TWO STRATEGIES OF AGENT-BASED MODELLING APPLICATION FOR MANAGEMENT OF LAKELAND LANDSCAPES AT A REGIONAL SCALE

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Abstract: This work presents two different strategies of ABM for management of selected lakeland landscapes and their impact on sustainable development. Two different lakeland research areas as well as two different sets of agents and their decision rules were compared. In Strategy 1 decisions made by farmers and their influence on the land use/cover pattern as well as the indirect consequence of phosphorus and nitrogen delivery to the water bodies were investigated. In this strategy, a group of farmer agents is encouraged to participate in an agri-environmental program. The Strategy 2 combines the decisions of farmers, foresters and local authorities. The agents in the model share a common goal to produce a spatial plan. The land use/cover patterns arising from different attitudes and decision rules of the involved actors were investigated. As the basic spatial unit, the first strategy employed a landscape unit, i.e. lake catchment whereas the second strategy used an administrative unit, i.e. commune. Both strategies resulted in different land use/cover patterns and changes, which were evaluated in terms of sustainability policy. The main conclusion for Strategy 1 is that during 5 years of farmer's participation in the agri-environmental program, there was significant decrease of nutrient leaching to the lake. The main conclusion for Strategy 2 should be stated that cooperating of the agents is better for the natural environment than the competitions between them. In both strategies, agents' decisions influence the environment but different spatial units of analysis express this environment.

Key words: agent-based modelling (ABM), land use/cover change (LUCC), geographical information systems (GIS), decision-making modelling, lakeland landscapes, Poland

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Introduction

Lakes take up an exceptional place in the structure of post-glacial landscape, constitute an inherent component of the hydrological cycle and participate in the process of sedimentation of mineral and organic matter. They differ in morphometric parameters, size and structure of drainage area and its hydrological regimes. The surroundings can greatly affect the water bodies therefore lakes should not be examined without their position in the landscape (Walsh et al. 2003, Soranno et al. 1996, 2009). From the environmental point of view, lakes perform many functions (Kostrzewski 2008):

– hydrological – includes the role of lakes in water circulation (especially its retentive capacity),

- morphological and lithological – includes the system of supply, circulation, deposition and carrying out of the matter,
- ecological – provides habitat to aquatic and semiaquatic living organisms,
- economical – includes the significance of lakes as a resource in geographical environment for human purposes,
- touristic and recreational – focuses on natural values of lakelands and their meaning in tourism and recreation,
- landscape – contains the influence of lakeland functioning on the development and changes of the landscape.

The large diversity of limnological and social characteristics of lakeland landscapes contributes to the complex relationships between human and aquatic systems. Nowadays lakes and lakeland landscapes are often objects of interdisciplinary research and their past and present-day state and functioning are used as an indicator of landscape evolution and human – environment interactions (Soranno et al. 1996, 2009, 2010, Walsh et al. 2003, Cheruvelil et al. 2008). The growing body of knowledge demonstrates that human impact may cause decrease of water quality due to nutrient flow especially from agricultural areas (Zwoliński 1998, Strayer et al. 2003, Foley et al. 2005, Hillbricht-Ilkowska 2005). Policy makers, farmers and residents are more and more aware of the damage they may cause to the environment because of bad land management practices. As a result, new management policies are being implemented in lakelands around the world.

Lakes are strongly linked to their watersheds. The type, distance, size and history of land cover/land use determines the quantity and quality of water as well as the amounts and types of sediment, nutrients and chemicals that are carried into the lake from their catchment. The eutrophication process is determined by both natural and anthropogenic factors. One of the more pronounced is Land Use/Cover Change (LUCC) associated with agriculture, urbanization and forestry, which play a significant role in the acceleration of the natural ageing of lakes (Soranno et al. 1996, 2009, 2010, Johnson et al. 1997, Walsh et al. 2003, Jones et al. 2004, Bajkiewicz-Grabowska 2008, Bremigan et al. 2008, Cheruvelil et al. 2008, Kostrzewski 2008, Dzieszko 2014, Giełda-Pinas et al. 2015).

Land surface is a very dynamic canvas on which human and natural systems interact. The many factors influencing LUCC have been the focus of scientific study across multiple disciplines, locations and scales (Parker et al. 2003). However, direct measurements alone are not sufficient to provide an understanding of the drivers of change. To cope with the complexity of land systems, agent-based models (ABM) have recently gained momentum in LUCC modelling (i.e. Brown 2006). ABM allows describing the decision-making architecture of the key actors in the geoecosystem under study.

Agent-based models are computational laboratories that allow for simulating different scenarios to show how different farmer attitudes and farming procedures affect water ecosystem functioning and create diverse patterns of LUCC. The modelling of social interactions is still primitive in ABM of land use. While GIS monitoring tools are useful in observing the empirical results of land use change, the data they provide are often not useful in capturing the fundamental policies, social drivers and unseen factors that show how landscapes are transformed.

Agents are the crucial component of ABM (Ligmann-Zielińska 2009). They are autonomous, they share an environment through agent communication and interaction and they make decisions that tie behaviour to the environment. As many authors state (Epstein and Axtell 1996, Conte et al. 1997, Weiss 1999, Janssen and Jager 2000, Dzieszko et al. 2013) agents have been used to represent a wide variety of entities, including atoms, biological cells, animals, people and organizations. ABMs are well suited for modelling interactions and feedbacks between socioeconomic and biophysical environments (Berger 2001, Parker et al. 2003, Matthews et al. 2007, Monticino et al. 2007, Valbuena et al. 2010).

The multi-actor based approaches to LULC models enable to include the 'actor-factor' interrelationship in the development and analysis of spatial scenarios. However, there is still a need to gain insight into the extent to which actor decision making affects their spatial environment (Ligtenberg et al. 2004). A central focus of planning is decision-making in the present to influence future developments for the benefit of future community (Myers 2001). For a long time, planning practice aimed at regulation of social dynamics through activities like allocating, zoning and protecting (Epstein and Axtell 1996). Over the last few decades, however, that governments started to collaborate with relevant stakeholders (like owners, private developers or other interest groups) when exploring future planning and design options (Slager et al. 2007). Consequently, it is essential to design a model in which actors have the common goal to produce a spatial plan acceptable by all involved individuals. A spatial plan is the result of a negotiation and deliberation among actors with different and sometimes orthogonal views upon the possible scenarios of a spatial environment. By linking land change data with data from decision makers, applied strategies are well positioned to move beyond description toward an understanding of land cover and land use change.

According to Waard (2005) actor-based process models like ABM can contribute to the improvement of landscape planning by:

1. bridging the gap between planning and realization,
2. improving communication and collaboration of stakeholders in planning and development,
3. facilitating and expanding future-focused thinking,
4. supporting decision-making, and
5. monitoring actual development compared to the developed scenarios and established policies.

The objective of this project was to investigate the role of ecological management practices and their influence on water bodies in Poznań Lakeland District and Gniezno Lakeland District in Wielkopolska Lowland. Specifically, this project focused on applying two different strategies of ABM (i.e. Strategy 1 for lake catchment and Strategy 2 for commune) for management of lakeland landscapes and assess their impact on sustainable development of investigated areas. This project demonstrated how popularization of good management practices and ecological farming supported by a suitable program might change land use/cover pattern and therefore nutrient flow to the water bodies improving water quality in lakes. The analysis determined the usefulness of the ABM methodology for management of lakeland landscape. The comparison of the presented strategies allowed for identification of attitudes to decision-making that result in more sustainable environment. This research also investigated the level of awareness of environmental hazards.

