#### A peer-reviewed version of this preprint was published in PeerJ on 19 February 2019.

<u>View the peer-reviewed version</u> (peerj.com/articles/6478), which is the preferred citable publication unless you specifically need to cite this preprint.

Dzierzbicka-Glowacka L, Pietrzak S, Dybowski D, Białoskórski M, Marcinkowski T, Rossa L, Urbaniak M, Majewska Z, Juszkowska D, Nawalany P, Pazikowska-Sapota G, Kamińska B, Selke B, Korthals P, Puszkarczuk T. 2019. Impact of agricultural farms on the environment of the Puck Commune: Integrated agriculture calculator—CalcGosPuck. PeerJ 7:e6478 https://doi.org/10.7717/peerj.6478

### Impact of agricultural farms on the environment of the Puck Commune: Integrated agriculture calculator - CalcGosPuck

Lidia A Dzierzbicka-Glowacka <sup>Corresp., 1</sup>, Stefan Pietrzak <sup>2</sup>, Dawid Dybowski <sup>1</sup>, Michał Białoskórski <sup>3</sup>, Tadeusz Marcinkowski <sup>2</sup>, Ludmiła Rossa <sup>2</sup>, Marek Urbaniak <sup>2</sup>, Zuzanna Majewska <sup>2</sup>, Dominika Juszkowska <sup>2</sup>, Piotr Nawalany <sup>2</sup>, Grażyna Pazikowska-Sapota <sup>4</sup>, Bożena Kamińska <sup>5</sup>, Bartłomiej Selke <sup>5</sup>, Paweł Korthals <sup>5</sup>, Tadeusz Puszkarczuk <sup>5</sup>

<sup>1</sup> Physical Oceanography Department, Ecohydrodynamics Laboratory, Institute of Oceanology of the Polish Academy of Sciences, Sopot, Poland

<sup>2</sup> Department of Water Quality, Institute of Technology and Life Sciences in Falenty, Raszyn, Poland

<sup>3</sup> Academic Computer Centre in Gdansk, Gdańsk, Poland

<sup>4</sup> Department of Environment Protection, Maritime Institute in Gdansk, Gdańk, Poland

<sup>5</sup> Municipality of Puck, Puck, Poland

Corresponding Author: Lidia A Dzierzbicka-Glowacka Email address: dzierzb@iopan.gda.pl

**Background.** Leaching of nutrients from agricultural areas is the main cause of water pollution and eutrophication of the Baltic Sea. A variety of remedial actions to reduce nitrogen and phosphorus losses from agricultural holdings and cultivated fields have been taken in the past. However, knowledge about the risk of nutrient leaching has not yet reached many farmers operating in the water catchment area of the Baltic Sea.

**Methods.** The nutrient balance method known as "at the farm gate" involves calculating separate balances for nitrogen (N), phosphorus (P) and potassium (K). After estimating all the components of the nutrient balance, the total balance for NPK is calculated and the data obtained is expressed as the ratio of total change (surplus) to the area of arable land on a farm. In addition, the nutrient usage efficiency on a farm is also calculated. An opinion poll was conducted in 2017 on 31 farms within the commune of Puck which is approximately 3.6 percent of all farms located in this commune. The area of the farms is variable ranging from 5 – 130 ha with an average of 45.82 ha including areas of arable and grass land. The former are on average 30.79 ha with a range of 4.45 to 130 ha while the latter has an average area of 12.77 ha and ranges from 0 to 53 ha.

**Results.** The average consumption of mineral fertilizer in the sample population of farms was 114.9 kg N, 9.3 kg P, and 22.9 kg K•ha<sup>-1</sup>of agricultural land (AL), respectively. N surplus in the sample farms being ranged from -23.3 to 254.5 kg N•ha<sup>-1</sup>AL while nutrient use efficiency ranged from 0.40 to 231.3 percent. In comparison, P surplus in the sample farms was 5.0 kg P•ha<sup>-1</sup>AL with the P use efficiency of 0.4-266.5 percent.

**Discussion.** Individual N fertilizer consumption in the tested farms was higher than the average usage across Poland and in the Pomeranian Voivodeship, compared to the lower consumption of potassium fertilizers. Phosphorus fertilizer consumption was higher than in the Pomeranian Voivodeship, but lower compared to the entire country. Generally, on the basis of designated research indicators of farm pressures on water quality concentrations of total nitrogen and total phosphorus were obtained. CalcGosPuck (an integrated agriculture calculator) will help to raise farmers' awareness about NPK flow on farm scale and thus to improve nutrient management.

#### **1** Impact of agricultural farms on the environment of the Puck

#### 2 Commune: Integrated agriculture calculator – CalcGosPuck

- 3 Lidia Dzierzbicka-Glowacka<sup>1</sup>, Stefan Pietrzak<sup>2</sup>, Dawid Dybowski<sup>1</sup>, Michał Białoskórski<sup>3</sup>,
- 4 Tadeusz Marcinkowski<sup>2</sup>, Ludmiła Rossa<sup>2</sup>, Marek Urbaniak<sup>2</sup>, Zuzanna Majewska<sup>2</sup>,
- 5 Dominika Juszkowska<sup>2</sup>, Piotr Nawalany<sup>2</sup>, Grażyna Pazikowska-Sapota<sup>4</sup>, Bożena Kamińska<sup>5</sup>,
- 6 Bartłomiej Selke<sup>5</sup>, Paweł Korthals<sup>5</sup>, Tadeusz Puszkarczuk<sup>5</sup>
- 7
- <sup>8</sup> <sup>1</sup>Physical Oceanography Department, Eco-hydrodynamics Laboratory, Institute of Oceanology
- 9 of the Polish Academy of Sciences, Sopot, Poland
- <sup>2</sup>Department of Water Quality, Institute of Technology and Life Sciences in Falenty, Raszyn,

11 Poland

- 12 <sup>3</sup>Academic Computer Centre in Gdansk, Gdańsk, Poland;
- <sup>4</sup>Department of Environment Protection, Maritime Institute in Gdansk, Gdańsk, Poland;
- <sup>5</sup>Municipality of Puck, Puck, Poland;
- 15
- 16 Corresponding Author:
- 17 Lidia Dzierzbicka-Glowacka
- 18 Powstańców Warszawy 55, 81-712 Sopot, Poland, P.O. Box 148
- 19 E-mail address: <u>dzierzb@iopan.gda.pl</u>
- 20
- 21
- 22
- 23
- 24
- \_ .
- 25 26
- ~-
- 27
- 28
- 29

2	0
-	U
-	0

#### 32 Abstract

33 Background. Leaching of nutrients from agricultural areas is the main cause of water pollution

and eutrophication of the Baltic Sea. A variety of remedial actions to reduce nitrogen and

35 phosphorus losses from agricultural holdings and cultivated fields have been taken in the past.

36 However, knowledge about the risk of nutrient leaching has not yet reached many farmers

37 operating in the water catchment area of the Baltic Sea.

38 **Methods.** The nutrient balance method known as "at the farm gate" involves calculating separate

balances for nitrogen (N), phosphorus (P) and potassium (K). After estimating all the

40 components of the nutrient balance, the total balance for NPK is calculated and the data obtained

41 is expressed as the ratio of total change (surplus) to the area of arable land on a farm. In addition,

- 42 the nutrient usage efficiency on a farm is also calculated.
- 43 An opinion poll was conducted in 2017 on 31 farms within the commune of Puck which is

44 approximately 3.6 percent of all farms located in this commune. The area of the farms is variable

45 ranging from 5 - 130 ha with an average of 45.82 ha including areas of arable and grass land.

