HPDA Service for Estimating the Brown Bear (Ursus arctos L.) Population in Bulgaria

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EURO^2

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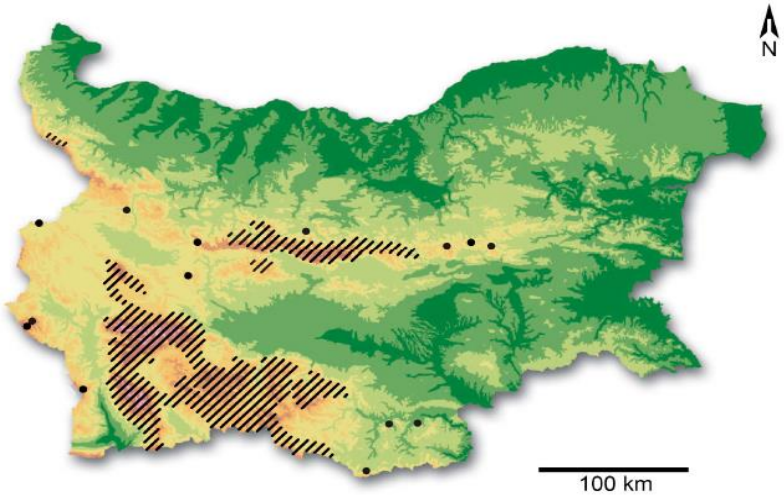
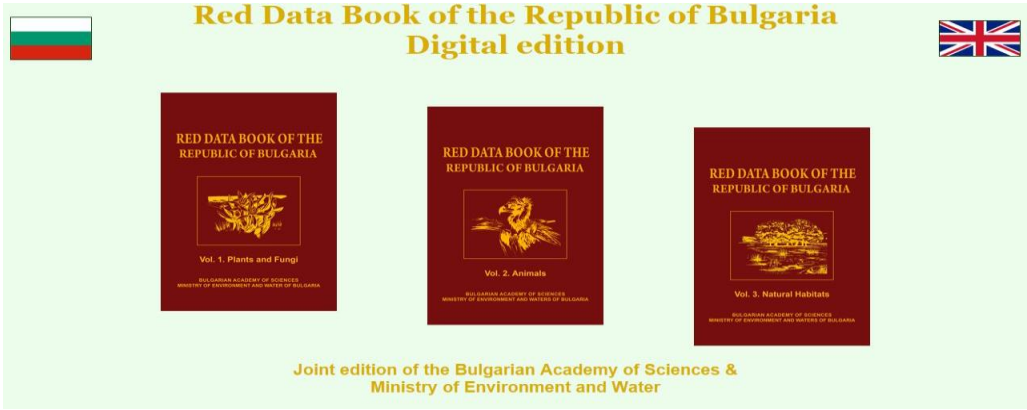
Motivation

- The Habitat Directive requires strict protection of the species and the declaration of special protected areas for the conservation of its habitats.
- According to the IUCN Red List (https://www.iucnredlist.org), the mammals are more than 5000 species worldwide, 26% of them threatened with extinction.
- Brown Bear (Ursus arctos) is a priority species for the conservation of mammals in the European Union. Conservation status: in Bulgaria endangered EN [C2a (i)], BA-II, III, International: Beck-II; CITES-II; DH-II, IV.
- Red Data Book of the Republic Bulgaria, Vol. 2 – Animals, Sofia, 2011. http://e-ecodb.bas.bg/rdb/en/



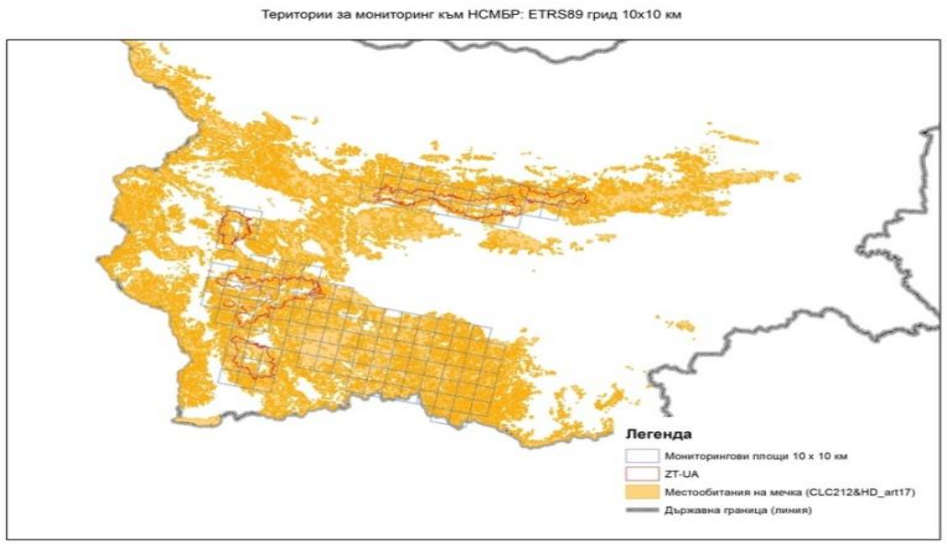


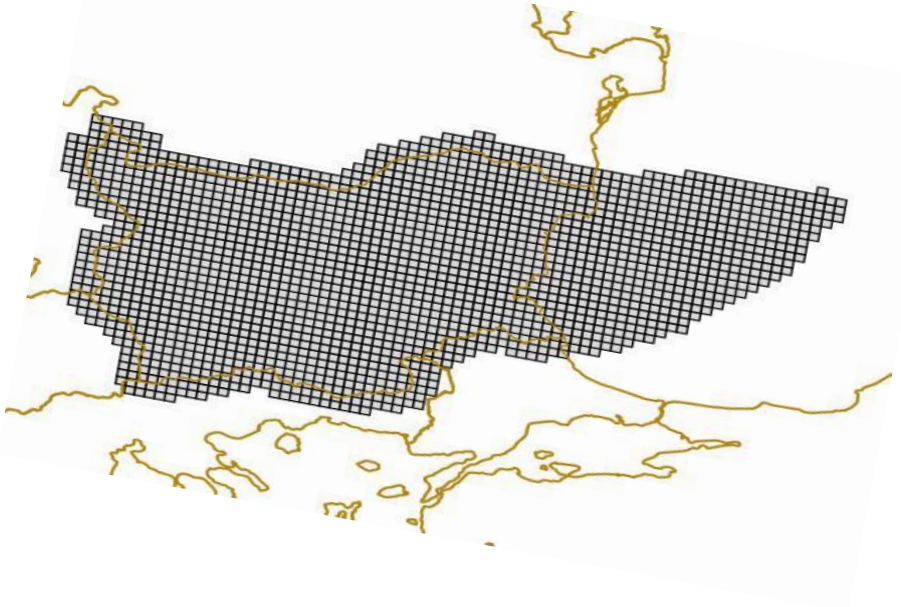
National monitoring

National Monitoring at the main mountain's habitats (start since 2016):