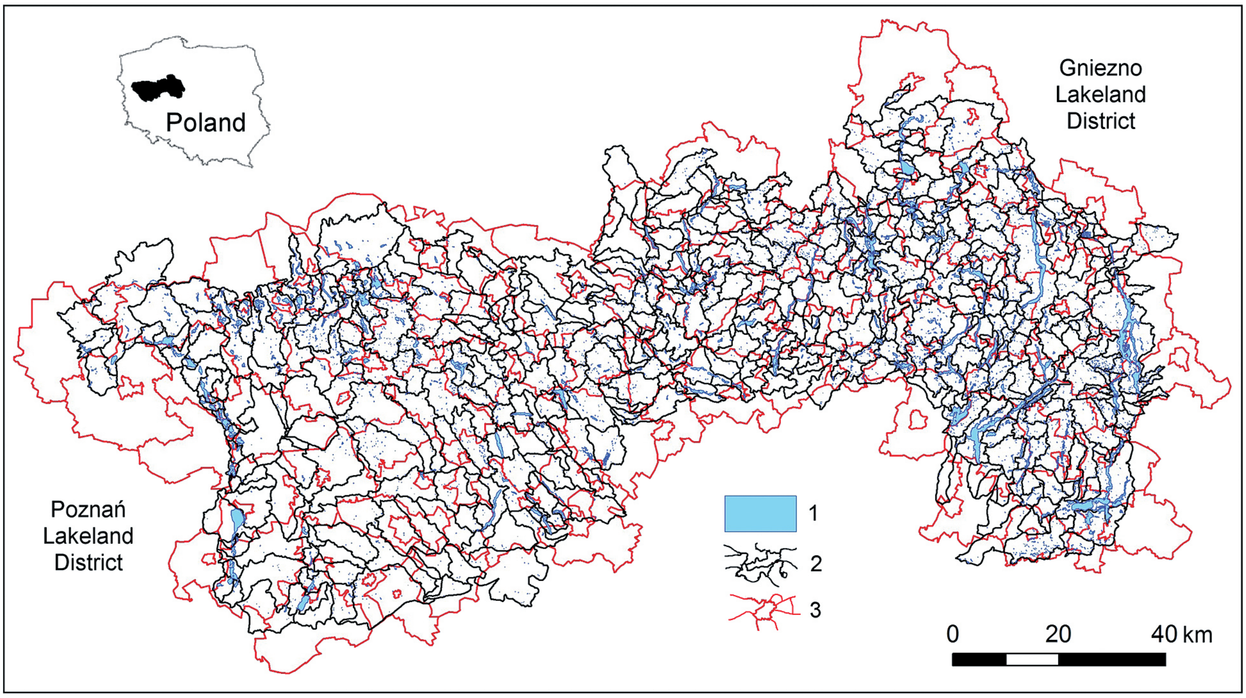

Fig. 1. Location of Poznań and Gniezno Lakeland Districts (PLD and GLD, respectively).
1 – lakes, 2 – border of catchments, 3 – border of communes.

Study area

Poland is a country with spatially diversified natural and economic conditions, affecting the leading economy sectors and the quality of life as well as functioning of its inhabitants. Polish Lowland is one of the regions within the eastern part of the North European Plain with the basic economic activity associated with the agricultural sector. Gniezno Lakeland District (GLD) and Poznań Lakeland District (PLD) are located in the central-west Poland and the central part of Polish Plain (Fig. 1). This region covers an area of approximately 8,384.2 square kilometres.

Both lakeland landscapes have a long history strictly connected with human activity. Transforming and in many cases degrading processes are present in the study area and thou crucial for natural environment, further economic and social development. Both districts are located close to Poznań, city with around 500,000 citizens. The most significant role for lakes in the region still plays farming (Giełda-Pinas 2012). Our study area is characterized by differential postglacial landscape with agricultural areas as an exceedingly dominating land cover type. The presented area is highly diversified in terms of landforms, as well as sedimentary deposits. This postglacial relief is dominated by ground moraines, tunnel-valleys and ribbon lakes. It is built by Quaternary sediments deposited in two phases of the last glaciation (Weichselian). The lake factor equals 1.8% in PLD and 4.0% in GLD. According to Hydrographic Division Map of Poland (IMGW 2007), the total number of lakes bigger than 1 ha is 218 for PLD and 428 for GLD, respectively. The basic morphometric characteristics of the investigated lakes suggest that the morphometric differentiation among the datasets is significant with both small lakes (with area less than 50 ha) and big lakes (with area bigger than 2,500 ha) present. Among the investigated lakes there are very shallow lakes (i.e. Barlin Lake (PLD) – average depth 1.5 m and Brzeźno (GLD) – 1.8 m) and very deep lakes (i.e. Śremskie Lake (PLD) – average depth 20.7 m and Powidzkie Lake (GLD) – 12.7 m).

Land cover composition in the two districts is presented in Table 1. Almost 60% of the PLD belongs to arable land and 74% of the GLD represents agricultural areas. Taking into account the past 25-year LULC trend, there is a small land use/cover transformation during that time (~1% – based on CORINE Land Cover 1990–2006, EEA 2006). In general, the developed areas, woodlands and water bodies increased, while agricultural and swampy areas decreased during that

Table 1. Pattern of land cover/use for Gniezno and Poznań Lakeland Districts (acc. to CORINE Land Cover; EEA 2006).

Level 1 classes	Code	Level 2 classes	Gniezno Lakeland		Poznań Lakeland	
			[km²]	[%]	[km²]	[%]
1. Artificial surfaces	1.1	Urban fabric	74.20	1.76	125.82	3.03
	1.2	Industrial, commercial and transport units	21.30	0.50	25.72	0.62
	1.3	Mine, dump and construction sites	27.60	0.65	4.07	0.10
	1.4	Artificial, non-agricultural vegetated areas	9.14	0.22	21.79	0.52
2. Agricultural areas	2.1	Arable land	2738.46	64.80	2426.22	58.35
	2.2	Permanent crops	0.34	0.01	5.24	0.13
	2.3	Pastures	136.80	3.24	165.10	3.97
	2.4	Heterogeneous agricultural areas	254.53	6.02	187.53	4.51
3. Forest and semi natural areas	3.1	Forests	789.84	18.69	1084.69	26.09
	3.2	Scrub and/or herbaceous vegetation associations	18.81	0.45	36.26	0.87
	3.3	Open spaces with little or no vegetation	–		0.99	0.02
4. Wetlands	4.1	Inland wetlands	18.81	0.45	8.21	0.20
	4.2	Maritime wetlands	–		–	
5. Water bodies	5.1	Inland waters	136.16	3.22	66.57	1.60
	5.2	Marine waters	–		–	
Sum			4225.99	100.00	4158.21	100.00

period. According to Dzieszko (2014) the biggest change in the last decade of the twentieth century took place in the type of permanent crops. The three land cover types (urban fabric, forests and scrub and/or herbaceous vegetation) increased their areas significantly. In the first six years of XXI century, the most dynamic type in the research area was arable land.

Agriculture in both Poznań Lakeland Landscape and Gniezno Lakeland Landscape is based on small, private farms. The average size is only 13.5 ha (in 2014). Agricultural land parcels are usually dispersed with the average size of 1 ha (GUS 2015). Since 2014, there have been some important changes in Polish agriculture techniques due to European Union's policy like introduction the offer of agri-enviornmental program. The goal of this program is to initiate the idea of sustainable agriculture, whose aim is to preserve or to reconstruct natural values of the countryside. The sustainable management of natural resources including lakes and hydrological elements like small ponds or lakes, preserving the unique landscape with the mosaic-like structure of the fields and numerous field margins may be archived thanks to farmers consent to cooperate.

Due to the complexity of the implemented ABM and the prohibitively high computational cost of the simulations, we further narrowed down our study sites to two representative spatial units: one lake catchment from GLD and one commune from PLD cantered around a selected lake (Fig. 2). For GLD, we selected the catchment of Lake Gorzuchowskie, which represents a typical rural catchment with almost 87.8% of the area in agricultural land (artificial land covers about 5.9%, waters nearly 4.6%, pasture 1.6%, and forest a mere 0.3% of the catchment). Gorzuchowskie Lake's area is 93.3 ha and the average depth is 2.5 m. Gorzuchowskie Lake was investigated to examine the hydrochemical state of lake water. Water quality in the lake is associated with many physical and chemical parameters, which are indirectly connected to lake morphometry and climatic conditions in the region, and directly to types of land cover and land use of its catchment.