46 The former are on average 30.79 ha with a range of 4.45 to 130 ha while the latter has an average

- 47 area of 12.77 ha and ranges from 0 to 53 ha.
- 48 **Results.** The average consumption of mineral fertilizer in the sample population of farms was
- 49 114.9 kg N, 9.3 kg P, and 22.9 kg K·ha<sup>-1</sup>of agricultural land (AL), respectively.
- 50 N surplus in the sample farms being ranged from -23.3 to 254.5 kg N·ha<sup>-1</sup>AL while nutrient use
- efficiency ranged from 0.40 to 231.3 percent. In comparison, P surplus in the sample farms was

52 5.0 kg P·ha<sup>-1</sup>AL with the P use efficiency of 0.4-266.5 percent.

53 **Discussion.** Individual N fertilizer consumption in the tested farms was higher than the average

54 usage across Poland and in the Pomeranian Voivodeship, compared to the lower consumption of

55 potassium fertilizers. Phosphorus fertilizer consumption was higher than in the Pomeranian

- 56 Voivodeship, but lower compared to the entire country.
- 57 Generally, on the basis of designated research indicators of farm pressures on water quality
- 58 concentrations of total nitrogen and total phosphorus were obtained. CalcGosPuck (an integrated
- 59 agriculture calculator) will help to raise farmers' awareness about NPK flow on farm scale and
- 60 thus to improve nutrient management.

#### 61 Main article text

#### 62 Introduction

Leaching of nutrients from agricultural areas is the main cause of water pollution and 63 eutrophication of the Baltic Sea. A variety of remedial order to reduce nitrogen and phosphorus 64 losses from agricultural holdings and cultivated fields have been taken in the past. However, 65 knowledge about the risk of nutrient leaching has not yet reached many farmers operating in the 66 watershed areas of the Baltic Sea. Nevertheless, the growing international consciousness on the 67 68 need for water quality improvement has influenced the desire to expand knowledge and social awareness of environmental implications of water quality worldwide. There are relatively cheap 69 and simple prevention measures (e.g., crop rotation, soil fertility analysis, separation of pastures 70 from water courses and reservoirs or systematic on-farm Advisory Services), but not all of them 71 have yet been implemented or entered into the list of 25 priority measures set out within the 72 framework of the Baltic Compass project (Salomon, Sundberg, 2012). One of the reasons for this 73 is that these measures should be worked out in practice by farmers based on their knowledge, 74 and then adapted to the given farming conditions (Ulén et al., 2013). 75 The farm is the basic organizational unit in agriculture and it produces food and raw materials for 76 industry. Production involves a large number of nutrients, only a fraction of which are converted 77 into animal and vegetable products. Some of the unused nutrients in production (surplus or lost 78 nutrients) accumulate in the soil, or are lost to surface waters, drain water, groundwater, or to the 79 80 atmosphere. Loss of nutrients has a negative economic impact (reduced production and higher cost of production inputs) and poses a threat to the environment. Nitrogen (N) and phosphorus 81 82 (P) compounds are of special concern in environmental quality management because they are 83 lost through several pathways such as surface runoff, subsurface flow and leaching within soils, water and wind erosion, emissions of gaseous forms of N and their deposition by atmospheric 84 precipitation. 85

Arguably, nutrient losses are inevitable, however, given their environmental and the economic
impacts on production and environmental quality, they should be limited to the possible
minimum. Therefore, it is essential to create farm production thresholds to ensure effective
nutrient management. The "at the farm gate" method is one way to drawing up a nutrient balance
for a farm. This method is a good educational and decision support tool in the area of agricultural
production activities, for such entities as: farmers, agricultural advisors, agricultural school and

university teachers as well as employees of state and local government institutions who are 92 responsible for agri-environmental policy implementation. It is particularly important for farmers 93 and agricultural consultants and advisors cooperating with them. In this partner system, the "in 94 the farm gate" method is used as a measure that could potentially improve the efficiency of 95 fertilizer components management in an agricultural holding which is a beneficial factor for both 96 economic and environmental reasons. Therefore, knowledge on how to estimate nutrient 97 balances should be more widely disseminated, especially among skilled farmers and agricultural 98 advisors (Pietrzak, 2013). However, there are some examples of appropriate actions helpful in 99 more effective use of nutrients on a farm and lower expenditures generation on fertilizers and 100 feeds which are already developed in some countries, especially with highly developed 101 agriculture. This actions are to provide generally available computer programs, in particular 102 (operating as independent tools or as modules of larger systems) which facilitate the nutrient 103 balance estimation, especially for N and P. In England, Wales and Scotland, for example, the 104 software for calculating "at the farm gate" nutrient balance is available for free use by farmers 105 and agricultural advisors (directly on the website or DVD) as a module of the PLANET 106 107 (Planning Land Applications of Nutrients for Efficiency and the Environment) system (PLANET nutrient management; Farmgate Nutrient Balance Help file). In Sweden, a computerized NPK 108 109 balancing system called "Greppa Näringen" (in English: "Focus on nutrients") was implemented on a large scale (Nilsson 2016). It is used by farmers in cooperation with agricultural advisors on 110 111 a voluntary basis, bringing good results (Jakobsson, 2012). Furthermore, in the United States, the application for balancing fertilizer components on the farm was disseminated nationwide as part 112 of the "Livestock and Poultry Environmental Stewardship - LPES" program (Koelsch; Koelsch, 113 Franzen, 2002). 114

The research presented in this paper was conducted as part of the project on modelling of the
impact of the agricultural holdings and land-use structure on quality of water in the Bay of Puck –
Integrated information and forecasting Service "WaterPUCK" (Dzierzbicka-Glowacka et al.,
2018).

119

120 Material and methods

#### 121 Integrated agriculture calculator - CalcGosPuck

The purpose of the project was to determine the current and future environmental status of surface water and groundwater quality in the Puck Commune and its impact on the Bay of Puck environment (Fig. 1). The most significant input of nutrients and pesticides in the environment comes from agricultural source and surface structure usage e.g. sewers or drainage ditches. Therefore, objective of the project was to estimate the impact of nutrient loading by compiling the recent knowledge, factoring in the essential in situ measurements, and using advanced modelling.

- 129 The web tools obtained within the project (service WaterPUCK with CalcGosPuck) were
- 130 modified account for many innovative measures, processes and models to provide a basis for the
- 131 "green economy" development that could be implemented in other Baltic Sea catchment areas.
- 132 This is in line with the objectives of European legislation, including: i) the Nitrates Directive
- 133 (91/676/EEC), ii) the Water Framework Directive (2000/60/EC), iii) the Marine Strategy
- 134 Framework Directive (2008/56/EC) and iv) the Habitats Directive (92/43/EEC) as well as with
- the HELCOM Baltic Sea Action Plan and the strategic program of environmental protection forthe Puck Commune.
- 137 The WaterPUCK service (Fig. 2) includes the following: a surface water model based on SWAT,
- a groundwater flow model "GroundPuck" based on Modflow, a 3D environmental model of the
- 139 Bay of Puck "EcoPuckBay" based on the POP code and an integrated agriculture calculator
- 140 called "CalcGosPuck". CalcGosPuck, presented in this paper, was developed as the first module
- 141 of the WaterPuck service. Data obtained from farms and defined in this model allow to
- 142 determine fertilizer components loads released from agricultural production to the environment,
- 143 including surface and groundwater.
- 144

#### 145 The general concept of nutrient balance on farms

The "at the farm gate" nutrient balance method usually involves calculating separate balances for NPK nutrient elements. The principle is the same for all three nutrients, with the exception that the N balance sheets include more factors because of larger number of N nutrient sources into the farms (e.g. legumes crops, deposition from the atmosphere). The procedure for establishing balance of nutrients using the "at the farm gate" method has been described in detail by Pietrzak (2013). Preparation of the nutrient balance by the farm gate method involves determination of

input and output streams on the farm (Fig. 3).