- **Width/length of the front footprint and/or back footprint**
- **Excrements**
- **Found bear marking**
- **A place where the bear has fed itself**
- **Visual observation of a bear**
- **Found winter dens**
- **Bear bed**
- **GPS coordinates of all bear's traces/signs**

EUROPEAN TERRESTRIAL REFERENCE SYSTEM 89 (ETRS89), Grids 10x10 km



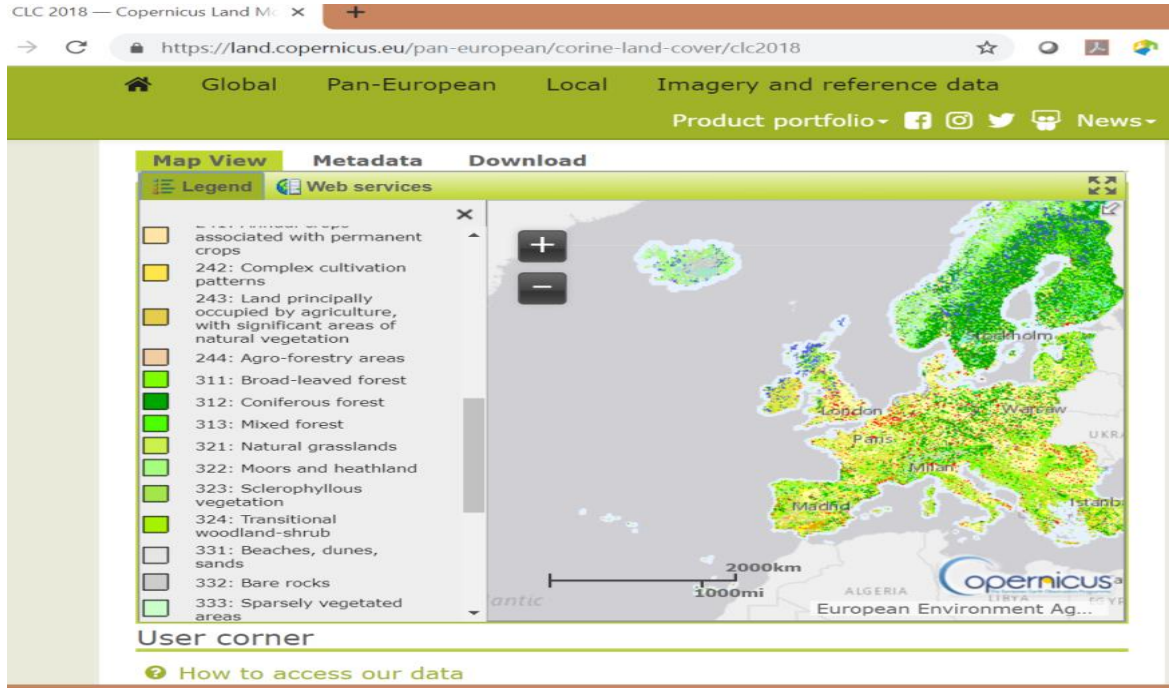


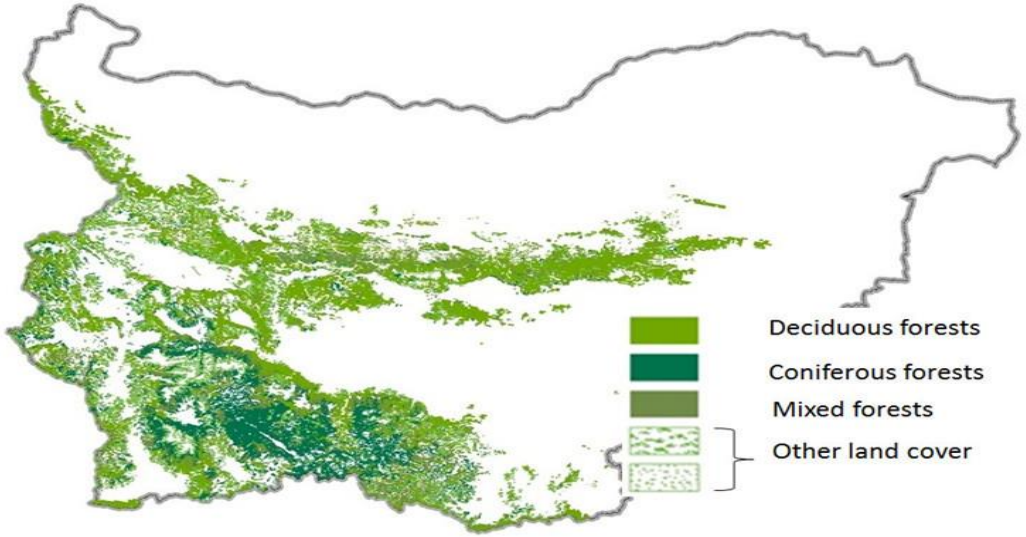
Number of grids in each subpopulation area

Areas for Monitoring	ETRS89 Grids 10x10 km	Number
Vitosha-Verila-Plana	E541N226; E541N225; E540N226; E540N225; E540N224; E540N223; E541N223;E541N224;E542N224; E542N225	10
Rila	E540N220; E540N221; E540N222; E541N219; E541N220; E541N221;E541N222; E542N219; E542N220; E542N221; E542N222; E542N223;E543N219; E543N219; E543N220; E543N221; E543N222; E544N220; E544N221; E544N222; E544N223; E545N220; E545N221; E546N222; E545N223; E543N223	26
Pirin	E542N215; E542N216; E542N217; E542N218; E543N215; E543N216; E543N217; E544N215; E544N216; E544N217	10
Rhodops	E546N217; E547N222; E548N219; E552N218; E552N220; E556N220; E545N218; E545N219; E546N219; E546N220; E547N217; E547N220; E547N218; E547N219; E547N221; E548N217; E548N218; E548N220; E548N221; E549N216; E549N217; E549N218; E549N219; E549N220; E549N221; E550N216; E550N217; E550N218; E550N219; E550N220; E550N221; E551N216; E551N217; E551N218; E551N219; E551N220; E551N221; E552N216; E552N217; E552N219; E552N221; E553N216; E553N220; E554N220; E556N218; E553N217; E553N218;E553N219; E553N221; E554N215; E554N216; E554N217; E554N218; E554N219; E554N221; E555N215; E555N216; E555N217; E555N218; E555N219; E555N220; E555N221; E556N216; E556N217; E556N219; E545N220	60
Central Balkan	E555N229; E551N230; E547N229; E549N229; E549N230; E556N231; E557N230; E558N231; E548N229; E548N230; E549N231; E550N229; E550N230; E551N229; E552N229; E552N230; E553N229; E553N230; E554N229; E554N230; E554N231; E555N230; E555N231;E556N230; E557N231	25
Kotlen mountain	E564N233;E564N234;E565N234; E566N234	4

CORINE Land Cover (CLC)

- CORINE Land Cover (CLC) is one of the most well-known and used products from the Copernicus Land Monitoring Service.
- It has previously been produced in 1990, 2000, 2006 and 2012 and now the **2018 edition is** available.