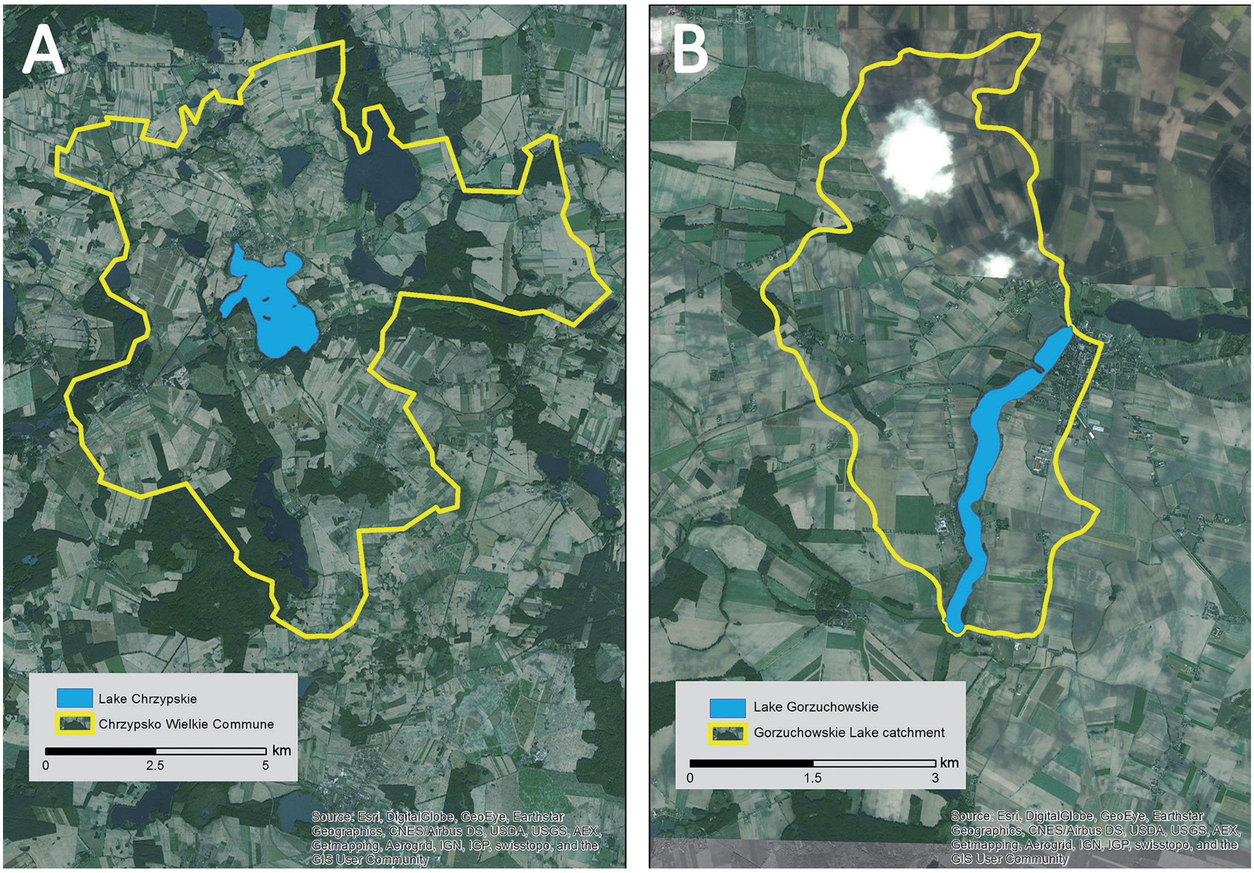

Fig. 2. Location of Chrzypsko Wielkie commune (A) in PLD and Lake Gorzuchowskie catchment (B) in GLD (source: Landsat 7 imagery).

The most important indicators of water pollution are phosphorus and nitrogen concentration (Morrice et al. 2008). The results of the field tests and laboratory analyses (August 2012) show that Gorzuchowskie Lake is an example of a eutrophic lake (average NH_4^+ = 0.48 mg dm^{-3} and P = 0.25 mg dm^{-3}), so all ecological activities are necessary to improve water quality.

For PLD, we chose Chrzypskie Lake as a representative object of detailed investigation. This lake is located in Commune of Chrzypsko Wielkie, which has an area of 83.4 square kilometres. Only 1% of the area of the commune is occupied by urban areas whereas 72% of the commune's area is covered by agricultural areas. Forests cover 17% of the commune and lakes constitute 10% of its area. Chrzypskie Lake has an area of 304 ha. It's mean depth equals 6.1 m while maximum depth is 15 m. Chrzypskie Lake is also an example of a eutrophic lake with average NH_4^+ = 0.41 mg dm^{-3} and P = 0.29 mg dm^{-3} (data collected in July 2010). Similarly to Gorzuchowskie Lake, Chrzypskie Lake also needs a full range of ecological activities to improve the quality of its water.

Data and methods

Most mathematical approaches require well-defined descriptions of the interactions between the processes amongst subsystems. In cases investigated here, ABM actors have a common interest to participate in the processes of land use development or transformation. During a decision-making process, an actor generates preferences of how the spatial environment needs to be organized in respect agent's desires and the overall goal. Agents and their decisions are spatially dependent, thus linking the ABM and GIS is a natural choice for this research (Fig. 3). ABM requires object-oriented modelling and spatial modelling requires GIS. ABM does not have sufficient tools for visualization, analysis, and storage of spatial data. On the other hand, one of the biggest weaknesses of GIS, in the context of modelling natural systems is the lack of adequate tools to carry out the time-dependent analysis (Langran 1992, Goodchild 2005, Peuquet 2005). Consequently, to determine the spatial relationships of agents we can use GIS spatial analysis techniques. The output layer of GIS analysis can serve as the input layer for agents in the decision-making process in ABM. This is why coupling GIS and ABM is so important. The land use/cover data is obtained from dataset CORINE Land Cover (EEA 2006).

Agents

In Strategy 1, an ABM was created to increase the knowledge about LULC that may appear in the individual catchment due to farmer's decision-making (Fig. 3). Since agricultural areas still occupy the largest space in the selected study sites, land owners – farmers constitute the leading decision making group that influences land/use changes in this region.

Farmers' decisions are the consequences of the implementation of the agri-environmental programme (2007–2013). The goal of this programme is to provide pro-ecological and sustainable development of agricultural areas. According to the European Union intentions, it was a programme complementary to the Common Agricultural Policy in a Member State. Programme participation is voluntary and conditional on agency approval. Land use/cover changes based on the program packages used in the model, may go only in two directions from agricultural to forest or pasture/fallow land. Farmers in the model possess an average size of a farm land which in this region is 15 ha divided into land parcels. Farmers have the knowledge about the land parcels they own and the decision if they want to join the programme is independent of the other farmers, but subsidiary to the location.