The masses of nutrients imported onto a farm are calculated as the amount of input in: i) mineral 153 fertilizers (own study based on data producers of mineral fertilizers); ii)purchased concentrated 154 fodders (Mercik, 2002); iii) purchased bred animals (Fagerberg et al., 1993; Wrzaszcz, 2009; 155 Rutkowska, 2010; Szewczuk, 2010); iv) natural fertilizers (farm-produced or externally 156 purchased manure) (Maćkowiak, 1997; Grabowski, 2009); v) other purchased products 157 (Fagerberg et al., 1993; Wrzaszcz, 2009; Rutkowska, 2010; Szewczuk, 2010); vi) deposition 158 (adopted for the Pomeranian Voivodeship) (IMGW); vii) symbiotically fixed nitrogen 159 (Schmidtke, 2008; Høgh-Jensen et al., 2004); viii) nitrogen introduced by free-living soil 160 microorganisms (Mazur, 1991); while the masses of nutrients exported from the farm are 161 calculated as the amount of output in sold animal and plant products (Fagerberg et al., 1993; 162 Wrzaszcz, 2009; Rutkowska, 2010; Szewczuk, 2010). 163

164

#### 165 Estimating nutrient balance and usage efficiency

After estimating all the components of the nutrient balance, the total balance for NP and K and 166 for all macronutrients combined was calculated. The data obtained was then expressed as a ratio 167 168 of total change (surplus) to area of arable land on the farm and the nutrient usage efficiency on the farm was also calculated. The use efficiency of NPK is the ratio of the amount leaving the 169 170 farm (outputs in plant and animal products, not including leaching, volatilization) to the amount entering the farm (inputs) expressed as a percentage. The nutrient usage efficiency was then used 171 172 to define the percentage of nutrients brought into the farm which are used directly for production. Analysis of the correlation between nitrogen and phosphorus surplus and selected elements of 173 the balance of these components was carried out using the STATISTICA 7 Soft. The 174 nonparametric method of calculating the Spearman rank correlation coefficient was used, 175 176 because the data being compared did not have a normal distribution. 177 **Farms in the Puck Commune** 178 Agricultural lands and livestock production 179

#### 180 An opinion poll was conducted on 31 farms within the Commune of Puck, which is

- approximately 3.6 percent of all farms in this Commune. The average area of the farms is 45.82
- 182 with a range of 5 to 130 ha including arable land. The average area of arable land is 30.79 ha

- with a range of 4.45 to 130 ha while the mean area of grassland is 12.77 ha ranging from zero to53 ha (Fig. S1).
- 185 Within the test area of the agricultural land, the majority of soils (90.3%, n=28) are medium -
- 186 Category III (21-35% content of particles with diameter less than 0.02 mm) (Jadczyszyn et al.,
- 187 2016). The soils in the remaining farms (9.7% n=3) includes light texture soils (11-20% content)
- 188 (Fig. S2). The types and areas of the field-scale crops and grasslands in farms participating in the
- 189 WaterPUCK project are given in Fig. 4, and animal population, type, and the barn maintenance
- 190 systems are given in Table 1.
- 191 The profile of production systems in the study farms is presented in Table 2.
- 192 In the majority of farms (96.8%, n=30) the management system of livestock manure was the

193 slurry and solid manure system, in which animals are maintained in livestock buildings on a

194 shallow litter. An exception was the farm marked Code 29, where some of the young animals

- 195 (calves and heifers) were kept in deep leaf litter, and one small farm (Code 31) where all the
- animals (calves and piglets) were kept in a deep barn, in a total of 1.3 of livestock unit (LU). The
- 197 livestock density was variable ranging from
- 198 a) 0.1 1.0 LU·ha<sup>-1</sup> on fourteen farms;
- 199 b) 1.1 2.0 LU·ha<sup>-1</sup> on nine farms; and
- 200 c) 2.1 3.0 LU·ha<sup>-1</sup> on two farms.

201 In the high density farms (c) the mass of nitrogen produced in natural fertilizers per hectare was

relatively high, with values ranging from 138 to 145 kg  $N \cdot ha^{-1}$ . However, it did not exceed the

203 limit of land application of 170 kg N·ha<sup>-1</sup> per year stated in the Nitrates Directive.

In a small portion of the farms (Codes: 9, 11, 20 and 23) involved in the production of milk and
beef livestock, animals have periodically been at pasture. The farm marked Code 27, which

206 breeds and raises horses, has also been using pastures.

207

#### 208 Crop rotation and after-crops

209 Out of the Puck Commune farms surveyed, the vast majority of them (96.8%, n=30) practice

crop rotation. The most common (76.6%, n=23) kind of crop rotation was cereal rotation (the

- share of cereal plants above 60%). The most distinctive types of cereal rotation were: silage
- 212 maize-winter wheat-spring grain mixtures, winter wheat-spring wheat-winter wheat-oat and
- 213 spring barley-oat-spring grain mixtures-potatoes.

- The most relevant rotation was field-corn cereal (above 60%), on 23 farms (76.7%).
- 215 Only 6 (19.4%) out of all the agricultural holdings use after-crops (a later crop of the same year
- from the same soil). On farms with additional vegetative cover two types of after-crops catch
- 217 crops and mixed cropping (companion crops), have been equally preferred. These after-crops
- 218 were in the majority of cases (83.3%, n=5) incorporated in green manure. The cultivated area
- with after-crops ranged from 14.4 to 35.7 percent of farms' total arable lands.
- 220

#### 221 Storage of natural fertilizers and silage

In every studied farm all structures used for the storage of manure regardless of size meet the 222 requirements of Polish legislation "Action program aimed at reducing the outflows of nitrates 223 from agricultural sources" (J. of Laws, 2018 item 1339) for minimum distance of 20 meters from 224 wells, edges of waterways and reservoirs. Moreover, a large proportion (82.6%, n=19) of the 225 dung panels and tanks for manure are less than 14 years old. Thus, there is a high probability of 226 227 effectively stopping leachate of manure and slurry leakage (Fig. S3). In three farms manure was stored directly on the ground, but the piles are located on flat terrain where the soil is neither 228 229 sandy nor waterlogged at a distance of more than 20 m from the edges of waterways and reservoirs. However, one of the farms was obligated to have a slurry storage tank, due to the 230 231 litter-free system of keeping livestock. On this farm the current tank was made in 2013 and is located at a distance of more than 20 m from the protected zones of water sources and water 232 233 intakes and the of the edges of reservoirs and waterways. In almost 50 percent of the farms (n=16), the most common practice to store compacted silage is special plastic bales that limit the 234 risk of silage juice although, about 30 percent (n=9) silage is stored in field piles directly on the 235 grounds less frequently. 236

237

#### 238 Permitted dates to use natural fertilizers

In accordance with the Polish law – Act of July 10, 2007 on fertilizers and fertilizing (J. of Laws,
2007 No. 147, item 1033), natural and organic fertilizers, in either liquid or solid form (manure,
liquid slurry, slurry), were allowed to be applied on field between March 1st and November 30th.
Permitted dates of solid manure use on arable lands and liquid natural fertilizers use (manure,
slurry) on permanent meadows with marked dates of fertilizer uses by farmers in the Puck
Commune are given in Figs S4 and S5, respectively.

