emergent behavioural patterns of the system. Keeping this in mind, the following section shall provide an overview of the modelling process, the assumptions used, and the process of execution.

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[2] Can be found here: https://ccl.northwestern.edu/netlogo/download.shtml

2.3 Agent-based modelling overview

The ‘overview, design concepts, and details’ (ODD) protocol as proposed by Grimm et al. (2010) is used in this research to provide an overview of the model processes. The ODD protocol was conceptualized by a group of modelers in retaliation to the non-standardisation of procedural descriptions which led to a lack of reproduction or replication (Grimm et al., 2020; Railsback & Grimm, 2019). This procedure was conceptualized targeting specifically modelling works that used individual or agent-based models. Since the description focuses on breaking down key aspects of the model at hand, the readability can also extend to those without technical expertise (Grimm et al., 2020). To ensure this research’s reproducibility and readability, the second update to the ODD procedure has been employed in this research (Grimm et al., 2020).

2.3.1 Purpose

The purpose of this model is to probe into digging tendencies of beavers during high water into levees in response to level of high water, duration of high water and windchill. This model represents an area in the Netherlands with floodplains where beavers reside. As such, the world created within NetLogo[3] is based on a Dutch floodplain (see Figure 1.1).

As beaver’s response in each combination of variables is not entirely known, the decision to dig into levees amongst beavers is a result of its perception of urgency to find safety and, its interaction with other beavers and competition for safety. The ultimate purpose of this model is to check if ABM’s are insightful for providing recommendations for better levee protection measures.

During high water, beaver families are forced to leave their flooded burrow in search of safety. Depending on the duration of high water and windchill, the beaver family decides to dig or not. Their choice of safe place is also determined by the availability of spaces that are not flooded. Based on the availability of safe places and their choice to dig, the beaver family shall make its way to safety as soon as possible.

2.3.2 Entities, state variables and scales

The ABM model that is made, has two entities:
1. The agents representing beaver families and competitors. Competitors here are badgers and other animals that affect the beaver family’s choice of a safe place. They also move and make decisions in the same manner as the beaver. Since all decision-making rests in the hands of adults, we consider one family as one beaver in this model.
2. The 2-dimensional patch cells representing the world that the agents shall navigate through. The patch cells are distinguished based on their landscape features and must be one of the following: floodplains, rivers, levees, trees, shrubs, and floods.

Agents are characterized by state variables: identification number (nr), energy (point), decision to dig (yes/no), safe place (coordinates: x,y). Each state variable is therein dependent on parameters, which in model are windchill (Celsius), level of high water (meter), duration of high water (days) and success? (yes/no). To create a level of complexity for the beavers, a radius of avoidance (nr. of patches) is an additional state variable. The patch cells are characterized by state variables: location (x,y), patch-type (levee/tree/shrubs/river/flood), and elevation (m). Patch-type of trees and shrubs also have height (meter). Further explanation about the state variables can be found in Table 2.1 .

[3] NetLogo is an open source multi-agent programmable modelling environment. (https://ccl.northwestern.edu/netlogo/)

The input parameters used in the model are windchill (Celsius), duration of high water (nr of days), level of high water (meter), number of beavers (nr), and number of competitors (nr). A detailed explanation about each input parameter can be found in Table 2.2.

Table 2.1 State variables, measure.