The main goal of the ABM applied to PLD was evaluating land use changes using three different types of agents (Fig. 3). The use of ABM allowed for investigating the influence of decision-making process on final land use pattern. The goal of the model was also to investigate the modelling results influenced by applied scenarios as well as to determine a Commune – an area where land cover transitions to anthropogenic i.e. the model simulates a decision about allocating new residential and industrial areas. If a commune assumes that arable land or pastures are going to expand, it tries to fulfil multiple objectives: farmers' expectations and preferences as well as local economic and environmental goals. If a commune assumes that forests are going to expand,

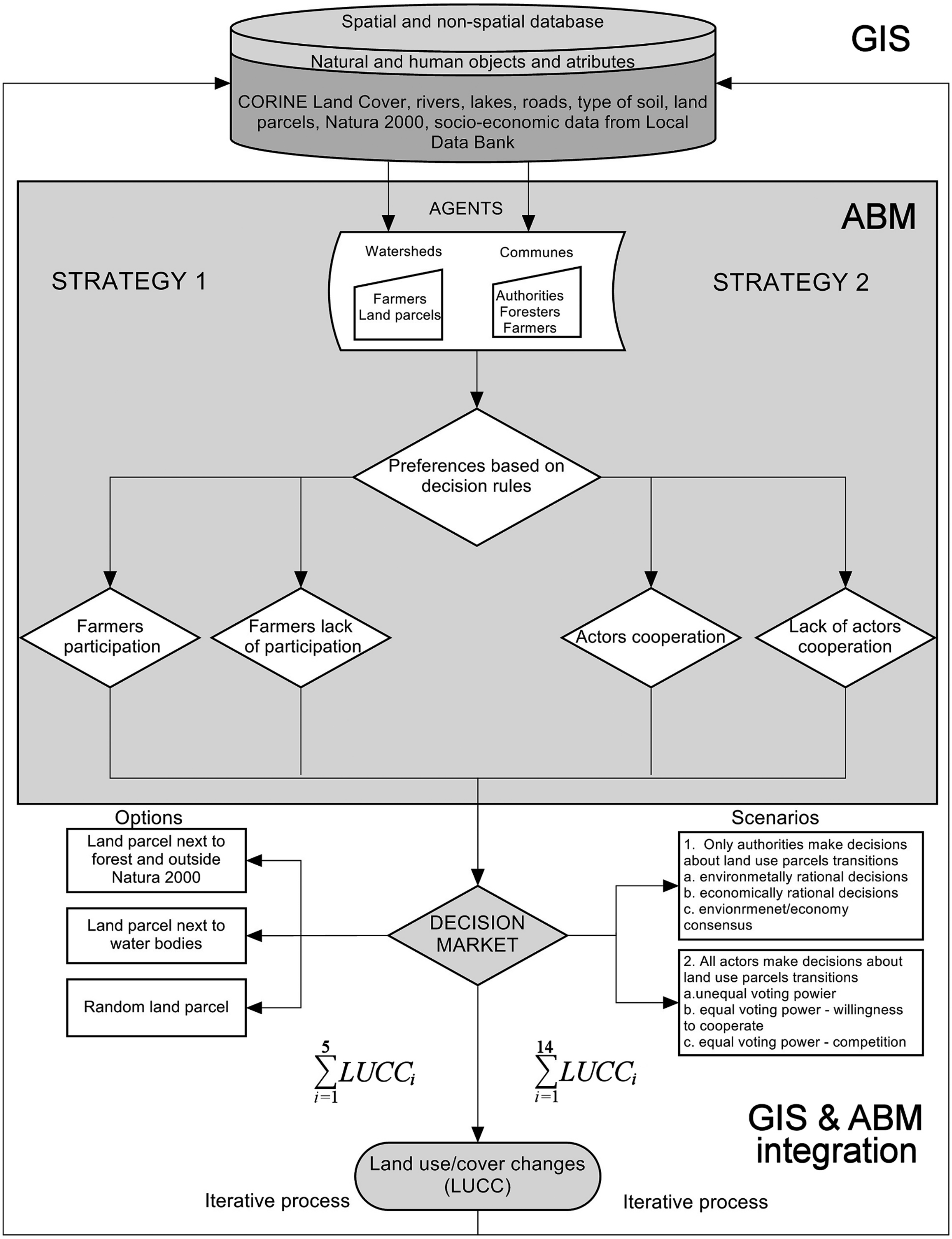

Fig. 3. Flowchart for integration of geographical information system and agent based modelling according to the Strategy 1 (lake catchment approach) and Strategy 2 (commune approach).

then it tries to fulfil foresters' expectations and preferences but it also care about its economic and environmental business.

Land use planning and land use/cover pattern changes are complex (Couclelis 1987, Itami 1994). Four crucial components cause this complexity. These are:

Actors – they can represent individuals or groups in the process of spatial planning. In PLD arable land and forests are the most important land use types. Commune is responsible for planning politics and cares about land transformation. Consequently commune, farmers and foresters should become the actors that are going to create the spatial plan for investigated landscape. Commune can make decisions concerning all land use transitions while farmers and foresters can make decisions about agricultural areas and forests, respectively.

Spatial environment – not all locations in a spatial environment are equally suitable for the various types of spatial functions. A location may show restrictions, opportunities or threats to a specific spatial function. In Strategy 2, spatial environment is expressed by a land use map of five types. These are: anthropogenic areas, arable land, forests, wetlands and water bodies. After creating their preferences, the actors send the information to the decision market. The result of the decision market is the updated (changed) land use map, which becomes an input map for the next step. It was assumed that the spatial environment develops in different ways depending on actors' decision rules, which differ in every investigated scenario. The hypotheses say that cooperative and multi-agent scenarios would promote spatial contiguity and compactness.

Actor-based processes – actors impose their spatial intentions upon their interest in the spatial organization. They are driven by their motivation to narrow the gap between the actor's perception of the current organization and their vision of the future organization. In Strategy 2 agents first analyse the information about their natural environment, which is represented by spatial data. Then the agents formulate their preferences (presented and described in next section). Finally, they try to allocate land transitions according to their decision rules, which directly correspond to their preferences. Agents can compete or cooperate with each other. Investigating the influence of their attitude on final land use pattern is the main goal of presented model.

Self-regulating processes – the environment itself is constantly changing by human activity. Presented strategies are bottom-up organized. Model can be considered as a laboratory to explore how actor's decisions influence the land use pattern that emerge during simulation process.

Decision market

Flowcharts of the two ABM application strategies and their respective case studies were unified into one diagram to show the differences between the models and to expose whole information flow for the presented work (Fig. 3).

Both strategies require a spatial and a non-spatial database to initialize the simulation. Spatial data such as CORINE Land Cover, river network, lakes etc. are available for actors to use in the decision process. Database is a pure GIS component of the model. It is crucial to notice that Strategy 1 concerns watersheds as a basic landscape unit while in Strategy 2 communes are basic landscape unit. In Strategy 2 there are three types of generic agents which are authorities, farmers and foresters. Their preferences can be to cooperate or to not cooperate. These attitudes influence the decision market and the decision rules. In the first strategy, only farmers make decisions using land parcels as the decision target. Farmers can participate in the agri-environmental programme that leads to land use/cover changes or they can refuse to participate in the programme and then changes will not happen.

For the Strategy 1, the model requires two types of components: the decision-making agent – the farmer, and the parcel object. Each parcel has ownership and location. Farmer-agent may decide to enrol in the environmental program, if its specific parcel meets the requirements of the program packages. In addition to ownership and location, each parcel object stores the information about its distance to water (rivers, lakes, small ponds) and forest. That information comes from GIS database. In addition, farmer-agent decision-making process requires human interpretation components like farmer's profit from the enrolment or his environmental concern.

Three program packages designated for water conservation were chosen. The first is Package 8

Soil and water protection. The aim of this project was to encourage famers to keep winter vegetation on their fields and use it as natural compost in spring. The second program used in the model is called *Buffer zones* (Package 9). When joining that program farmers were supposed to create buffer zones on their fields adjacent to lakes or rivers. The third is the *Afforestation Program*. Joining any of these programs by farmers results in land use/cover change. Joining Package 9 produces a buffer zone where agricultural land changes to forest. Joining Package 8 results in conversion of arable to pasture and fallow. Finally, when a framer plans a new forest area his agricultural area changes to forest.

In Strategy 2 every agent reads the data about the environment and prepares preferences about it. Every agent follows five steps that are necessary to interact with each other (Ligtenberg et al. 2004). The directions of changes depend on agents' preferences, their will for cooperating and their decision power:

1. interpreting the environment and generating its perceived spatial organization,
2. comparing the definition of the spatial organization with agent's future objectives and determining the differences between them,
3. prioritizing their wishes depending on an auxiliary imposed set of restrictions and possibilities,
4. adapting the current spatial organization in order to narrow the gap between the desired and the existing organization, and
5. effectuating the adaptations by decision making with other actors.