#### 246 **Results**

#### 247 Integrated agriculture calculator - CalcGosPuck

248 In accordance with the "at the farm gate" concept method, the agriculture calculator

249 "CalcGosPuck" was developed. The CalcGosPuck calculator works as an independent

application designed to calculate the nutrient inputs and outputs, and then the surplus/deficit and

- the nutrient use efficiency on a farm. The user gives the farm size and selects the required
- 252 province, input and output products for balance and gives their amount. CalcGosPuck works
- 253 properly (see the website <u>www.waterpuck.pl</u> in Service Fig. 5).

254 One should enter specified data (Fig. 6) into the CalcGosPuck calculator in order to determine

inputs, outputs, NP surplus (or deficit) and the use efficiency of nutrients on the farm: i) the area

of agricultural land of the farm (in hectares) (Fig. 6a); ii) the province in which the farm operates

257 (Fig. 6b); iii) select indicators of what is imported onto the farm (mineral fertilizers, concentrated

258 fodder (mixed cattle feed, mixed pig feed, mixed poultry feed), purchased animal products,

259 natural fertilizers, other purchased plant products, by atmospheric precipitation, by legumes, and

260 fixed by soil microorganisms) (Figs. 6c); iv) select indicators of what is exported from the farm

261 (in animal and plant products sold) (Fig. 6d); v) give the amount of each selected indicator (Fig.

262 6e). After each parameter is selected, the basic data are automatically set down: input, output,

surplus (or deficit = value with a minus sign) and also the data related to the efficiency of the

farm are displayed in the top bar (Fig. 6f).

265

266 Case Study Application of the Calculator (on the example of a farm marked Code 9)

267 Step 1: Enter the area of agricultural land [in ha]: 70;

268 Step 2: Select the Voivodeship: Pomerania;

- 269 Step 3: Select inputs and their amounts:
- in mineral fertilizers: urea =100 dt, ammonium nitrate = 50 dt,
- in energy and protein fodders: rape cake for animals = 240 dt, dried pulp = 150 dt,
- post-extraction soya meal = 400 dt;
- in other plant and animal products: maize (grain) =120 dt, heifers = 15 dt;
- 274 Step 4: Select outputs and their amount:
- animal products: milk = 3500 dt, dairy cattle = 35 dt.

- 276 Step 5: Results of the calculations (Fig. 6f):
- 277 Budget:

278	Inputs:	N: 10996.00 kg;	P: 609.00 kg;	K: 645.95 kg;
279	Outputs:	N: 1977.50 kg;	P: 375.90 kg;	K: 530.95 kg;
280	Surplus:	N: 9018.50 kg;	P: 233.10 kg;	K: 115.00 kg;
281	Efficiency:	N: 17.98%;	P: 61.72%;	K: 82.20%.

282

#### 283 Consumption of natural fertilizers

- 284 The average consumption of mineral NPK ha<sup>-1</sup>in the study area ranged within the respective
- levels of: 114.9 kg N, 9.3 kg P, and 22.9 kg K·ha<sup>-1</sup> AL. On the individual farms consumption of
- the components listed was highly variable with a range 0 232.6 kg N·ha<sup>-1</sup> (Fig. 7); 0 31.2 kg
- 287 P·ha<sup>-1</sup> (Fig. 8) and 0 159.6 kg K·ha<sup>-1</sup> (Fig 9).
- 288

#### 289 Environmental aspects of fertilizer usage

- 290 With regard to the conditions of fertilizers application, it was determined that:
- On 29 out of the 31 tested farms (93.5%), the annual dosages of nitrogen fertilizers
   (mineral, natural, organic) were divided into parts during the growing season, usually
   into three in case of arable lands and two fertilizations of permanent meadows.
- 19 farms (61.3%) have arable land on parcels with steep slopes (more than 10%). On 16
- out of them (84.2%) the general rules of fertilizer usage on steep slopes were taken. In
- only two agricultural holdings (10.5%) the rules have not been followed. In cases of
- parcels with a slope of more than 10%, cultivation treatments have been carried out in adirection transverse to the slope leaving the ridge up the slope.
- 299 On 2 farms (6.5%) fertilizers were applied on field in situations when the soils was
- flooded, covered by snow or frozen to a depth of 30 centimeters, and during rainfall.
- Municipal sewage sludge has not been used in areas of special flood hazard, temporarily
  flooded and swampy areas, or on high permeability areas on any of the farms.
- On the majority of the tested farms (87.1%, n=27), there were agricultural lands located at a distance of less than 50 meters from the edges of waterways and lakes. On the other hand, on most of them (63%, n=17) in the areas close to waterways or reservoirs,

### NOT PEER-REVIEWED

306		fertilization has not been used. In 6 cases (22.2%) fertilization has been used at a
307		distance less than 20 meters from the edges of waterways and lakes.
308	_	Records of agricultural treatments containing information about dates and doses of
309		fertilization were being kept on 23 agricultural holding (74.2%). On the remaining 7
310		farms (22.6%) agro-technical practices were not documented and on one – there were no
311		data.
312	_	Only one of the analyzed farms (3.2%) kept records of natural fertilizers disposal
313		(agreement for sale of any surpluses).
314	_	Nitrogen balance estimation and fertilization plans were being developed on 20 (64.5%)
315		of all the farms. In remaining ones, there were either no balance sheets and fertilization
316		plans or there was no information about that.
317		
318	The S	urplus and Use Efficiency of Nitrogen, Phosphorus and Potassium
319	Nitrog	en surpluses on the analyzed farms ranged from -23.3 to 254.5 kg N·ha <sup>-1</sup> AL while N use
320	efficie	ncy ranged from 0.40 to 231.3 percent (Fig. 10). The lowest efficiency, 0.4 percent, was
321	observ	red in the horse breeding farm (Code 27) while the highest level, 231.3 percent, was
322	record	ed in the sole plant production farm (Code 17). The average nitrogen surplus in all 31
323	farms	was 120.6 kg N·ha <sup>-1</sup> AL while efficiency of this component use was 31.8 percent.
324	In the	case of phosphorus, the average P surplus value for all farms was 5.0 kg P·ha <sup>-1</sup> AL (Fig.
325	11) wi	th a farm range of -17.11 to 28.7 kg P·ha <sup>-1</sup> AL (Fig. 11). The average P use efficiency was
326	66.2 p	ercent while on farms ranged from 0.4 to 266.5 percent.
327	Potass	ium surpluses and use efficiency on study farms ranged from -54.1 to 159.8 kg K·ha <sup>-1</sup> AL
328	and fr	om 1.5 to 432.3%, respectively (Fig. 12). The average K surplus value was 10.8 kg K·ha <sup>-1</sup>
329	AL wl	nile average K use efficiency was 62.2%.
330	With r	regard to all agricultural holdings, in general structure of N inputs the largest amounts came
331	from r	nineral fertilizers (65%) and purchased concentrated fodder (17.7%). The next order was
332	as foll	ows: legumes (6.3%), atmospheric precipitation (5.1%), soil microorganisms (4.2%) and
333	others	(0.6%). In structure of N outputs the largest amount was nitrogen sold in plant products
334	(62.3%	%) while the remaining N part (37.7%) was sold in animal products.