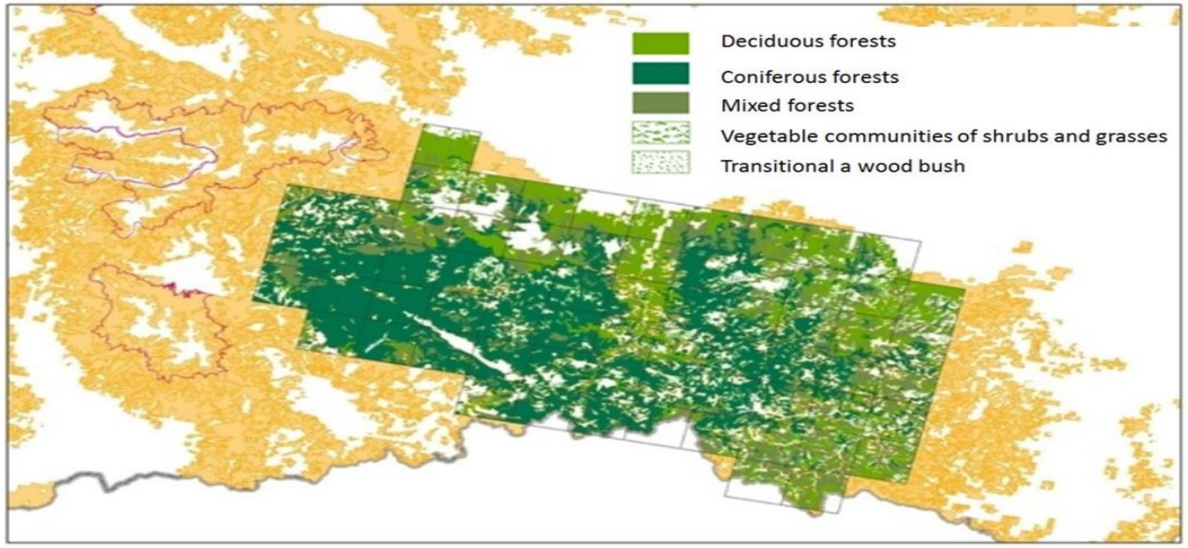


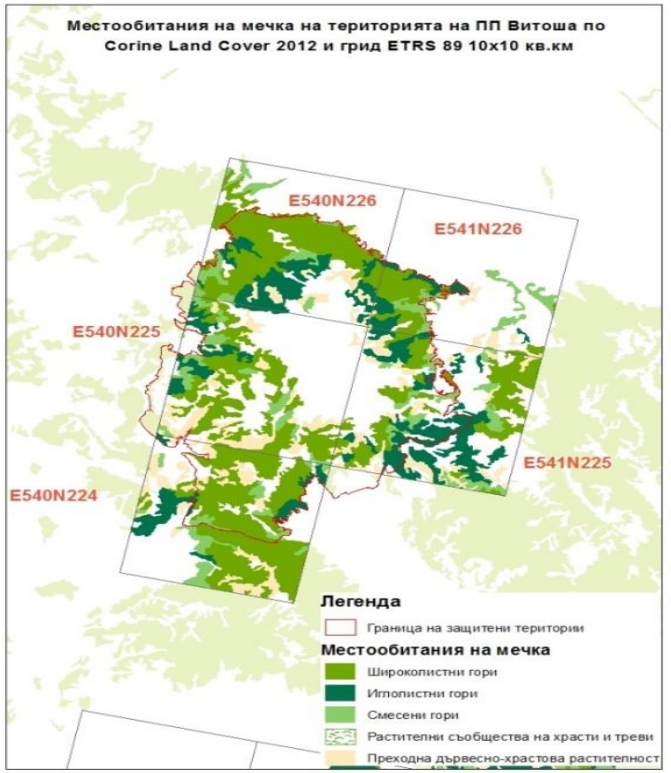
Transect method

It is based on the collection of brown bear sign on predefined set of routes (transects) and the determination of the unique traces (especially footprints).

Statistical estimates for population size of the brown bears using data of national monitoring and developed HPDA service.

- **Type of the forests:**
  - **Deciduous forests** **311**
  - **Coniferous forests** **312**
  - **Mixed forests** **313**
  - **Vegetable communities of shrubs and grasses** **322**
  - **Transitional a wood bush** **324**
  - **Other land cover** **no code**





Bears' habitat for monitoring in the Western Rhodopes and Vitosha mounting

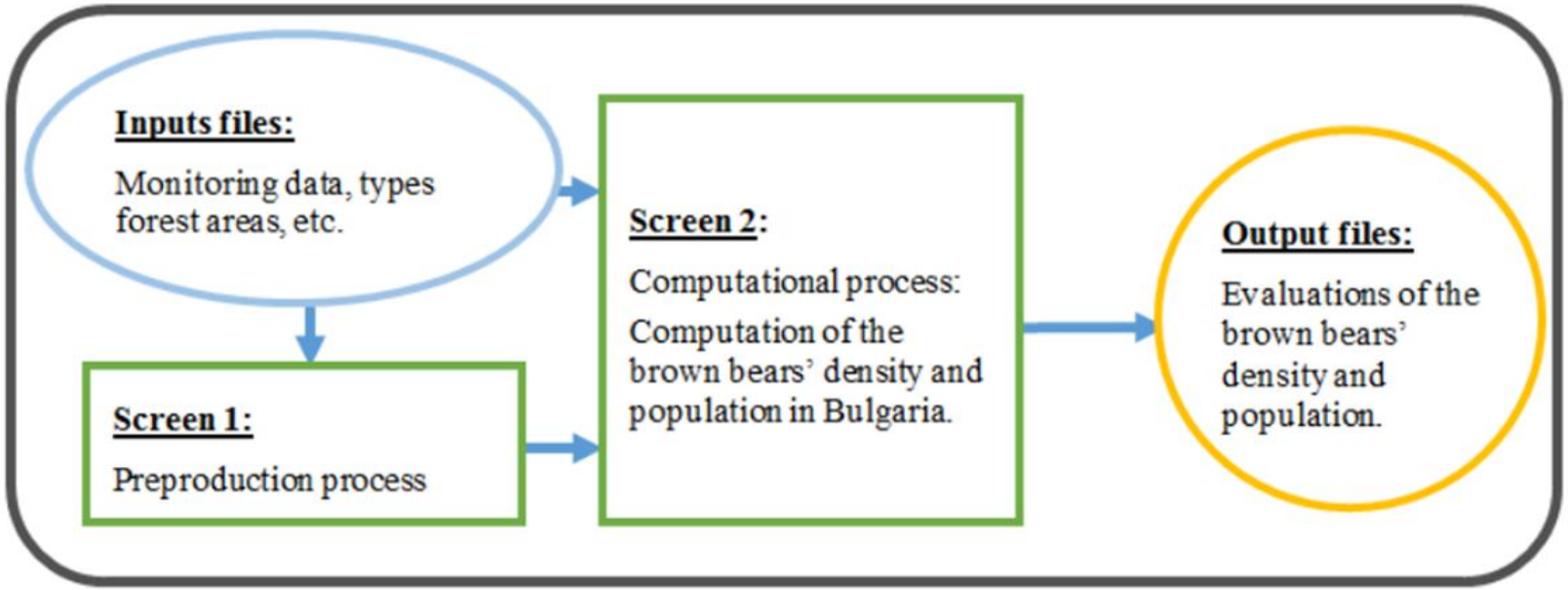
Start of the HPDA service

- Input the monitoring data to start the preproduction process

Estimation of the population size of the brown bears (1/2)

The evaluation is done in two steps.