This process leads to a decision market, which is quite different in both strategies but also shares some mutual components. In both strategies, agents' decisions influence the environment but different basic units of analysis express this environment.

Clearly different ways of making decisions, negotiating and finding consensus lead to different development scenarios of land use pattern. Authorities have the biggest influence on land use planning process in Poland. For this reason, we considered authorities as a main actor while foresters and farmers as ancillary actors. Their willingness to cooperate has a positive influence on the environment and the functioning of the Lakeland areas.

Strategy 1 is implemented for five time steps (equivalent to 5 years). Strategy 2 is implemented for 14 time steps (14 years). After each time step, the process is iterated. In both strategies the user of the model can decide how long simulation lasts.

Results and Discussion

Strategy 1: lake catchment approach

Details on the scenario-based approach can be found in Giełda-Pinas et al. (2015). Scenarios were established based on surveys and census data. In a "positive scenario", farmers earn profit from the programme and they are aware of the possible positive effect of their actions on the environment. About 10% will enrol in the program. In Scenario 2 – a "neutral scenario" – the group of farmers are aware of environmental issue but the investment is less profitable than in the "positive scenario". A smaller group will decide to join the programme (about 1%). In Scenario 3 – a "negative scenario" – farmers do not care about the conservation and the profit is quite small. Very few will join (about 0.1%). In this paper, we present only the "neutral" scenario. One year is a time step in the model, because only once a year a farmer may apply and join the program. Simulations were run for five years be-

Table 2. The results of simulating land cover/use changes for Gorzuchowskie Lake catchment.

Run/Year	Total Area	Land use							
		Water	Urban	Forest		Agricultural		Pasture and fallow	
	[ha]				[%]	[ha]	[%]	[ha]	[%]
"0"	1810.48	83.59	106.79	5.21	100.0	1585.53	100.0	29.35	100.0
1	1810.48	83.59	106.79	7.44	142.7	1487.23	93.8	125.42	427.3
2	1810.48	83.59	106.79	10.37	198.9	1376.87	86.8	232.86	793.4
3	1810.48	83.59	106.79	11.95	229.2	1281.68	80.8	326.47	1112.4
4	1810.48	83.59	106.79	13.94	267.4	1214.48	76.6	391.67	1334.5
5	1810.48	83.59	106.79	15.11	289.9	1142.61	72.1	462.37	1575.4

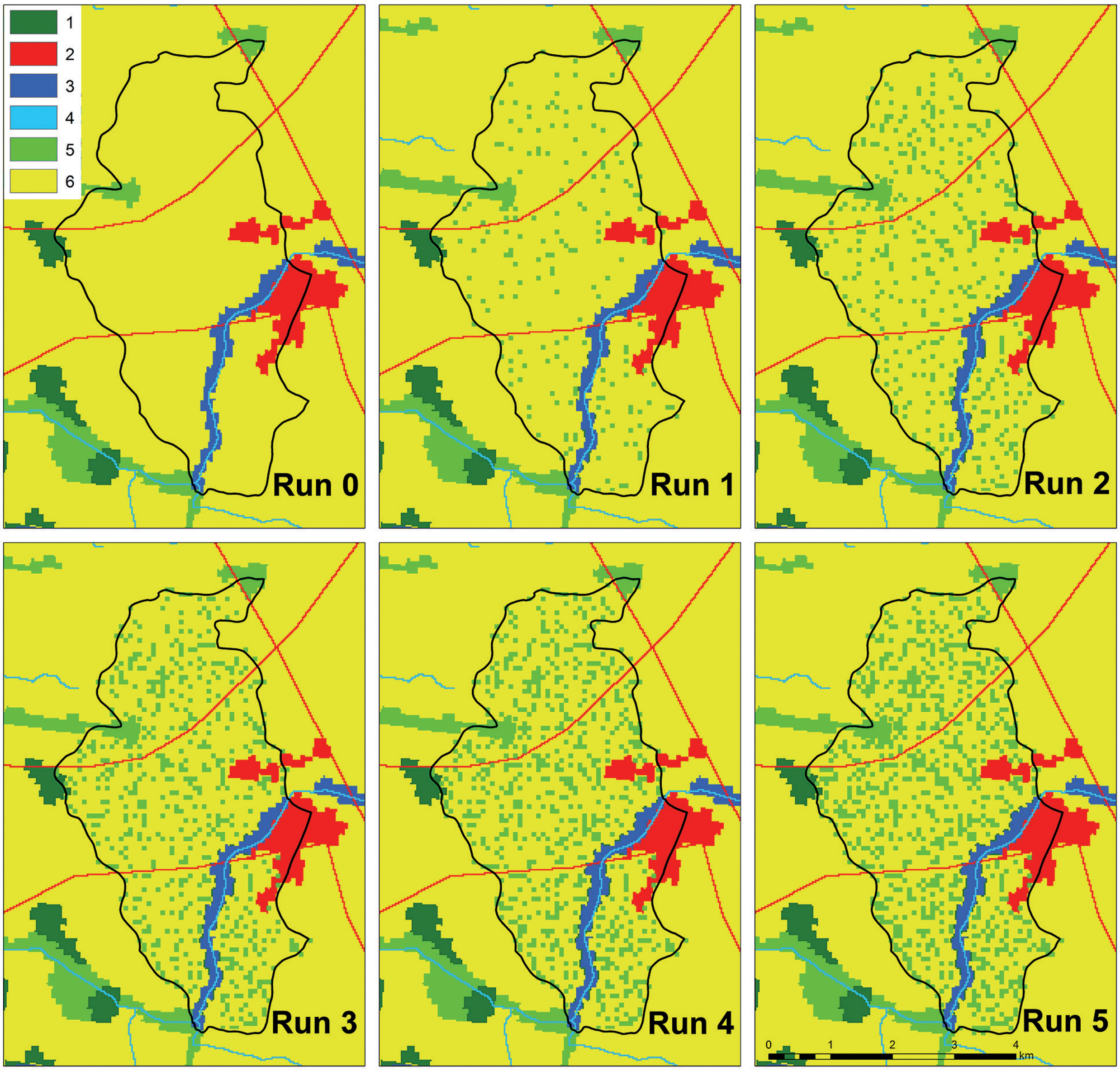

Fig. 4. Simulated land use/cover changes in Lake Gorzuchowskie catchment (GLD) during 5 runs of model according to the Strategy 1 (lake catchment approach).
1 – forest, 2 – urban, 3 – water-lakes, 4 – water-rivers, 5 – pasture/fallow, 6 – agricultural.

cause it is the shortest obligatory period to stay in the program. The resulting land use/cover changes during five-year simulation are presented in Table 2 and the outputs maps are presented in the Fig. 4.

There are five main types of land use/cover but two of them cannot be changed due to the limited decision-making. Farmers may decide if they want to change their agricultural land but have no influence on water and artificial land. For the entire catchment area, the most significant changes were in two land use/cover types: agricultural (decrease) and pasture/fallow (increase). Those changes are caused by the most popular package: *Soil and water protection*. From farmer's point of view, this particular program is easy to perform and there is no loss in crops. From environment perspective the erosion is detained and fewer nutrients get to water body (Szpikowski 2003). Changes in woodland are relatively small, but still significant. This class is created on the edge of the already existing forest. At the beginning (year "0") there were only about 5 hectares of forest in Gorzuchowskie catchment, so afforestation process occupied small areas in the shape of belts. This class is also created next to the water bodies as a buffer zone. On the other hand, when changes in the percentage are considered, the forest increase to 290% and pasture/fallow to 1,575%, which gives a very optimistic prognosis for future development of water conservation practices.