In P balance, the order of the largest proportions of P input was: mineral fertilizers (63%),

- purchased concentrated fodder (32.7%), atmospheric precipitation (2.5%), others (1.6%) while P
  was output in sold plant (57.4%) and animal products (32.7%).
- 338 As with N and P, in K balance the order of individual inputs was: mineral fertilizers (79.4%),
- purchased concentrated fodder (10.6%), atmospheric precipitation (9.1%) and others (0.9%). In
- 340 structure of K outputs sold plant products (77.4%) predominated over animal products (22.6%).
- 341

#### 342 **Discussion**

Impact of agricultural farms on the environment of the Puck Commune caused by dispersion of 343 fertilizer components, was determined by a set of natural and anthropogenic factors conditioning 344 the activities of these farms. Undoubtedly, the most important factors were those that concerned 345 the use of mineral fertilizers. Nitrogen fertilizers consumption in the tested farms was higher 346 than average usage across Poland and in the Pomeranian Voivodeship, compared to the lesser 347 consumption of potassium fertilizers (Table 3). Phosphorus fertilizers consumption was higher 348 than in the Pomeranian Voivodeship, but lower compared to the entire country. Most of the 349 350 farms of the Puck Commune used N fertilizers in doses of 50-100 (35.5%, n=11) and 100-150 kg N kg N·ha<sup>-1</sup> AL (the same) while P fertilizers in doses of 10-15 kg P·ha<sup>-1</sup>AL (32.3%, n=10) 351 and 5-10 kg P·ha<sup>-1</sup> AL (25.8%, n=8). In case of K fertilizers, the largest two groups of farms 352 (35.5%, n=11) used them in doses of 0-20 and 20-40 kg K·ha<sup>-1</sup> AL.N:P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O ratio in average 353 fertilizer dose for all farms was 1.0:0.19:0.24 (what means that for every 1 kg of N only 0.19 kg 354 of P<sub>2</sub>O<sub>5</sub> and 0.24 kg of K<sub>2</sub>O were applied). These proportions may raise some doubts in the light 355 of the general recommendations of crop fertilization. According to them, 1.00:0.50:0.98 356 proportions are recommended for fertilization that is sustainable for field crops in Polish soil 357 conditions and 1.00:0.46:0.68 for permanent grassland (Kucharska et al., 1996). In should be 358 also emphasized that in conditions of wrong N:P:K ratios in fertilizers usage there may occur 359 some disturbances in process of N acquirement by plants and increased losses of this 360 component, causing environmental hazards. 361

Considering the environmental aspects of fertilizer usage, it can be concluded that the majority of farms in the Puck Commune used the correct approach in mineral fertilizers management (e.g. dividing doses, not using fertilizers in high-risk conditions, observing rules for fertilizer use on slopes, no fertilizers in proximity to surface water, keeping agro-technical practices records).

366 However, in most of farms there were natural conditions that could create increased fertilizers

- 367 losses during their application, especially in which arable lands were located in steep-slope areas
- 368 (more than 60% of all farms). On such plots, surface runoff could be formed, delivering
- 369 nutrients from land to watercourses and water reservoirs. As a consequence, this could lead to
- their eutrophication (Andraska, Bundy, 2003; Miller et al. 2011). Therefore, the higher
- 371 fertilizers doses were used, the greater could be the loss of nutrients by surface runoff (Thayer,
- 372 2011; Smith, Jackson, Pepper, 2001).
- 373 NP and K in mineral fertilizers constituted the largest shares in total components input brought
- onto the analyzed farms from outside (on average, 65.0, 63.0 and 79.4 percent, respectively).
- 375 Moreover, the relationship between N, P and K content in mineral fertilizers and their surplus
- 376 generated by farms has a strong positive correlation (Table 4-6). The average N and K surplus
- 377 had also a statistically significant positive impact on purchased concentrated fodder while in
- case of average P surplus this relationship did not occur. These two sources frequently
- determine the N surplus size estimated by "at the farm gate" method (Pietrzak, 2009; Kupiec,2011).
- 381 In addition to purchased fertilizers and concentrated fodder, the factors that had a significant
- impact on the results of N, P and K balances were sold plant products as well as sold animal
- 383 products it was an inverse relationship. In the N and P cases, there were also significant
- 384 positive correlations between surpluses of these nutrients and their outputs in sold animal
- products. With regard to K balances, no such relationships were found.
- 386 The average N surplus in farms of the Puck Commune was 120.6 kg N·ha<sup>-1</sup> AL while the
- average P surplus was at a level of  $-5.0 \text{ kg P} \cdot \text{ha}^{-1} \text{ AL}$  (values of these indicators were
- 388 characterized by a considerable variety among the surveyed farms). According to various
- authors works (Godinot et al., 2015; Olofsson, 2015), the levels of N and P surplus determined
- using farm scale nutrient balance are closely related to their business profile the largest NP
- 391 surplus are generated on farms focused on animal production.
- The broad majority of farms in the Puck Commune (80.6%, n=25) was focused on livestock
- 393 production, in particular, milk and beef (48%, n=12), only pork (24%, n=6), only beef (8%, n=2),
- beef and pork production (24%, n=6) and horse breeding (4%, n=1).Comparing study farms
- average N surplus, it can be concluded that its value was smaller in relation to a similar category
- of French farms (Table 7), while compared to Swedish farms, it was at comparable level (Table

8).Comparable in level to farms in Sweden was also an average P surplus calculated for all 397 surveyed farms in the Puck Commune. In view of the fact that in Sweden huge attention to 398 reducing the losses of nutrients from agriculture is paid, especially due to need of counteracting 399 Baltic Sea eutrophication, it seems that N and P surplus generated by farms of the Puck 400 Commune can be considered acceptable in the context of their impact on the environment. 401 The average surplus of K – a component regarded as neutral for the environment – in study farms 402 was 10.8 kg K·ha<sup>-1</sup> AL. The level of this surplus was 28% lower than in K balance found in other 403 researches undertaken in Poland on a comparable group of farms (in terms of number of farms and 404 their specialization of production), but located in a region with more intensive agriculture (Kupiec, 405 2015). 406

With regard to the presented results of nitrogen, phosphorus and potassium balance, it should be 407 noted that they may be affected by some uncertainty associated to method of obtaining results for 408 their preparation, based on interviews with farmers. Therefore, it is right to postulate that 409 keeping records on agro-technical practices or nutrient booking containing necessary information 410 for balance sheets preparation should be implemented (in particular records on purchased 411 412 fertilizers and concentrated fodder as well as sold agricultural products) (Kupiec, Zbierska, 2008). Apart from purely cognitive values of nutrient balance results, they have an educational 413 414 significance in shaping farmers' awareness. This meaning is widely articulated in many sources and can be expressed in the form of the following opinions and statements: 415

The "at the farm gate" nutrient balance method is a basic and simple way to increase
knowledge and farmers' awareness about nitrogen, phosphorus and potassium flow - to
and from a farm, - creating a starting point for discussion on how to use these components
efficiently on farm scale and on impact of NPK and their incomplete use on farm
economics as well as the environment (Nilsson, 2013);

<sup>o</sup> Nutrient balance enables farmers to easily review NPK flow at farm gate level by

- 422 calculating the amount of nutrient imported and exported to the farm. Thanks to that, a
- 423 well-prepared nutrient balance can help the farmer to evaluate and improve their nutrient
- 424 management which can contribute to lower operating costs of the farm by showing the425 actual amount of nutrients needed for production (Nutrient balance; Farmgate Nutrient
- 426 Balance Help file PLANET);

Farm gate nutrient balances are a useful tool to compare farms and farm systems as well
as to identify high-risk areas where a lot of nutrients is gathered and hotspots for nutrient
emissions (Ramnerö, 2015);

By calculating the nutrient balances at farm gate level, based on the principles of farmers'
voluntary participation and through their dialogue with the advisory institutions, an agreement
may be achieved – in order to reduce NPK surpluses and to increase farm profit (Olofsson,

433 2014).