Entity	State variable	Measure	Explanation
Beaver family	Identification number	Number	Unique identity number for each beaver
	Energy	Likert-scale	How tired/anxious is the beaver?
	Decision to dig?	Yes/no	Decision on whether to dig or not to dig based on the combination of parameters
	Safe place	Patch number	The target choice of hiding place
	Success?	Yes/no	Calculated based on the final safe place and the decision to dig .
	Radius-avoidance	Nr of patches	Radius within which the beaver must avoid other beavers and competitors at all times
River	Elevation	Meter	Elevation of each patch of river
	Location	X,y	Location of each patch of river
Floodplains	Elevation	Meter	Elevation of each patch of floodplain
	Location	X,y	Location of each patch of floodplain
Levees	Elevation	Meter	Elevation of levees
Trees	Height	Meter	Height of each tree
	Location	X,y	Location of each tree
Shrubs	Height	Meter	Height of each shrub
	Location	X,y	Location of each shrub
Competitors	Identification number	Number	Unique identity number for each competitor
	Energy	Likert-scale	How tired/anxious is the beaver?
	Decision to dig?	Yes/no	Decision on whether to dig or not to dig based on the combination of parameters
	Safe place	Patch number	The target choice of hiding place
	Success?	Yes/no	Calculated based on the final safe place and the decision to dig .

Table 2.2 Input parameters used in the model.

Parameter	Unit	Description	Range
Water-level	Meter	Increase in water level during the model	0 - 8 m
Water-duration	No of days	Duration of the model	0 – 10 days
Windchill	Celsius	Range of temperature that can be experienced	10 to -10
No of beavers	Nr	Initial number of beavers that the model will run with	0 – 40
Energy	Likert scale	Initial amount of energy that the beaver and competition start with (in terms of points)	0 – 60
No of competitors	Nr	Initial number of competitors that the model will run with	4 (default, can be reset with no limit on number)

2.3.3 Process overview and scheduling

In this model, there are multiple processes performed by the beaver families and competitors. All outcomes of combinations of parameters were determined following the conversation with an ecologist and a beaver expert (meeting on 14th September 2023) see 2.1, as well as literature (K.-A. Nitsche, 2001; V. K. Nitsche, 2003). The processes used by **both** the beavers and competitors are described below and can be seen in Figure 2.1.

The first process is that of deciding to dig. Both beavers and competitors must decide whether to dig based on the combination of parameters. Further explanation of this decision is provided under section Sub-models below. See section 2.3.6.

The next process is that of finding a safe place. This determined by the proximity of the location, whether it is currently occupied by other beaver families or competitors and beaver family's or competitor's decision to dig or not.

Movement is described as the way beavers and competitors move from one patch to another. Beaver families and competitors are allowed to move two patches in each step they make. Movement here is highly deterministic and so both beaver families and competitors will move towards the safe place chosen in the previous step.

Randomness in this model is introduced by the avoidance radius for beaver families in their journey to their safe place. Avoidance here in this model is the number of patches of distance that beaver families must maintain at all costs from other beaver families and competitors.