Taking into account the individual years, the most significant changes have occurred in the first and second year. The smallest in the last, fifth year. We hypothesize that this may be caused by more land parcels meeting the requirements of the chosen packages at the beginning of the simulation.

Lakes' functioning is strongly dependent on the land use/cover in the catchment, especially the non-point nutrient pollution from agriculture. Nitrogen loads from arable land are one of the major sources of water pollutants (Ferench and Dawidek 2010, Ptak and Ławniczak 2011). According to the cited paper, there is an estimated amount of the annual nutrient leaching form different types of areas. To estimate the approximate amount of nitrogen and phosphorus that gets each year into the Gorzuchowskie Lake, the average amount per hectare was multiplied by the area of each land use/cover in the catchment (Table 3).

The 5-year simulation shows that in Gorzuchowskie Lake there were changes in both phosphorus and nitrogen loads to the lake from its catchment. Changes in the amount of both nutrients are noticeable in all three land use/cover types that were modified during simulation process. The increase of nutrient per year is correlated with the increase of relevant type of land. Analogously, the load from agricultural land decreases during the 5-year simulation. This result may lead to a false conclusion that changes in land use/cover caused the increase in nutrient flow, when classes of forest and pasture/fallow are considered separately from agricultural. Only by summing up the total amount of each nutrient for the whole catchment the result is appropriate. In conclusion comparing year "0" with year "5", the decrease in phosphorus was 116.15 kg ha^{-1} yr^{-1} (i.e. 11.7 %), even though the loads from forest and pasture/fallow increase. Simultaneously, the decrease in nitrogen was 944.99 kg ha^{-1} yr^{-1} (i.e. 5.6%). The result is caused by the dom-

Table 3. Estimated amount of the annual nutrient leaching form different types of land cover/use from Lake Gorzuchowskie catchment.

Five model runs	Land use types					Total load	
	Water	Urban	Forest	Agricultural	Pasture and fallow		
[years]	[kg ha^{-1} yr^{-1}]						[%]
			Phosphorus (P)				
Ref.*	0	0.90	0.20	0.56	0.30	–	–
0	0	96.11	1.04	887.90	8.80	993.86	100.0
1	0	96.11	1.49	832.85	37.63	968.08	97.4
2	0	96.11	2.07	771.05	69.86	939.09	94.5
3	0	96.11	2.39	717.74	97.94	914.18	92.0
4	0	96.11	2.79	680.11	117.50	896.51	90.2
5	0	96.11	3.02	639.86	138.71	877.71	88.3
			Nitrogen (N)				
Ref.*	0	6.20	6.50	10.10	8.00	–	–
0	0	662.11	33.89	16013.87	234.79	16944.66	100.0
1	0	662.11	48.36	15021.07	1003.36	16734.90	98.7
2	0	662.11	67.40	13906.38	1862.85	16498.74	97.4
3	0	662.11	77.68	12944.93	2611.74	16296.46	96.2
4	0	662.11	90.62	12266.30	3133.34	16152.37	95.3
5	0	662.11	98.24	11540.33	3698.99	15999.67	94.4

*Reference data from Ptak, Ławniczak (2011).

inance of the agricultural land in the catchment and mostly because the annual nutrient leaching from agricultural land is higher than from forest or pasture/fallow.

Strategy 2: commune approach

In Strategy 2 it was assumed that influence of different actors (commune, farmers and foresters) on land use spatial pattern is worth investigating. The main goal of presented Strategy 2 was to provide means to include human decision making without losing the strength of the concept of the spatial environment's self-organization. The main and ancillary actors whose decision can have influence on land use pattern were firstly determined. These are commune (the main actor) and farmers and foresters (the ancillary actors). They can transform land use types and their goals and willingness to cooperate differ in every scenario. The decision rules and information flowchart for the agents are presented in section *Decision market*. Also main transitions to be modelled were determined. These transitions are showed in Fig. 5. The main focus of this research is to include the variety of actor-based normative ideas related to the allocation of spatial functions that feed a land use change simulation process.

Commune authorities want the new anthropogenic areas to be located close to forests and lakes. It makes the price of these areas highest. New anthropogenic areas should be located as close to existing roads as possible. On the other hand, commune tries to fulfil the assumptions of

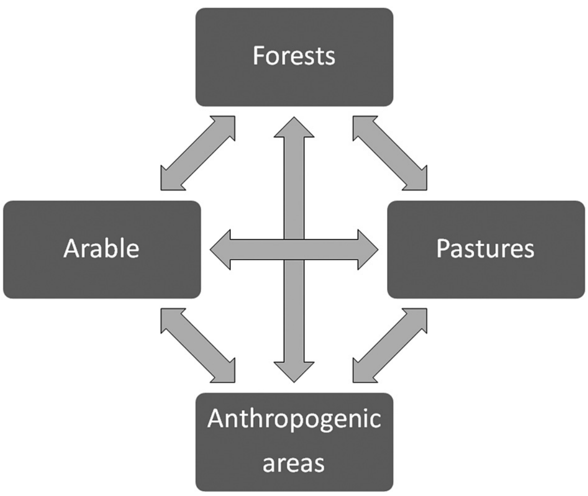

Fig. 5. Transitions of land cover/use types to be modelled in the Strategy 2 (commune approach).

study of commune's conditions and spatial planning, which says that the basic objectives of each commune are:

- rational management of space, water, stock and energy,
- undertaking and the promotion of sustainable development directions,
- providing a certain quality of air, water, greenery and soil, and
- preservation of natural values through partial forms of protection.

Farmers – they do not want arable lands and pastures to be occupied by anthropogenic areas. If it does happen, pastures should first transition to anthropogenic areas, only then transition from arable land to anthropogenic areas is permitted. Farmers want new anthropogenic areas to be located as close as possible to existing anthropogenic areas. In some cases it could be profitable to transform agricultural areas to forests. If arable lands are going to be expanded they should be located on fertile soils and should be located as far as possible from anthropogenic areas.

Foresters – they want to keep actual forest area or to expand the forests. They do not want the forest to be transformed into agricultural anthropogenic areas. The proposed new forest should be located as far as possible from anthropogenic areas.

For the purpose of the research goal of Strategy 2, there are few scenarios that are needed to be examined. Firstly, scenarios differ according to who makes decisions in the model (cf. Fig. 3):

1. only authorities make decisions:
   a. environmentally rational decisions,
   b. economically rational decisions,
   c. environment – economy consensus,
2. all agents make decisions:
   a. equal voting power,
   b. unequal voting power – willingness to cooperate,
   c. unequal voting power – competition.

Then for selected scenario different decision rules used by actors were investigated. They could make decisions that were economically profitable firstly, then they made decisions that were environmentally profitable and lastly they tried to find a consensus between the economics and the environment.

In the presented paper only the results of scenarios 1a, 2b and 2c were investigated (Fig. 3).

Table 4. Land cover/use changes for CLC 2006 data and simulated scenarios for Chrzypsko Commune – year 2020.

Data	Total area	Land use								
		water	urban		forest		agricultural		pasture and fallow	
	[ha]	[ha]	[ha]	[%]	[ha]	[%]	[ha]	[%]	[ha]	[%]
CORINE Land Cover 2006	8433	843.3	84.33	1	1433.61	17	5818.77	69	252.99	3
1a scenario	8433	843.3	84.33	1	2023.92	24	5228.46	62	252.99	3
2b scenario	8433	843.3	252.99	3	2276.91	27	4891.14	58	168.66	2
2c scenario	8433	843.3	421.65	5	1180.62	14	5903.10	70	84.33	1

Firstly the quantitative analysis was carried out. The CORINE Land Cover data from 2006 (EEA 2006) was compared with analysis results for scenarios 1a, 2b and 2c (Table 4).

The full conceptual model was developed and first simulation was performed. Study of conditions and spatial development of the commune was used to determine the amount of land in hectares to be transformed during the every time step which express one year.