434 In the light of the above, preparation of tool called Integrated agriculture calculator –

435 CalcGosPuck within the WaterPUCK project is well grounded and fully justified. Its

436 dissemination may contribute to broadening farmers' knowledge on correct nutrient management

and fertilizer on farm scale and thus reduce environmental pressure exerted by agriculturalactivities.

439

#### 440 **Conclusion**

441 The environmental impact of study agricultural holdings in the Puck Commune (which can be taken as representatives of the entire collectivity in this commune) was mainly related to the 442 amount of mineral nitrogen and phosphorus fertilizers consumption in these farms as well as 443 practices and conditions of their use. The individual N fertilizers consumption per 1 ha of 444 agriculture land in the study area was significantly higher in comparison to their average unit 445 usage in Poland, while the consumption of P fertilizers was slightly lower than the national 446 average. At the time of application these fertilizers, the recommendations for reducing their 447 environmental impact were considered. The amount of purchased N, P and K fertilizers had a 448 significant impact on the results of nutrient balances estimated by the "at the farm gate" method. 449 The results of nutrient balances showed, in particular, that average N, P and K surplus generated 450 by the analyzed farms ranged within the respective levels of 120.6 kg N, 5.0 kg P and 10.8 kg 451 K·ha<sup>-1</sup> AL. Comparing nutrient surplus amount in agricultural holdings of the Puck Commune to 452 similar farms and farm systems, e.g. in countries with well-developed agriculture, such as France 453 454 and Sweden, average N and P surplus in study area can be assessed as moderate while average K surplus as being in the range of its average values typical for farms in Poland. 455 Notwithstanding the above, the results of estimated NPK balance well showed their practical 456 dimension. In this regard, it should be indicated that estimating N, P and K values in a nutrient 457

balance can lead to many practical conclusions helping to reduce the impact of agricultural 458 production on the environment and to improve the farming economy. An example of the latter 459 would be the results of more effective use of nutrients on a farm and lower expenditures on 460 fertilizers and feeds. Therefore, knowledge on how to estimate nutrient balances should be more 461 widely disseminated, especially among farmers and agricultural advisors. Helpful role in this 462 area can play program developed within the WaterPUCK project called "Integrated agriculture 463 calculator - CalcGosPuck". CalcGosPuck works as an independent application to calculate the 464 pollution emission from agricultural holdings to the environment, including surface and 465 groundwater, but it also can serve to calculate the nutrients' distribution over agricultural areas. 466

467

#### 468 Acknowledgements

We express our gratefulness to the anonymous reviewers for their valuable comments on theearlier versions of the manuscript.

471

#### 472 **References**

473 Andraski T.W., Bundy L.G. 2003. Relationships between phosphorus levels in soil and in runoff

474 from corn production systems. *J Environ Qual*. 32(1): 310-316;

475 Annex of Regulation of the Council of Ministers Decree of June 5, 2018 for adoption of "Action

476 program aimed at reducing the outflow of nitrates from agricultural sources" (J. of Laws, 2018

477 item 1339);

478 Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against

479 pollution caused by nitrates from agricultural sources;

480 CSO 2018. Means of production in agriculture in the 2016/2017 farming year - updated tables.

481 Warsaw: Central Statistical Office. Available at: <u>https://stat.gov.pl/obszary-</u>

482 <u>tematyczne/rolnictwo-lesnictwo/rolnictwo/srodki-produkcji-w-rolnictwie-w-roku-gospodarcz</u>

483 ym-20162017,6,14.html (in Polish);

484 Dzierzbicka-Głowacka L., Janecki M., Dybowski D., Szymczycha B., Obarska-Pempkowiak H.,

485 Wojciechowska E., Zima P., Pietrzak S., Pazikowska-Sapota G., Jaworska-Szulc B., Nowicki A.,

486 Kłostowska Ż., Szymkiewicz A., Galer-Tatarowicz K., Wichorowski M., Białoskórski M.,

487 Puszkarczuk T. 2019. A new approach for investigating the impact of pesticides and nutrient flux

- 488 from agricultural holdings and land-use structures on the coastal waters of the Baltic Sea. *Polish*
- 489 Journal of Environmental Studies 29(5) DOI: 10.15244/pjoes/92524 (in press);
- 490 Fagerberg B., Salomon E., Steineck S. 1993. The computer program NPK-FLO. Internal
- 491 Publications Swedish University of Agricultural Sciences. Department of Crop Production
- 492 *Science* **9**;
- 493 Farmgate Nutrient Balance Help file PLANET, version 3.0. Available at:
- 494 http://www.planet4farmers.co.uk/PlanetWebsiteTutorialsFiles%5CHelpEngland%5CPLANET%
- 495 20v3%20Farmgate%20Nutrient%20Balance%20Help.pdf;
- 496 Godinot O., Leterme P., Vertès F., Faverdin P. Carof M. 2015. Relative nitrogen efficiency, a
- 497 new indicator to assess crop livestock farming systems. *Agronomy for Sustainable Development*.
- 498 35(2): 857–868;
- 499 Grabowski J. 2009. Chemical composition of mineral fertilizers. Available at:
- 500 http://www.oschrbialystok.internetdsl.pl/pdf/nawozy\_naturalne.pdf (in Polish);
- 501 Grześkowiak A. 2016. Fertilization of vegetables in the field cultivation. Available at:
- 502 http://www.polifoska.pl/module-Publikacje-action-Nawozenie-file-content\_83.html.html (in
- 503 Polish);
- 504 Høgh-Jensen H., Loges R., Jørgensen F.V., Jensen E.S., Vinther F.P. 2004. An empirical model
- 505 for quantification of symbiotic nitrogen fixation in grass--clover mixtures. *Agricultural Systems*
- 506 82: 181–194;
- 507 Jadczyszyn J., Niedźwiecki J., Debaene G. 2016. Analysis of agronomic categories in different
- soil texture classification system. *Polish Journal of Soil Science* XLIX/1): 61-72,
- 509 DOI:10.17951/pjss.2016.49.1.61;
- 510 Jakobsson C. 2012. 61 Focus on Nutrients: Advisory Service, Training and Information. In:
- 511 Jakobsson C., ed. Sustainable Agriculture. Uppsala: Baltic University Press, 461-466;
- 512 Koelsch R. Lesson 2: Whole Farm Nutrient Planning. Available at: <u>https://articles</u>.
- 513 extension.org/pages/14850/lesson-2-whole-farm-nutrient-planning;
- 514 Koelsch R., Franzen A. 2002. Estimating A Whole Farm Nutrient Balance. Available at:
- 515 https://water.unl.edu/article/animal-manure-management/software#wfnb;
- 516 Kucharska D., Staśkiewicz B., Wronka T. 1996. Guide for fertilizing and protecting plants 1997-
- 517 1998. Warsaw: AGROCHEM- SITR (in Polish);