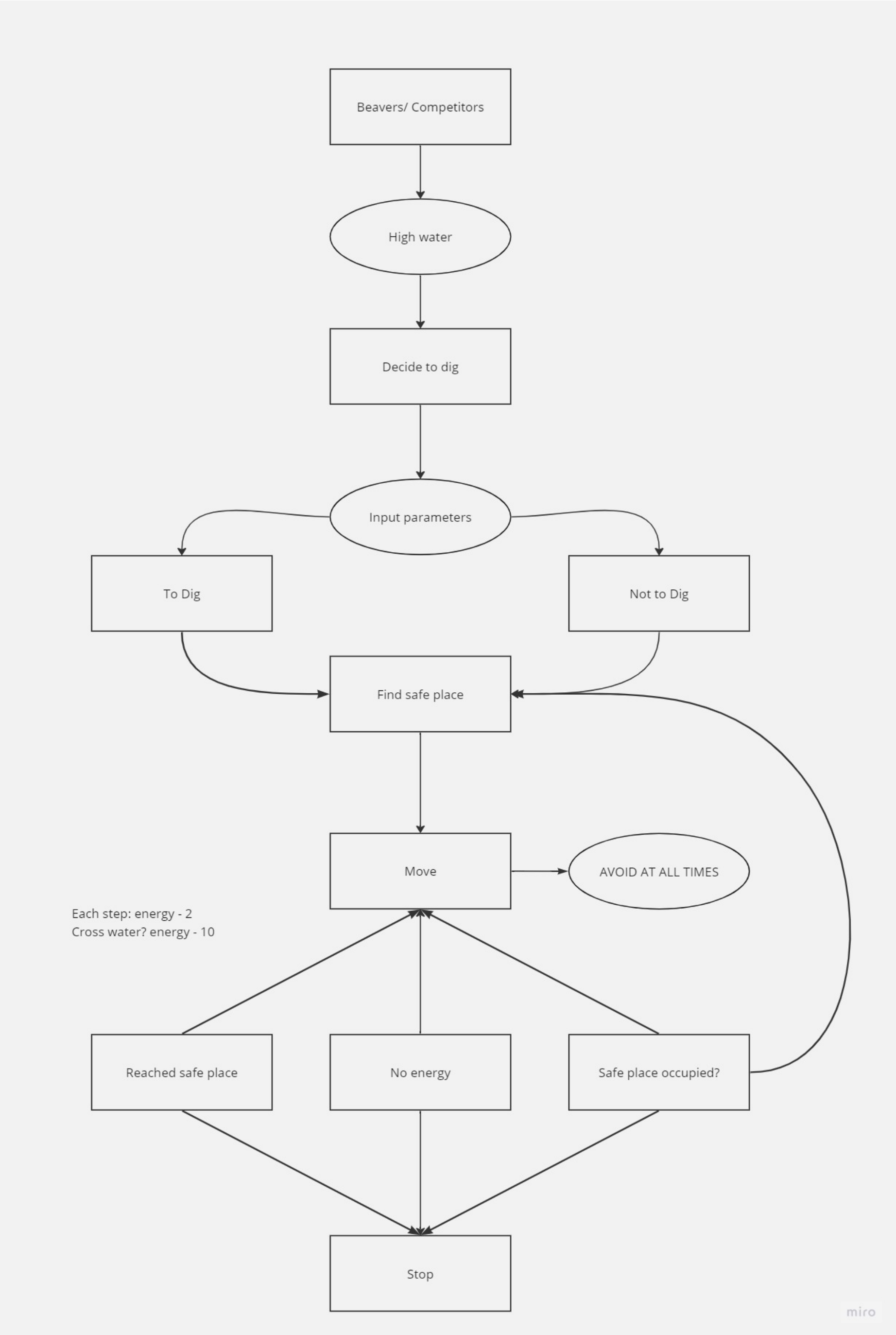


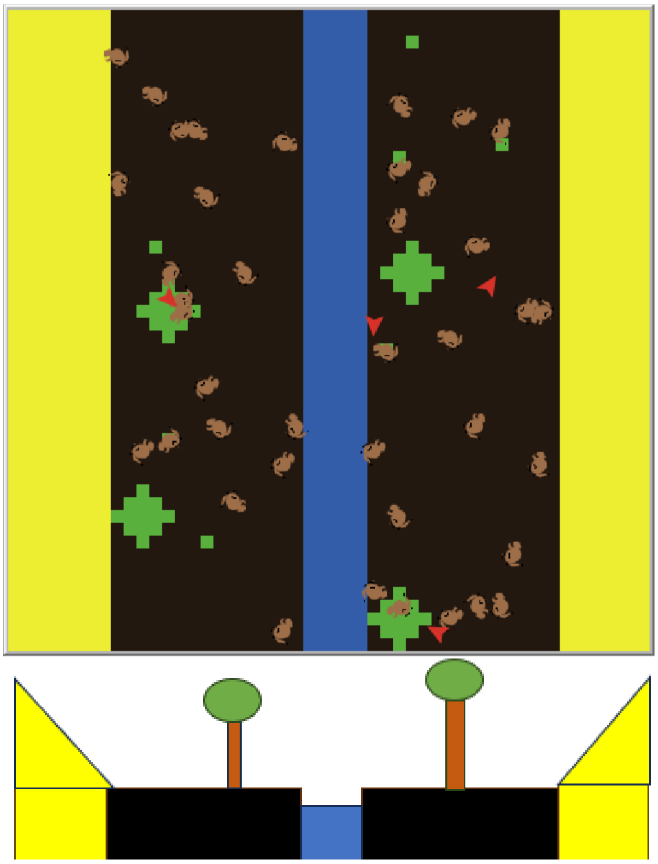
Figure 2.1 Conceptual diagram showing the overview of processes used in the model.