In scenarios 1a and 2b the decrease in agricultural areas can be observed. The only change is observable for the amount of this change. In scenario 2b the decrease of agricultural land is more significant. In scenario 2c where actors are competing with each other very small increase of agricultural land can be observed. The problem that Chrzypsko Wielkie commune is facing is the lack of areas that can be dedicated for new anthropogenic (urban) areas. This is quite important to investigate which scenario allocates the new urban areas in the most efficient way in the point of view of natural environment. When the commune make decisions which are environmentally rational (scenario 1a), in these scenario there are no new anthropogenic (urban areas). The amount of the agricultural areas decreases and amount of the forests increases by 7%. In the scenario 2b, actors have a willingness to cooperate and they are ready to make some trade-offs. In this scenario anthropogenic areas occupy 3% of the commune while the share of forests is the highest – 27%. In the last investigated, which was 2c, the amount of anthropogenic areas is the highest and is also 5 times bigger than in initial conditions. The amount of agricultural areas is in this scenario 70%. The forests occupy only 14% of the land. This means that competition amongst actors lead to the highest sprawl of anthropogenic areas but also to significantly lower share of forests than in initial conditions (EEA 2006).

These results indicate that using this model with such a definition of agents and their decision rules, the land transformation is the most appropriate for the natural environment when only the commune makes decisions about land transformation but natural environment is for the commune the most important. What is more, if all agents are involved in the decision process, then it turned out that cooperating is much more beneficial than competition.

For CORINE Land Cover map (EEA 2006) as well as maps being the results of all three investigated scenarios simulation, landscape metrics were calculated. This analysis was performed to see in which scenarios generated landscape patterns are more balanced and sustainable. In Figure 6 maps of CORINE Land Cover data and the best selected scenario (2b) are presented.

For landscape ecology analysis the following metrics were selected and calculated: Largest Patch Index, Radius of Gyration, Fractal Dimension Index, Contiguity Index (Table 5). It is common that landscape metrics are redundant. An appropriate selection of landscape metrics used in the work is always hard task. Here four mentioned metrics were selected because they are not redundant to each other and give a quick and good insight in how the landscape is fragmented. They are also easy to interpret which makes them one of the most often used in land cover map comparison.

Investigating the results of selected landscape metrics calculated for the Chrzypsko Wielkie commune, the first obvious conclusion is that the value of Largest Patch Index is highest for initial conditions (CLC 2006 map). Significantly lower value can be observed for 1a scenario while values for scenarios 2b and 2c are very similar. The value of Largest Patch Index indicates the percent of the study area occupied by the biggest patch. The biggest patch in the study area belongs to the

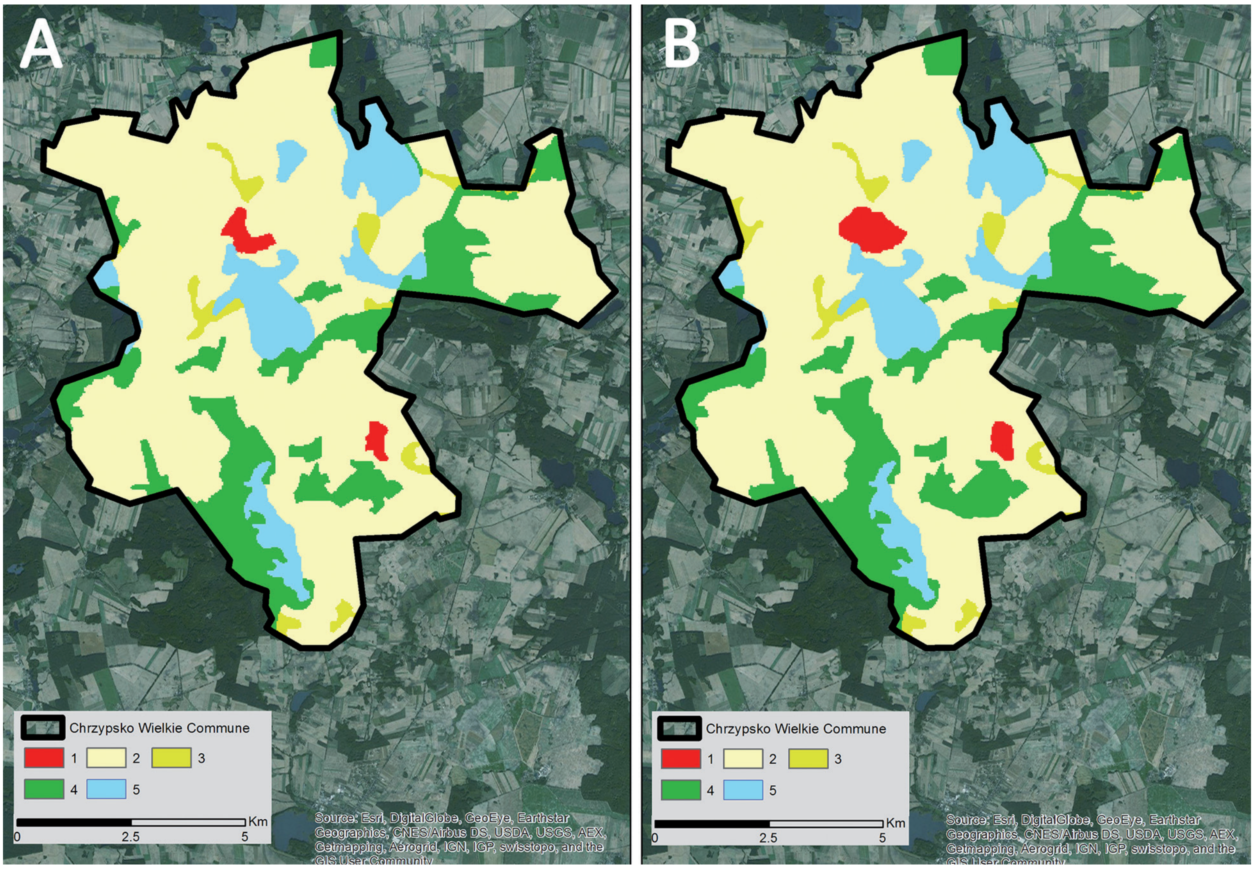

Fig. 6. CORINE Land Cover 2006 data (A) and results of the simulation according to 2b scenario within the Strategy 2 (B) for Chrzypsko Wielkie commune (PLD).
1 – urban, 2 – agricultural, 3 – pasture/fallow, 4 – forest, 5 – water.

type of agricultural areas. It can be observed that this biggest patch is becoming smaller in every simulation scenario. But when only commune makes environmentally rational decisions this value is the lowest (12.1). All agents involved in decision making process keep the value of largest patch index at the level of about 13.

The Radius of Gyration can be considered a measure of the average distance that needs to be followed within a patch before encountering the patch boundary from a random starting point. When summarized for the landscape as a whole, like in this case, this metric is also known as correlation length and gives the distance that one might expect to traverse the map while staying in a particular patch, from a random starting point and moving in a random direction (Keitt et al. 1997). The boundaries between patches (or edges) represent another fundamental spatial attribute of a patch mosaic. So in this case higher Radius of Gyration seem to be better for a landscape as whole.

Radius of Gyration pattern behaves similar to largest patch index pattern. Its value is the lowest for 1a scenario and highest for initial conditions. Probably in investigated scenarios, when the big-

Table 5. Landscape metrics for Chrzypsko Wielkie Commune according to CORINE Land Cover 2006 (EEA 2006) and every investigated scenario in 2020.

Landscape metrics	Largest Patch Index	Mean Radius of Gyration	Fractal Dimension Index	Contiguity Index
	[%]	[m]	[–]	[–]
CLC 2006	14.25	211.8	1.25	0.62
1a scenario	12.10	209.2	1.28	0.63
2b scenario	13.00	209.8	1.17	0.61
2c scenario	12.80	210.3	1.12	0.62

gest patch is becoming smaller, then it has a significant influence on the radius of gyration.