First step: Identify unique traces based on collected observations in the national monitoring. The number of unique traces is determined by experts using the developed software product. Once the unique number of traces has been obtained, the program automatically allocates them by number in the respective 5 types of forest and in the residual area.



Input File - 1

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
FID	Shape	Label	Form_ID	Form_Name	Date	Type	Width_	Length_	Width_	Length	Soil_Type_0	Notes	X	Y
9	Point	00015	00015200001000075930	Brown bear (	19.5.2015	Trace	16,00	15,00			mud	Both ti	24,9541	42,6844
85	Point	00016	00016900001000002133	Brown bear (	6.11.2015	Trace			11,00	20	Sand		24,8983	41,7569
84	Point	00015	00015400001000023854	Brown bear (	5.11.2015	Trace							23,4342	42,0336
83	Point	00015	00015400001000023945	Brown bear (	4.11.2015	Trace	13,00		14,00	21	mud	Conifer	23,5423	42,0587
82	Point	00015	00015400001000023697	Brown bear (	5.11.2015	Trace	9,00		9,00	18	Soil	Fresh	23,395	41,976
81	Point	00015	00015400001000023470	Brown bear (	5.11.2015	Trace	12,00				Sand, Fresh	Conifer	23,2401	42,0763
80	Point	00015	00015200001000087813	Brown bear (	13.10.2015	Trace	12,00		11,00	16	Sand		24,4501	42,785
8	Point	00015	00015200001000080184	Brown bear (	5.11.2015	Trace			12,00	23	Soil	meado	24,493	42,7529
79	Point	00014	00014100001000001027	Brown bear (	4.11.2015	Trace	11,00				mud		24,0796	41,9304
78	Point	00014	00014100001000001027	Brown bear (	4.11.2015	Trace	11,00				mud		24,0738	41,9304
77	Point	00015	00015400001000015827	Brown bear (	5.11.2015	Trace	12,00				Sand		23,2401	42,0763
76	Point	00015	00015200001000078738	Brown bear (	4.11.2015	Trace	12,00	11,00					24,8236	42,7562
75	Point	00015	00015200001000087753	Brown bear (	20.5.2015	Trace	13,00	13,20			mud. Beech		24,9464	42,7775
74	Point	00015	00015200001000087393	Brown bear (	20.5.2015	Trace	10	10			Soil in Beec		24,9614	42,7567
73	Point	00015	00015200001000089717	Brown bear (	8.8.2015	Trace							25,1394	42,6713
72	Point	00015	00015200001000083544	Brown bear (	4.12.2015	Trace							24,3603	42,7651
71	Point	00011	00011500001000005847	Brown bear (	4.11.2015	Trace				23	Sand		23,9724	41,9324
70	Point	00011	00011500001000005847	Brown bear (	4.11.2015	Trace			13,5	23	Sand		23,9731	41,9309
7	Point	00015	00015200001000075466	Brown bear (	19.5.2015	Trace	17		17	24	mud	Trace i	24,4956	42,7593
69	Point	00011	00011500001000005847	Brown bear (	4.11.2015	Trace			14	21	Sand		23,9858	41,9198
68	Point	00011	00011500001000005847	Brown bear (	4.11.2015	Trace			14		Sand		23,9848	41,9187
67	Point	00011	00011500001000005847	Brown bear (	4.11.2015	Trace	15		15	22	Sand		23,9879	41,917

Sheet1 Sheet2 Sheet3

Input file -2

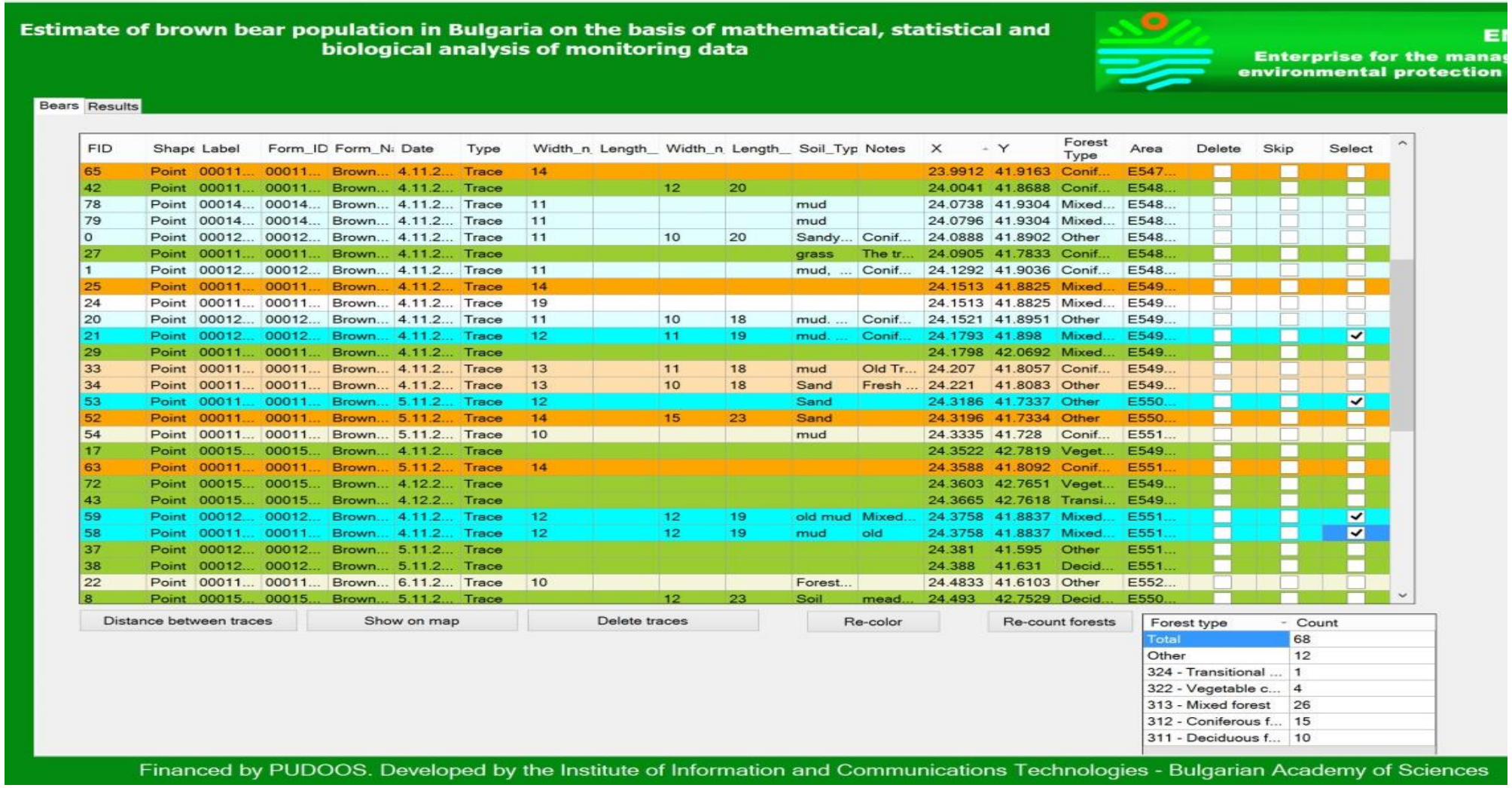
Code for each grid (10x10 km) according to:

- Code of the mountain
- Type of areas in hectares

	A	B	C	D	E	F	G	H	I	J
1	Area	Mountain	Alpine or continental region	311	312	313	322	324	Sum	Other
2	E547N229	1	2	2445	134	4355	290	526	7750	2250
3	E548N229	1	2	1807	779	1831	396	270	5083	4917
4	E548N230	1	2	3820	199	2648	0	1077	7744	2256
5	E549N229	1	2	1719	581	2887	785	395	6367	3633
6	E549N230	1	2	4501	0	3871	0	384	8756	1244
7	E549N231	1	2	4904	211	2506	0	686	8307	1693
8	E550N229	1	2	3185	276	3030	0	449	6940	3060
9	E550N230	1	2	2622	0	4344	0	719	7685	2315
10	E551N229	1	2	2163	0	1769	55	460	4447	5553
11	E551N230	1	2	2611	77	3250	0	450	6388	3612
12	E552N229	1	2	2925	781	645	358	1633	6342	3658
13	E552N230	1	2	5354	0	3048	339	139	8880	1120
14	E553N229	1	2	1912	315	571	422	1686	4906	5094
15	E553N230	1	2	4825	252	1561	0	1162	7800	2200
16	E554N229	1	2	4800	55	1026	0	1213	7094	2906
17	E554N230	1	2	3606	17	1812	916	250	6601	3399
18	E554N231	1	2	2258	262	2788	0	300	5608	4392
19	E555N229	1	2	1259	31	348	0	356	1994	8006
20	E555N230	1	2	5720	0	1612	73	116	7521	2479
21	E555N231	1	2	4903	173	3551	0	351	8978	1022
22	E556N230	1	2	4892	13	586	0	521	6012	3988
23	E556N231	1	2	5910	243	1482	0	368	8003	1997
24	E557N230	1	2	2649	336	1176	0	264	4425	5575
25	E557N231	1	2	6658	26	1520	0	101	8305	1695
26	E558N231	1	2	6030	200	2533	0	223	8986	1014
27	E540N223	5	1	2251	974	569	0	946	4740	5260
28	E541N223	5	1	3875	523	761	0	617	5776	4224
29	E545N218	2	1	311	5718	2072	0	1046	9147	853