2.3.4 Initialisation

The world is split into floodplains, rivers, levees, trees, shrubs, floods. The world is made of 49 * 49 square patches. These square patches are defined by their elevation and their patch type. The topography of the landscape with the different patch types is initialized when the model starts. Beaver families are randomly placed in this environment, particularly concentrated in the floodplains. Each beaver family and competitor are also provided with a value of energy selected before the run. This energy is on a Likert scale and a maximum value is 60.

Trees and shrubs are placed within fixed positions (see Figure 2.2).

The model world is created using a valley effect. In other words, the highest areas are the levees (around 9m) from which the elevation reduces in a slope from the floodplain till the river. The river elevation is at 0m. The trees are randomly assigned heights between 8 – 12 m while all shrubs are 4m. As such, when the model is run, several patches may become flooded depending on the level of high water.



Yellow : levees on each side of the river.
Blue : river.
Green : trees and shrubs.
Brown : beavers.
Red : competitors or badgers.

Figure 2.2 Model world when you press "setup" (top view and side view).

2.3.5 Input data

The input parameters described in Table 2.2 are used as input data. The input parameters selected at the start of the model can also be manipulated during run-time.

2.3.6 Sub-models

All major process used in a model are broken down into independent sub models (Railsback & Grimm, 2019). These sub models are capable of ultimately mimicking the process as described in paragraph 2.3.3 Process overview and scheduling. This section therefore describes the several components of sub models used in the model.

Create-flooding is the first sub-model to get initialized within the "go" function and is used to create the effect of flooding. Based on the level of high water, the river gets full and is assumed to initiate the flooding. Patch-type of the patch will then be changed to floods if the elevation of the patch type is less than the level of flooding.

Decide-to-dig is a sub model that is called to determine the choice of a beaver family's safe place. This is determined by the global variables of windchill and duration of high water (see Appendix A) :

- When windchill is between 0 to 10 degrees Celsius and the duration of high water is less than 3 days, then the initial-decision is **Not to Dig**.
- When windchill is between -10 and 0 and the duration of high water is less than 3, then initial-decision is **Not to Dig**.
- When the windchill is between -10 and 10 degrees Celsius and the duration of high water is greater than 3 days, then the initial-decision is **To Dig**.

If the decision is to dig, then the safe place must be one where the elevation of the patch is greater than the level of high-water and must be a levee or floodplain. If the decision is not to dig, then the *target-patch* must be one where elevation of the patch is greater than the level of high-water and must be levee, floodplain, tree, or shrubs.

find-target-patch is another sub model used to decide which patch will be the beaver family's or competitor's safe place. Based on the decision to dig, the beaver family and competitor must choose a safe place appropriately. They first calculate how many steps they can take based on their energy provided as input data. The maximum number of steps becomes its potential radius within which a safe place needs to be found. If such a patch cannot be found within the said radius, then the radius is increased by 5. As a last resort, the beaver family or competitor chooses any patch where elevation of the patch is greater than the water level.

Once a safe place has been found, the beaver family or competitor then calculates the exact distance to the patch within *calculate-target-patch*.

The beaver family is also expected to *avoid-others* by taking the input from the Radius-Beaver slider to indicate the distance of avoidance.

The *move* submodel defines exactly how the beaver family moves during high water situation. The beaver family and competitor face their safe place and move directly towards it. They will continue moving as long as their energy level is more than 0 and they still have some distance to their safe place.