Fractal Dimension Index has the range of its values between one and two. The value of one means very simple patches which are similar to squares. Value of two means very complicated and not obvious shapes of the patches. The highest value of Fractal Dimension Index are observed for 1a scenario in which only the commune make decisions. It means that this environmentally rational scenario leads to the highest complexity of the patches shapes. Through the scenarios of all agents involved in decision process, 2b scenario leads to the lower value of Fractal Dimension Index than 2c scenario. It means that willingness to cooperation of the agents produces the result map with lower patch complexity.

Contiguity Index has its values from zero to one. If all neighbours of the one raster cell are of the same type, then value of Contiguity Index equals zero. If a cell has eight neighbour cells and all of them belong to different type, then for that cell Contiguity Index equals one. In all simulated scenarios the mean Contiguity Index equals over 0.6 which is more than 0.5. It means that this landscape is fragmented. All of the Contiguity Index values for all scenarios and initial conditions map are very similar. This means that the decision process and decision rules do not have influence on landscape fragmentation.

Simulations showed that if actors' willingness to cooperate is higher and commune allows the possibility of foresters' and farmers' decision-making, generated landscape pattern is more balanced and sustainable as it can be observed in Table 5. The results were also compared with trends observed by Dzieszko (2014) for this research area while using neural networks in simulation process. Transitions were modelled by using multi-layer perceptron (MLP) method. Using the historical rates of land use changes between years 1990 and 2000 as well as the transition potential model, land use map for year 2006 was predicted. This method was developed by Eastman (2012). CORINE Land Cover 2006 database (EEA 2006) was used for model validation. In designed agent-based model emergent land use pattern is quite different than discovered by Dzieszko (2014). It means that bottom-up approaches need to be developed and they can give a new insight to investigated LUCC problems. To be able to draw more conclusions more simulation needed to be run. Then it will be possible to compare both models quantitatively using landscape metrics.

Strategy 2 revealed that cooperating scenarios lead to more compact land use pattern. Land use types are located closer to each other and more homogenous patches are created when commune actor allows other actors to participate in decision-making process. It can be assumed that involving more actors in decision-making process can be considered as less risk-taking behaviour from commune's point of view. In this case, less risk-taking behaviour of agents lead to more sustainable land use pattern development.

Conclusions

Following Epstein (2008) it is good sign when models surprise us, make us curious and even lead us to the new questions. Modelling is always a cycle. It means that after every implementation there are results which produce more questions. This cycle can become perpetual. Consequently, modellers always make assumptions and simplifications in their work. It is impossible to find the answers for all questions. This work proved that for some land use/cover change problems and simulation of these processes some questions can be answered using ABM.

Land use/cover changes affect both local and biogeochemical processes that occur in landscapes. Especially lakeland landscapes are susceptible to direct and indirect land use/cover changes, because of their valuable and vulnerable to environmental modifications, elements – lakes. Using agent-based approaches the possible effect on lakes in lakeland landscapes was shown in the presented work. In Strategy 1 agent-based model is designated to create potential pattern of land use/cover based on agri-enviornmetal program. Results of the performed simulations confirm the assumption of positive influence of the program to example Gorzuchowskie Lake. During 5 years of farmer's participation in the program, there were changes in three land use/land cover types: agricultural, forest and pasture/fallow. The largest changes occurred in first and second year of simulation. As a consequence there was significant decrease of nutrient leaching to the lake (11.7% of phosphorus and 5.6% of nitrogen) from its catchment. The decrease of nutrient appears even when only 1% of the group show interest in the program. This confirms the assumption of usefulness of the program for water protection practices.

All land use/cover changes that occur in the lake catchment due to model simulation during 5 years are strictly connected with decision making process and in consequences with selected packages so the model does not include spontaneous changes or unexpected events. This fact classified performed model among explanatory models not predictive ones thou the model become useful tool for testing hypotheses (Giełda-Pinas 2015, Giełda-Pinas et al. 2015). In land-chance science that fact is crucial for future model development and when analysing time and spaces model variables. Potential land development, especially in susceptible landscape, should be precisely analysed by policy makers to avoid long-lasting mistakes and to perform environmental friendly action. The simulation were performed in local scale to show the potential positive effect of the program on specific lake (Gorzuchowskie Lake), but the offer is nationwide, so regional changes may be expected on whole lakeland landscape. Changes in Strategy 1 are strictly connected with human decision making process and though represent an example of human-nature interaction in coupled human and natural systems. This is why agent-based modelling was chosen to represent this process.

During the implementation of the Strategy 2, it was assumed that different ways of making decisions, negotiating and finding the consensus by actors involved in decision process lead to the different development scenarios of land use pattern. Authorities, farmers and foresters are in Poznań Lakeland District the main actors involved in creating land use pattern. Authorities have the biggest influence on land use planning process in Poland. The study revealed that indeed decision making process has an influence on the landscape. In the first investigated scenario (1a) only commune authorities could make decisions about land use transformations and they main concern was the quality of the environment. In the second scenario (2b) all agents were involved in the decision making process but they were able to cooperate and finding consensus. In the last scenario (2c) all agents were making decisions but they care only about their own interests. The influence of these decisions on the landscape was measured using four selected landscape metrics.

One hypothesis can be confirmed with this work and one need to be rejected. Confirmed one says that analysing the selected landscape metrics it need to be observed that the best configuration of the patches in the result scenarios from the point of view of natural environment is in scenario 2b. This configuration is better than for scenario 2c. It means that when three main agents involved in decision making process (commune authorities, farmers and foresters) are cooperating with each other instead of competing, the configuration of the landscape is better. The hypothesis that needs to be rejected says that in scenario 1a, where only commune authorities were making decisions the configuration of the landscape patches is the worst. This is really surprising results because in scenario 1a commune authorities were transforming land caring about natural environment. The assumption is that in this particular case the configuration should be the best. This is one of the examples of Epstein's words (2008) that model lead us to the new questions. The main conclusion should be stated that cooperating of the agents is better for the natural environment than the competitions but without any doubt more simulations must be run.

It is well known that ABM method has a great potential in many fields of science. This work revealed that this potential can increase when ABM is coupling with GIS. The main conclusion from Strategy 1 is that during 5 years of farmer's participation in the program, there was significant decrease of nutrient leaching to the lake, even when only 1% of the group show interest in the program. This confirms the assumption of usefulness of the program for water protection practices. The main conclusion from Strategy 2 is that when three main agents involved in decision making process are cooperating with each other instead of competing, the configuration of the landscape is better. It was then possible to address spatial questions about water quality or landscape configuration and implement the models which helped to find answers for these questions. It is important to remember that such models, as presented in this work, are not strictly predictive models. They are more like a simulation laboratory for testing different scenarios. Using ABM scientist learns from models as well as they are teaching models how to perform. ABM of course has some disadvantages. It is hard to validate the models, there are no standards for model validation in ABM and their structure must be as simple as possible to make the results understandable. But even though using this method solved the scientific questions addressed in this article.

For both strategies free and easy available data and spatial data were used. Strategy 1 was implemented using Agent Analyst in ArcGIS software environment. Strategy 2 was implemented using NetLogo software. In both strategies PC is sufficient and efficient hardware for running the models.

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Author Contributions

Katarzyna Giełda-Pinas is responsible for data collecting, carrying out the modelling simulations, developing the Strategy 1 and description of ABM. Piotr Dzieszko is responsible for data collecting, carrying out the modelling simulations, developing the Strategy 2 and preparing the literature background for the article. Zbigniew Zwoliński is responsible for the conception of the paper, the preparation of both strategies, the critical insight into the whole paper and the final approval of the paper to publishing process. Arika Ligmann-Zielińska is responsible for the initial preparation of both strategies and the critical insight into the whole article. The authors admit to divide the following percentage contribution: Katarzyna Giełda-Pinas – 35%, Piotr Dzieszko – 35%, Zbigniew Zwoliński – 20%, and Arika Ligmann-Zielińska – 10%.

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