areas | legenda | Sheet3

Preproduction process: Define the unique traces



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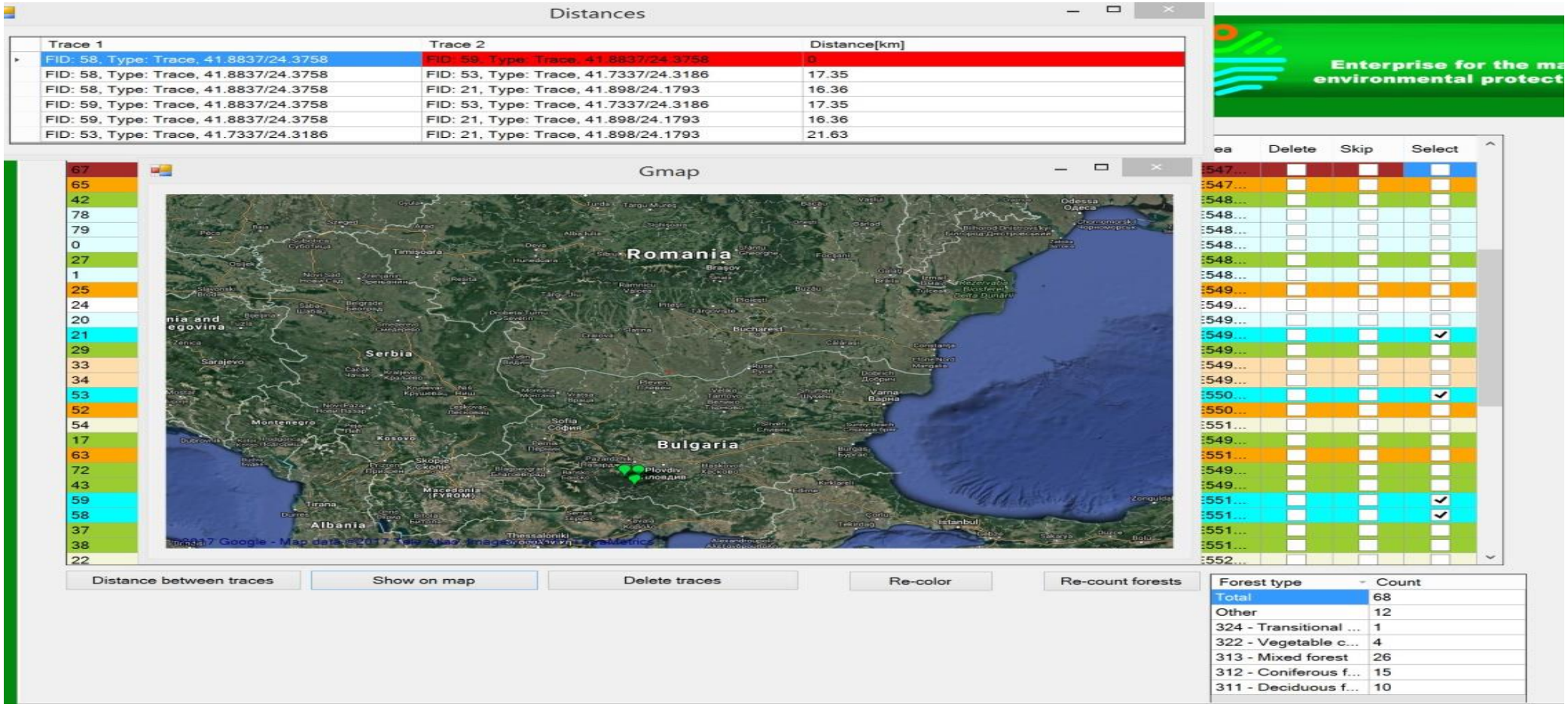
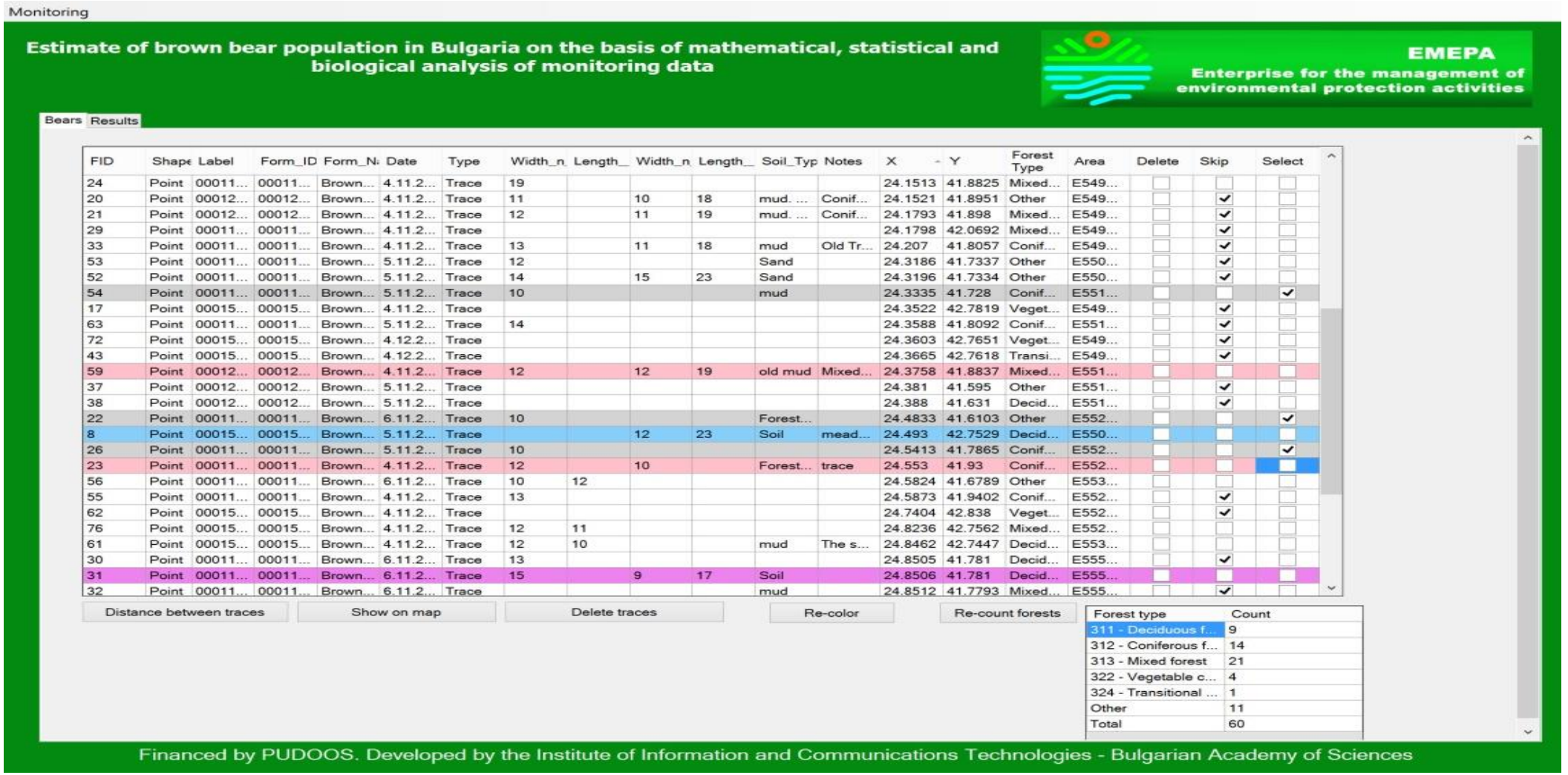
65	Point	00011...	00011...	Brown...	4.11.2...	Trace	14						23.9912	41.9163	Conif...	E547...			
42	Point	00011...	00011...	Brown...	4.11.2...	Trace			12	20			24.0041	41.8688	Conif...	E548...			
78	Point	00014...	00014...	Brown...	4.11.2...	Trace	11				mud		24.0738	41.9304	Mixed...	E548...			
79	Point	00014...	00014...	Brown...	4.11.2...	Trace	11				mud		24.0796	41.9304	Mixed...	E548...			
0	Point	00012...	00012...	Brown...	4.11.2...	Trace	11		10	20	Sandy...	Conif...	24.0888	41.8902	Other	E548...			
27	Point	00011...	00011...	Brown...	4.11.2...	Trace					grass	The tr...	24.0905	41.7833	Conif...	E548...			
1	Point	00012...	00012...	Brown...	4.11.2...	Trace	11				mud, ...	Conif...	24.1292	41.9036	Conif...	E548...			
25	Point	00011...	00011...	Brown...	4.11.2...	Trace	14						24.1513	41.8825	Mixed...	E549...			
24	Point	00011...	00011...	Brown...	4.11.2...	Trace	19						24.1513	41.8825	Mixed...	E549...			
20	Point	00012...	00012...	Brown...	4.11.2...	Trace	11		10	18	mud. ...	Conif...	24.1521	41.8951	Other	E549...			
21	Point	00012...	00012...	Brown...	4.11.2...	Trace	12		11	19	mud. ...	Conif...	24.1793	41.898	Mixed...	E549...			✓
29	Point	00011...	00011...	Brown...	4.11.2...	Trace							24.1798	42.0692	Mixed...	E549...			
33	Point	00011...	00011...	Brown...	4.11.2...	Trace	13		11	18	mud	Old Tr...	24.207	41.8057	Conif...	E549...			
34	Point	00011...	00011...	Brown...	4.11.2...	Trace	13		10	18	Sand	Fresh ...	24.221	41.8083	Other	E549...			
53	Point	00011...	00011...	Brown...	5.11.2...	Trace	12				Sand		24.3186	41.7337	Other	E550...			✓
52	Point	00011...	00011...	Brown...	5.11.2...	Trace	14		15	23	Sand		24.3196	41.7334	Other	E550...			
54	Point	00011...	00011...	Brown...	5.11.2...	Trace	10				mud		24.3335	41.728	Conif...	E551...			
17	Point	00015...	00015...	Brown...	4.11.2...	Trace							24.3522	42.7819	Veget...	E549...			
63	Point	00011...	00011...	Brown...	5.11.2...	Trace	14						24.3588	41.8092	Conif...	E551...			
72	Point	00015...	00015...	Brown...	4.12.2...	Trace							24.3603	42.7651	Veget...	E549...			
43	Point	00015...	00015...	Brown...	4.12.2...	Trace							24.3665	42.7618	Transi...	E549...			
59	Point	00012...	00012...	Brown...	4.11.2...	Trace	12		12	19	old mud	Mixed...	24.3758	41.8837	Mixed...	E551...			✓
58	Point	00011...	00011...	Brown...	4.11.2...	Trace	12		12	19	mud	old	24.3758	41.8837	Mixed...	E551...			✓
37	Point	00012...	00012...	Brown...	5.11.2...	Trace							24.381	41.595	Other	E551...			
38	Point	00012...	00012...	Brown...	5.11.2...	Trace							24.388	41.631	Decid...	E551...			
22	Point	00011...	00011...	Brown...	6.11.2...	Trace	10				Forest...		24.4833	41.6103	Other	E552...			
8	Point	00015...	00015...	Brown...	5.11.2...	Trace			12	23	Soil	mead...	24.493	42.7529	Decid...	E550...			