Energy is another sub model that dictates if the beaver family or competitor will reach its target. With every possible step that they make, they must check the patch-type of the patch it is on. If the patch-type is of river or floods, then the *energy* is reduced by 10. If not, it is reduced by 3.

Find-success-failure is used to ascertain if the beaver family or competitor has completed the task it has set to. The task is considered a success in two conditions: if the decision was to dig and then end up on a patch of levee or floodplain, then it is termed as success. In the other case, if their decision was not to dig, it is considered a success if the beaver family or competitor ends up on any patch except rivers or floods and the elevation of the patch is greater than the level of high water. In this manner, the probability of digging is ascertained as the number of beaver families that have successfully dug divided by the initial number of beavers in the model.

Mid-way-check is a submodel where the beaver family is asked to check if its safe place is occupied when the distance to their safe place is less than 5 patches or when energy is less than 10. If the safe place is occupied, the beaver family and competitor are required to find a new safe place using *find-target-patch*. If not, it may continue moving.

Finally, we have the *stop-entirely* submodel where the beaver family are requested to stop once *distance-to-target* or *energy* is equal to or less than 0. The model is stopped when all beaver families and competitors have stopped moving.

2.3.7 Code processing and access

The code used in the model can be accessed using a NetLogo file (.nlogo) when requested by the authors of this report[4]. The .nlogo file can then be uploaded on NetLogo Web (can be accessed via https://www.netlogoweb.org/launch#https://www.netlogoweb.org/) to run the model.

[4] Frans.vandenberg@deltares.nl or Aditi.natarajan@deltares.nl

3 Results

This research investigates the feasibility of using an agent-based model with the assumed conditions to predict the behavior of beavers during high water. The assumed conditions are discussed with ecologists and a zoologist and are used as input parameters in this model. The input parameters include windchill, duration of high water, level of high water, number of competitors, and number of beaver families. The interaction of the mentioned parameters has an impact on the beaver family's choices for finding safety and therefore, their tendency to dig into levees. The model is set up with these relevant variables that can be manipulated, changed or turned off.

Competitors are also included in this study as a variable that affects the direction of movement as beaver families are assumed to avoid other beaver families and other competitors (e.g. badgers). This was done to create a certain level of complexity to see if the agents in this model were able to adapt to a new situation. When the model is run, the beaver is seen choosing a safe place based on the environmental variables and then proceeds in the direction of its target. Its journey to the target when confronted with obstacles or rapidly losing energy, forces the beaver to change its route or its target. The model is finally stopped when all beavers have either reached their target or have lost all energy to move (see Figure 3.1).

After the model stops running, the probability of the beavers digging into levees with the given environmental conditions is calculated (see Figure 3.2). As such, this trial model answers the main research question using the probability of digging as a proxy for the risk that it poses to levee structures. For each given combination of variables provided in the 'Interface' tab in NetLogo, a probability of digging is derived. There is still quite some uncertainty around the behaviour of beavers and the decisions they would make when faced with an obstacle. The absolutism inherent in the choices that beaver families make in this version is very deterministic. We hope to overcome this using the randomness employed with the starting patches that each beaver family is assigned at the start of the simulation as well as the avoidance radius.