### NOT PEER-REVIEWED

- 518 Kupiec J., Zbierska J. 2008. Possibilities of using the balance at the farm gate to assess the
- 519 potential threat to water quality on the example of farms located in areas covered by the nitrates
- 520 directive. *Melioration and Meadow News* 4(419): 189-192 (in Polish);
- 521 Kupiec J. 2011. Trend of balance and nitrogen balance structure in small-area farms. *Science*
- 522 *Nature Technologies* 5(2) (in Polish);
- 523 Kupiec J. 2015. Potassium balance in various specialized small-area farms. *Fragm. Agron.* 32(2),
- 524 51-62 (in Polish);
- 525 Maćkowiak C. 1997. Organic fertilizers in farms and their influence on the environment.
- 526 Przysiek. ODR(in Polish);
- 527 Mazur T. 1991. Nitrogen in arable soils. Warsaw: Polish Scientific Publishers (in Polish);
- 528 Mercik S. 2002. Agricultural chemistry. Theoretical and practical basics. Collective work.
- 529 *Warsaw: SGGW Publisher* (in Polish);
- 530 Miller J.J., Chanasyk D.S., Curtis T.W., Olson B.M. 2011. Phosphorus and nitrogen in runoff
- after phosphorus- or nitrogen-based manure applications. *J Environ Qual.* 40(3): 949-958;
- 532 Nilsson C. 2013.Farm gate nutrient balance. The report prepared within the Baltic Deal project;
- 533 Nilsson C. 2016. Focus on nutrients. Baltic Deal. Personal communication;
- 534 Nutrient balance. Available at: <u>http://www.balticdeal.eu/measure/nutrient-balance/;</u>
- 535 Olofsson S. 2014. The setup for the voluntary nutrient balances in Sweden. Tema: Miljø 84
- 536 Obligatory or voluntary nutrient balances? Plantekongres produktion, plan og miljø 350-351;
- 537 Olofsson S. 2015. Focus on Nutrients, a voluntary on-farm initiative for environment and
- 538 economy. Available at: <u>https://www.teagasc.ie/media/website/publications/2015/Olofsson\_S.pdf;</u>
- 539 Pietrzak S. 2009. Nitrogen cycling in agricultural macro- and microsystems. Water-
- 540 Environment-Rural Areas 9(3): 143-158 (in Polish);
- 541 Pietrzak S. 2013. Preparation of nutrients balance with the method "at the gate of the farm, In:
- 542 Ulén B., Pietrzak S., Tonderski K. (eds), Farms' self- evaluation in the fields of: nutrients'
- 543 management and the environmental conditions' analysis. Institute of Technology and Life
- 544 Sciences in Falenty, Poland, 1-99 (in Polish);
- Ramnerö B. 2015. Self-evaluation of the Risk of Enhanced Nutrient Leaching by Polish Farmers
- 546 Nutrient balances, Soil maps, Farm walks and other tools. Master's Thesis. Swedish University
- 547 of Agricultural Sciences;

- 548 Rutkowska A. 2010. Determination of the- AlgaPlant and AlgaminoPlant growth promoters'
- 549 impact on the yield green maze mass on green fodder. Research report. Puławy.
- 550 IUNG-PIB (in Polish);
- 551 Salomon E., Sundberg M. 2012.Implementation and status of priority measures to reduce N and
- 552 P leakage. Summary of country reports. Available at: <u>www.balticcompass.org</u>;
- 553 Simon J. C., Le Corre L. 1992. The apparent balance of nitrogen at the farm level: methodology,
- examples of results. *Fourrages* 129: 79-94 (in French);
- 555 Schmidtke K. 2008. How to optimise symbiotic nitrogen fixation in organic crop rotations, In:
- 556 Organic agriculture in Asia. ISOFAR Conference. 13-14 March 2008. Dankook University,
- 557 Republic of Korea. Available at: <u>http://orgprints.org/13272/01/13272.doc;</u>
- 558 Schweder P., Kape E.-H., Brick M. 1998.Informationon fertilization and indicative values for an
- agricultural practice Guidelines for the implementation of the fertilizer regulation.
- 560 Mecklenburg-Vorpommern. Ministry of Agriculture and Nature Conservation (in German);
- 561 Smith K.A., Jackson D.R., Pepper T.J., 2001. Nutrient losses by surface run-off following the
- application of organic manures to arable land. 1. Nitrogen. *Environ Pollut*. 112(1): 41-51.
- 563 Available at : <u>http://www.ncbi.nlm.nih.gov/pubmed/11202653</u>;
- 564 Szewczuk Cz. 2010. Before you sell the straw the balance of nutrients. Agricultural News
- 565 *Poland*. Available at: <u>http://www.wrp.pl/zanim-sprzeda%C5%BC-s%C5%82om%C4%99-</u>
- 566 <u>%E2%80%93-bilans-substancji-od%C5%BCywczych(in Polish);</u>
- 567 Thayer Ch. 2011. Nutrient Runoff Following Manure Application. Biological Systems
- 568 Engineering. Dissertations, Theses, and Student Research 17. Available at:
- 569 <u>http://digitalcommons.unl.edu/biosysengdiss/17</u>
- 570 The Act of July 10, 2007 on fertilizers and fertilizing (J. of Laws, 2007 No. 147, item 1033);
- 571 Ulén B., Pietrzak S., Tonderski K., 2013. Farms' self- evaluation in the fields of: nutrients'
- 572 management and the environmental conditions' analysis. Institute of Technology and Life
- 573 Sciences in Falenty, Poland. 1-99,(in Polish);
- 574 Wrzaszcz W. 2009. Nutrients Balance and the balance sheet of organic matter in individual
- farms. The research on the socially sustainable agriculture. T7. multi-annual program 2005-2009.
- 576 The economic and social conditions for the development of Polish food economy after Polish
- 577 accession to the European Union. Warsaw, Poland, IERiGŻ-PIB. 1-98 (in Polish).

Map of the study area: Puck District and Bay of Puck.

The Bay of Puck, southern Baltic Sea is an example of a region that is highly vulnerable to anthropogenic impact. Therefore, it has been included into Natura 2000.



The shame of the WaterPUCK Service.

Integrated information and prediction Service WaterPUCK includes surface water model (based on SWAT Soil and Water Assessment Tool), groundwater flow model (based on Modflow code), 3D environmental model of the Bay of Puck EcoPuckBay (based on the POP code and 3D CEMBS model of the Battic Sea) and integrated agriculture calculator called "CalcGosPuck" plus large Database WaterPUCK.



Schema of the nutrient balance method "at the farm gate"; own elaboration (Pietrzak 2013).



Type and area of arable land or grassland in farms participating in the WaterPUCK project.



The selection page of the CalcGosPuck agricultural's calculator



Calculating nutrients balance in farm. Choose parameters for farm.

#### NOT PEER-REVIEWED



The consumption of nitrogen fertilizers in individual farms in farms participating in the WaterPUCK project.



The consumption of phosphorus fertilizers in the individual farms in farms participating in the WaterPUCK project.



The consumption of potassium fertilizers in the individual farms in farms participating in the WaterPUCK project.



Farm code

Surplus and efficiency of nitrogen (N) use in farms participating in the WaterPUCK project.



## Figure 11

Surplus and efficiency of phosphorus (P) use in farms participating in the WaterPUCK project.



## Figure 12

Surplus and efficiency of phosphorus (K) use in farms participating in the WaterPUCK project.



### Table 1(on next page)

Animal population, type and the maintenance system in study farms of Puck Commune.