Forest type	Count
Total	68
Other	12
324 - Transitional ...	1
322 - Vegetable c...	4
313 - Mixed forest	26
312 - Coniferous f...	15
311 - Deciduous f...	10

Compute distances and show traces on the Gmap



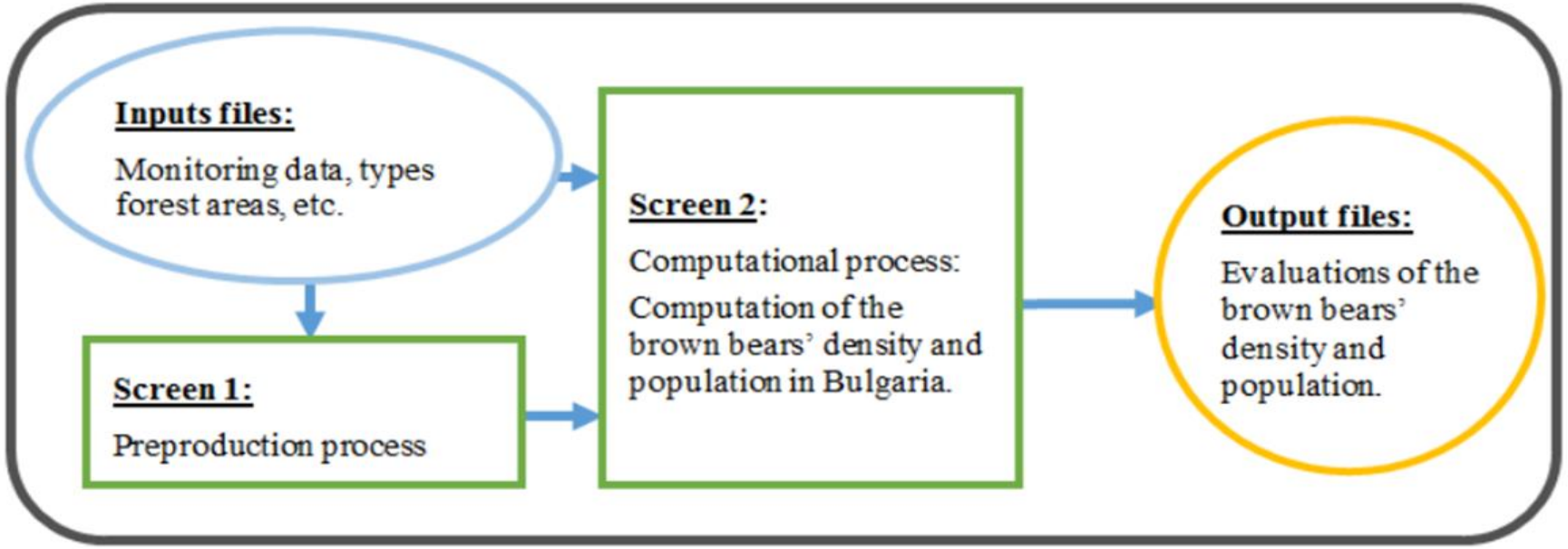
Skipping, re-coloring and re-counting



FID	Shape	Label	Form_ID	Form_N	Date	Type	Width_n	Length_	Width_n	Length_	Soil_Typ	Notes	X	Y	Forest Type	Area	Delete	Skip	Select
24	Point	00011...	00011...	Brown...	4.11.2...	Trace	19						24.1513	41.8825	Mixed...	E549...			
20	Point	00012...	00012...	Brown...	4.11.2...	Trace	11		10	18	mud. ...	Conif...	24.1521	41.8951	Other	E549...		✓	
21	Point	00012...	00012...	Brown...	4.11.2...	Trace	12		11	19	mud. ...	Conif...	24.1793	41.898	Mixed...	E549...		✓	
29	Point	00011...	00011...	Brown...	4.11.2...	Trace							24.1798	42.0692	Mixed...	E549...		✓	
33	Point	00011...	00011...	Brown...	4.11.2...	Trace	13		11	18	mud	Old Tr...	24.207	41.8057	Conif...	E549...		✓	
53	Point	00011...	00011...	Brown...	5.11.2...	Trace	12				Sand		24.3186	41.7337	Other	E550...		✓	
52	Point	00011...	00011...	Brown...	5.11.2...	Trace	14		15	23	Sand		24.3196	41.7334	Other	E550...		✓	
54	Point	00011...	00011...	Brown...	5.11.2...	Trace	10				mud		24.3335	41.728	Conif...	E551...			✓
17	Point	00015...	00015...	Brown...	4.11.2...	Trace							24.3522	42.7819	Veget...	E549...		✓	
63	Point	00011...	00011...	Brown...	5.11.2...	Trace	14						24.3588	41.8092	Conif...	E551...		✓	
72	Point	00015...	00015...	Brown...	4.12.2...	Trace							24.3603	42.7651	Veget...	E549...		✓	
43	Point	00015...	00015...	Brown...	4.12.2...	Trace							24.3665	42.7618	Transi...	E549...		✓	
59	Point	00012...	00012...	Brown...	4.11.2...	Trace	12		12	19	old mud	Mixed...	24.3758	41.8837	Mixed...	E551...			
37	Point	00012...	00012...	Brown...	5.11.2...	Trace							24.381	41.595	Other	E551...		✓	
38	Point	00012...	00012...	Brown...	5.11.2...	Trace							24.388	41.631	Decid...	E551...		✓	
22	Point	00011...	00011...	Brown...	6.11.2...	Trace	10				Forest...		24.4833	41.6103	Other	E552...			✓
8	Point	00015...	00015...	Brown...	5.11.2...	Trace			12	23	Soil	mead...	24.493	42.7529	Decid...	E550...			
26	Point	00011...	00011...	Brown...	5.11.2...	Trace	10						24.5413	41.7865	Conif...	E552...			✓
23	Point	00011...	00011...	Brown...	4.11.2...	Trace	12		10		Forest...	trace	24.553	41.93	Conif...	E552...			
56	Point	00011...	00011...	Brown...	6.11.2...	Trace	10	12					24.5824	41.6789	Other	E553...			
55	Point	00011...	00011...	Brown...	4.11.2...	Trace	13						24.5873	41.9402	Conif...	E552...		✓	
62	Point	00015...	00015...	Brown...	4.11.2...	Trace							24.7404	42.838	Veget...	E552...		✓	
76	Point	00015...	00015...	Brown...	4.11.2...	Trace	12	11					24.8236	42.7562	Mixed...	E552...			
61	Point	00015...	00015...	Brown...	4.11.2...	Trace	12	10			mud	The s...	24.8462	42.7447	Decid...	E553...			
30	Point	00011...	00011...	Brown...	6.11.2...	Trace	13						24.8505	41.781	Decid...	E555...		✓	
31	Point	00011...	00011...	Brown...	6.11.2...	Trace	15		9	17	Soil		24.8506	41.781	Decid...	E555...			
32	Point	00011...	00011...	Brown...	6.11.2...	Trace					mud		24.8512	41.7793	Mixed...	E555...		✓	