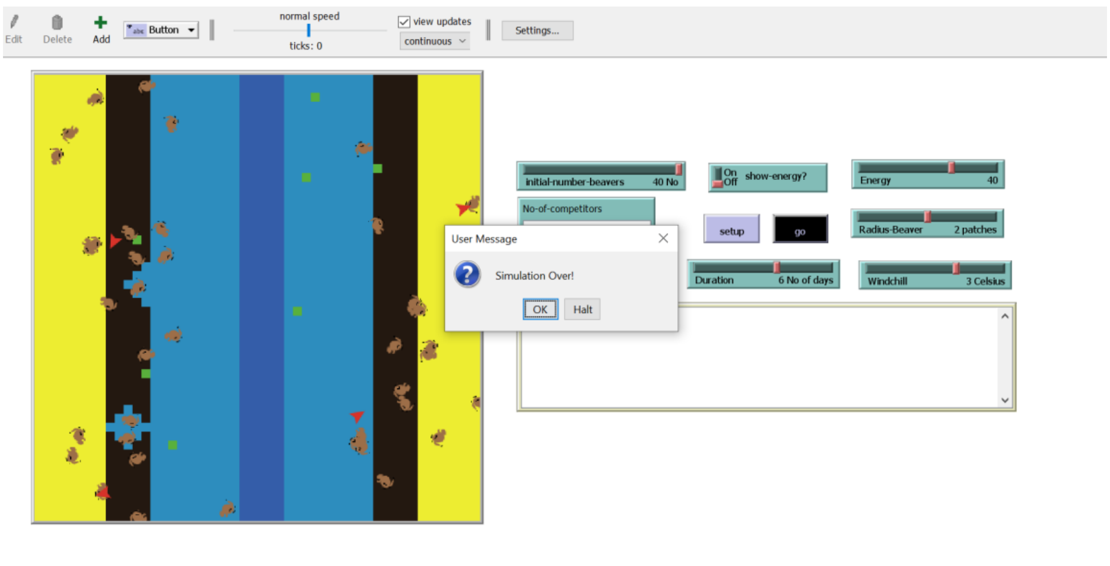


Figure 3.1 NetLogo Interface tab when the model is over i.e. all beavers have either found their safe place or have run out of energy.

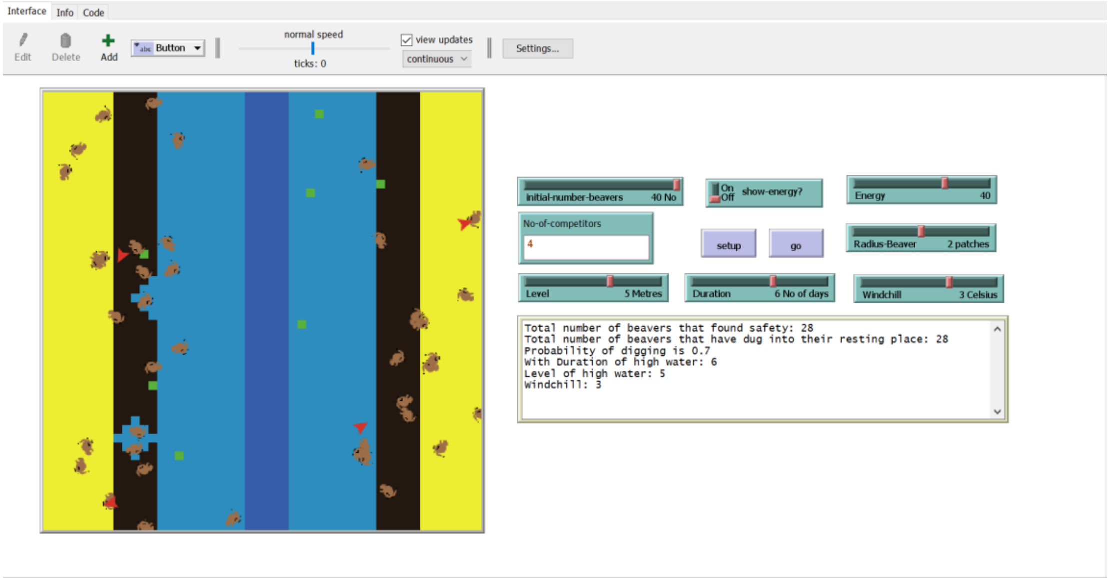


Figure 3.2 The NetLogo Interface tab calculates and shows the output (probability of digging) in the box on the right side as shown in the image

4 Conclusions and recommendations

4.1 Concluding statement

The reintroduction of the beaver in the Netherlands in 1988 and its protected status have led to an exponential growth of the beaver. The water authorities in the Netherlands indicate that there is a major problem with water safety due to the presence of the beaver (Van den Berg & Koelewijn, 2023). The beaver digs into earthen structures such as flood defenses and thus reduces the water safety of the flood defense. In recent years they have also been digging in the flood defenses at a high water level.