	Farm		Stocki densit	ing V	Production of nitrogen in natural fertilizers		
Farm Code	ode area (in ha)	production		LU ha <sup>-1</sup>	Animals maintanance system	kg N	kg N ha <sup>-1</sup>
1	48	milk and beef livestock	51.3	1.1	shallow litter	2308	48
3	81	milk and beef livestock	85.6	1.1	shallow litter	3843	48
4	17.3	beef and pork livestock	18.4	1.1	shallow litter	495	27
5	51.5	beef and pork livestock	15.4	0.3	shallow litter	917	18
6	16	milk and beef livestock.	14.3	0.9	shallow litter	772	48
7	38.2	beef livestock	21.2	0.6	shallow litter	723	19
9	70	milk and beef livestock	70.3	1.0	shallow litter	3192	46
10	29.5	milk and beef livestock	47.3	1.6	shallow litter	1899	64
11	18	beef and pork livestock.	8.3	0.5	shallow litter	422	24
13	43	pork livestock	52.4	1.2	shallow litter	3402	79
14	10.5	pork livestock	2.9	0.3	shallow litter	214	28
15	100	milk and beef livestock	61.6	0.7	shallow litter	2662	30
18	77.5	pork livestock.	67.6	0.8	litter free	4449	56
19	120	milk and beef livestock	148.6	1.2	shallow litter	6527	54
20	45	beef livestock.	34.4	0.8	shallow litter	1171	26
21	15	pork livestock.	45.0	3.0	shallow litter	2073	138
22	62	milk and beef livestock	36.6	0.6	shallow litter	1603	26
23	36	milk and beef livestock	24.0	0.7	shallow litter	1095	30
24	7.24	pork livestock	5.42	0.8	shallow litter	349	48
26	118	milk and beef livestock.	45.5	0.4	shallow litter	4716	40
27	19	farming and horse breeding	24.7	1.3	shallow litter	836	40
28	38	milk and beef livestock	41.9	1.1	shallow litter	1828	48
29	16.5	milk and beef livestock	34.9	2.1	deep/ shallow litter	2385	145
30	5.0	pork livestock	6.4	1.3	shallow litter	398	80
31	13	beef and pork livestock.	1.3	0.01	deep litter	70	5

3

### Table 2(on next page)

The profile of production systems in the study farms in the Puck Commune.

2

Production System	No. of Farms	Proportion of Total (%)
Milk and Beef	12	38.7
Pork only	6	19.4
Pork and Beef	4	12.9
Beef only	2	6.5
Horse Breeding	1	3.2
None	6	19.4

3

### Table 3(on next page)

Consumption of mineral fertilizers (calculated on the pure ingredient) per 1ha of agricultural land in the marketing year of 2016/2017.

\*CSO 2018. Means of production in agriculture in the 2016/2017 farming year - updated tables. Warszawa. Central Statistical Office. Available online:: <u>https://stat.gov.pl/obszary-tematyczne/rolnictwo-lesnictwo/rolnictwo/srodki-produkcji-w-rolnictwie-w-roku-gospodarczym-20162017,6,14.html</u> (in Polish).

	1					
Area	Mineral fertilizers consumption. kg·ha <sup>-1</sup> AL					
	Total (NPK)	Nitrogen (N)	Phosphorus (P)	Potassium (K)		
Poland*	121.6	79.4	10.3	31.9		
Pomeranian Voivodship*	121.1	82.8	8.8	29.5		
Farms surveyed – average	147.1	114.9	9.3	22.9		
¥		•				

### Table 4(on next page)

The relationship between the surplus of N and selected factors.

Correlation Spearman ranks order, marked (in red) correlations are significant - with p < 0.05.

	Surplus N (kg ha <sup>-1</sup> )	Efficiency (%)	Nitrogen in mineral fertilizers (kg ha <sup>-1</sup> )	Nitrogen in feeds (kg ha <sup>-1</sup> )	N share in the sold animal production (%)	N share in the sold plant production (%)
Surplus N (kg ha <sup>-1</sup> )	1.00					
Efficiency (%)	-0.58	1.00				
Nitrogen in mineral fertilisers (kg ha <sup>-1</sup> )	0.57	0.04	1.00			
Nitrogen in feed (kg ha <sup>-1</sup> )	0.48	-0.18	0.03	1.00		
N share in the sold animal production (%)	0.36	-0.53	-0.20	0.64	1.00	
N share in the sold plant production (%)	-0.36	0.53	0.20	-0.64	-1.00	1.00

PeerJ Preprints | https://doi.org/10.7287/peerj.preprints.27419v1 | CC BY 4.0 Open Access | rec: 8 Dec 2018, publ: 8 Dec 2018

### Table 5(on next page)

The relationship between the P surplus and selected factors.

Correlation of the Spearman ranks order, marked (in red) correlations are significant - with p < 0.05.

<sup>1</sup> 2

	Surplus P (kg ha <sup>-1</sup> )	Efficiency (%)	Phosphorus in mineral fertilizers (kg ha <sup>-1</sup> )	Phosphorus in feeds (kg ha <sup>-1</sup> )	P share in the sold animal production (%)	P share in the sold plant production (%)
Surplus P (kg ha <sup>-1</sup> )	1.00					
Efficiency (%)	-0.91	1.00				
Phosphorus in mineral fertilisers (kg ha <sup>-1</sup> )	0.57	-0.43	1.00			
Phosphorus in feed (kg ha <sup>-1</sup> )	0.33	-0.10	-0.04	1.00		
P share in the sold animal production (%)	0.44	-0.44	-0.12	0.51	1.00	
P share in the sold plant production (%)	-0.44	0.44	0.12	-0.51	-1.00	1.00

- 3 4 5 6 7 8 9

### Table 6(on next page)

The relationship between the K surplus and selected factors.

Correlation of the Spearman ranks order, marked (in red) correlations are significant - with p < 0.05.

	Surplus K, kg·ha <sup>-1</sup>	K efficiency, %	K in mineral fertilizers, kg·ha <sup>-1</sup>	K in feeds, kg·ha <sup>-1</sup>	K in sold animal products, kg·ha <sup>-1</sup>	K in sold plant products, kg·ha <sup>-1</sup>
Surplus K, kg·ha <sup>-1</sup>	1.00					
K efficiency, %	-0.81	1.00				
K in mineral fertilizers, kg·ha <sup>-1</sup>	0.65	-0.41	1.00			
K in feed, kg·ha <sup>-1</sup>	0.36	-0.19	0.01	1.00		
K in sold animal products, kg·ha <sup>-1</sup>	0.26	-0.06	0.02	0.52	1.00	
K in sold plant products, kg·ha <sup>-1</sup>	-0.52	0.62	0.14	-0.40	-0.48	1.00

2 3

### Table 7(on next page)

Mean surplus N and N-efficiency in nine farming system categories in France (based on: Godinot et al., 2015).

		Farming system categories							
	Beef cattle	Beef cattle and crops	Beef cattle and pigs	Crops	Crops and milk	Milk	Milk and pigs	Pigs	Poultry
Number of farms	47	35	13	24	53	299	36	30	20
Surplus N (kg N ha <sup>-1</sup> AL)	228	128	448	141	124	245	420	852	377
N-efficiency (%)	11.6	30.4	17.5	41.7	27.9	16.9	21.9	23.5	26.8

3

4 5

### Table 8(on next page)

Farm gate balances of conventional farms in southern Sweden (based on: Olofsson, 2015).

1
-

	Type of farms				
	Crop	Dairy	Pig		
Number of farms	965	976	204		
Surplus N (kg N ha <sup>-1</sup> AL)	45	143	104		
Surplus P (kg P ha <sup>-1</sup> AL)	-1.4	4.7	7.6		

4