In this case study we investigated whether it is possible to use Agent-Based Modelling (ABM) to simulate the behavior of beavers during high water and thus determine the chance that they will dig into the levee. This information can serve as input to determine dike safety during high water. Following this, mitigations can be assessed. For example, the creation of higher areas in floodplains, netting, sheet piles, stones, etc. NetLogo also allows the use of GIS data which would also allow the assessment to be spatial in nature. The recommendations provided in this report will also serve as a good starting point for the potential future of agent-based models.

Overall, ABM helps to steer research in a new direction. Focus on what triggers certain digging patterns is an important step towards safeguarding levee and dike structures and focuses on a more system-based approach. Greater complexity within the model, however, is required to gain more insight into their digging patterns. ABM using NetLogo is also easily upgradable, web-based, and open-source. Given the feasibility of ABM to provide this insight as shown in this research, we hope that the mitigation strategies used based on this approach will prove useful in the long run, both for the beavers and the human population that the levees protect.

4.2 Recommendations

The first attempt at an agent-based model to understand beaver digging patterns kept the movement of beavers and its decision-making very simple through several model assumptions as explained in 0 under Process Overview and Scheduling.

Based on this, we provide the following recommendations for the next versions:

- *Inclusion of variability in vegetation* – We found that this strongly affects the beavers choice of where to burrow following the conversation with our expert panel. This is also reflected in the literature that they would choose certain shrubs or wooded areas more than others (Brazier et al., 2021; Nolet et al., 1994).
- While this report showcases the attempt to use ABM for simulating beaver digging patterns, the following versions can do so along with the use of graphs for gaining more *probability patterns in different scenarios*.
- Beavers also choose areas where the water level is sufficient to keep safe from other predators and competition (Brazier et al., 2021; Nica et al., 2022). The capacity to also *dig into areas below the water level* needs to be accounted for.
- Other research indicated that beavers tend to also choose burrows in areas where there is *natural inundation in the banks* (Nica et al., 2022). The next version can also therefore account to play with such measures to see if the beaver would choose these locations instead of levees.

- *Differences in the age of the beavers* also need to be accounted for. This would also provide an opportunity to create new agents such as the lonely beavers. Lonely beavers are beavers above ages of two who must leave their family to find a new territory.
- *Territory* is also an important feature. The current trial uses the avoidance radius as a proxy to understand territory. However, this should also be included in the following versions.
- *Comparing observations to models* is also another way of verifying the validity of the model to see if the interaction of the input parameters chosen results in realistic predictions (Grimm & Railsback, 2012).

Looking ahead to 2024
It is recommended to move from a conceptual world to existing situations and take all the recommendations from above into account. This will make the beaver's behaviour more concrete. With the help of the ABM drawn up and the D-Eco impact[5] developed by Deltares, the behaviour of the beaver in an existing environment is modelled. This makes it possible to determine in an existing situation where there is a chance that the beaver will dig, based on various parameters, when high water approaches, so that measures can be taken to reduce the risk of flooding due to digs. It will also be determined where the less attractive areas for beavers are. For existing situations, cooperation can be found with Water Authorities.

[5] https://www.deltares.nl/en/software-and-data/products/d-eco-impact

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A Model Assumptions

The model assumptions for the ABM are based on a list drawn up in collaboration with a beaver expert, Vilmar Dijkstra (Zoogdierenvereniging), Daan Bos (ecologist and lector at Van Hall Larenstein University of Applied Sciences) and Marc Weeber (Deltares). This list is given below.

Sort	Parameter	Normal situation (N)/ High water situation (HW	Remarks	Indicator	Used in model	Group
1	**Availability of alternative resting place**	HW	The quality of this alternative is of course very important. Are there other place inwards, availibility of waterways inward. Territory can exists of 1 -100 burrows. Alternative has to be stable for a long period.	Number/ km^2	Yes	E&W
2	**Air temperature**	HW	Also the windchill plays a big role- combination with wind direction. The bigger the animal, less effect of the windchill. When the beaver is in a burow he will use less energy.	° Celsius	Yes, as aboundary condition	E&W
3	**Wind direction & - speed**	HW		Orientation/ km/h	Yes, as aboundary condition	E&W
4	**Precipitation (rain/hail/snow)**	HW		mm/ week	Yes, as aboundary condition	E&W
3	**Kind of vegetation**	N HW	With little vegetation, there is less chance that they will dig. Vegetation like: roots, certain plants, thicket. There are 150/200 species of plants that beavers eat.	-	Yes, with or without vegetation	E&W
4	**Age Beaver**	HW	Beavers start digging from 0,5 years old, but will be mature at 2 years old. They will leave their family at 2 years old.	years (average 7-8, max 15)	Yes, as boundary condition. Super individual	A, C & B
5	**with or without established territory**	N HW	Based upon age (knowledge based)	yes/ no	-	A, C & B
6	**Social status/territory drift**	N HW	Social status in animals refers to the hierarchical position an individual holds within its social group, often determined by factors like dominance, access to resources, and reproductive opportunities. It can be quantified by observing behaviors such as aggression, submission, and priority of access to limited resources. Also related to other animals. Lonely beavers are looking for a place to stay. If the habitat is suitable, there can be up to 100 burrows in one territory. Based upon age (knowledge based)	-	-	A, C & B
7	**Relation to other agents nearby**	HW	In this case other agents are beavers. This is one of the factors which can be investigated with earmarked beavers, there are signs that this could be a factor. Scent marks on the slopes play an important role. (Is this family or not otherwise very hostile reaction). Also relation to other animals, predators, boats. Based upon age (knowledge based)	friendly, hostily, neutral, fled, etc	-	A, C & B
8	**Timing in the season**	HW	Less burrowing in summer/late spring because of the temperature. Until now no signs that beavers behave different if they have young offspring (highwater during may/june) An important factorin the winter period. **Correlated with windchill.**	Season	yes, as aboundary condition. Winter	E&W
9	**sex beaver**	N HW		male/ female	yes, as aboundary condition. One family male & female and 2	A, C & B
10	**Steepness slope of the levee**	N HW		%	-	E&W
11	**Water depth**	N		m	-	E&W
12	**obstruction (revetment, netting, riprap)**	N HW		sort	-	E&W
13	**Duration high water situation**	HW	Together with height of the water. The longer HW interfers with wind chill the more and more they wil look for a shelter.	Hours	-	E&W
14	**Water temperature**	N HW	Near cooling water systems (no data known)	Degrees Celsius	-	E&W
15	**Family size**	N HW	If they have children, they are more likely to dig. How many beaverkids per family?	-	-	A, C & B
16	**Origin/experience in this territory**	N HW	Own territory realted	max xx m	-	A, C & B
17	**Experience with previous high water**	HW	Important, but difficult to model, correlated with age realated with #16	-	-	A, C & B
18	**Moving out offspring**	HW		-	-	A, C & B
19	**Natural enemies**	N HW	Wolf, sea eagle	-	-	A, C & B
20	**Protected status**	N HW		yes/ no	-	A, C & B
21	**Dike material**	N HW	Not important for beaver. If they want to dig a hole they will cut through roots aswell. Perhaps a lime (2%) clay mixture as a top layer helps against digging.	Clay/ Peat/sand	-	E&W

Group E & W = Environment & wheather conditions
Group A, C & B = Attributes, capabilities, and behaviors of the agents in the model

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