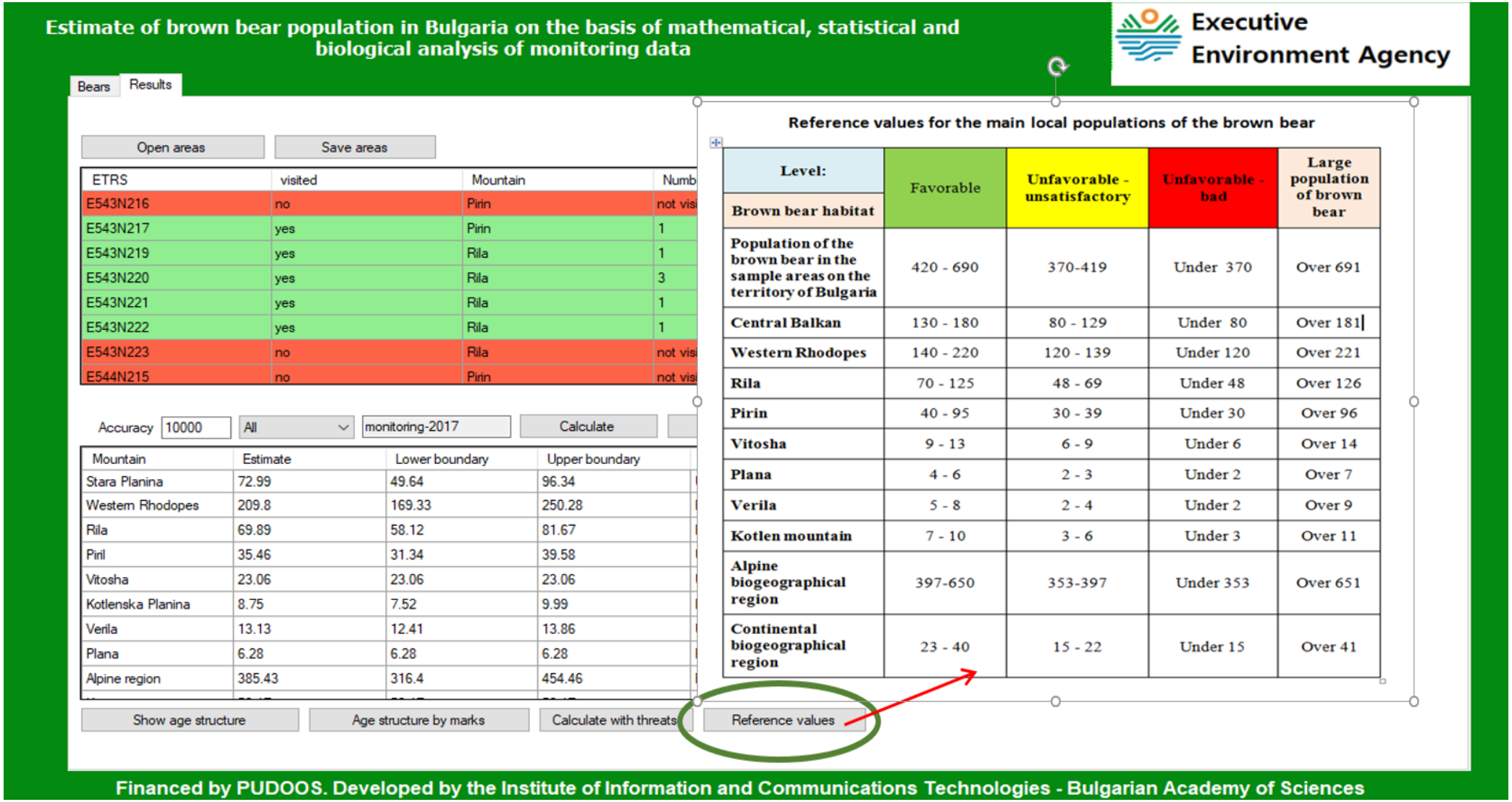
Estimation of the population size of the brown bears

Second step: At this stage, the program statistically estimates the number of population and the distribution density of the brown bear on the 6 geographic areas (mountains) and on two geographic climatic areas (alpine and continental).
Since there are not enough 232 transects covering all 142 grids during the national monitoring, the program automatically divides the number of grids into **two sets.**
The first set includes those grids which contain transects (grids) visited during the national monitoring. The number of the brown bear is estimated statistically using the **maximum likelihood method.**
The second set includes those grids which contain transects (grids), not visited during the national monitoring. The number of population in the second set is obtained by extrapolation.



Computational process

- Computation of the density and the population of the species



Statistical estimation of the bears' population

- We use maximum likelihood method with following parameters.
- We have introduced the **coefficients $\lambda_1, \ldots, \lambda_5$**, to estimate the probability of detecting the presence of a bear in a given area (forest type), which are the parameters of the Poisson distribution (assumed the distribution is Poisson).
- These parameters describe the number of bears per unit area in the respective forest type.
- We have also introduced **the coefficients $\psi_1, \ldots, \psi_5$**, which correspond to the probability of finding a bear if it is in the relevant area (grid) and type of forest.

$$P(i,j,d) = e^{-\lambda_j} \sum_{k=d}^{\infty} \binom{k}{d} \psi_i{}^{d} (1-\psi_j)^{k-d} \psi_j{}^{d} (1-\psi_j)^{k-d} \frac{\lambda_j{}^{k}}{k!}$$

- **Using these coefficients, we have constructed a likelihood function.**
- When $\psi_j = 1$, (in case we have forest animal feeders in the each grid) we obtain simpler formula:

$$e^{-\lambda_j} \frac{\lambda_j{}^{d}}{d!},$$ where d is the number of the unique traces.

- Using **maximum likelihood estimation we can** estimate the values of the **coefficients $\lambda_1, \ldots, \lambda_5$**, and **$\psi_1, \ldots, \psi_5$.**

Age structures by unique traces

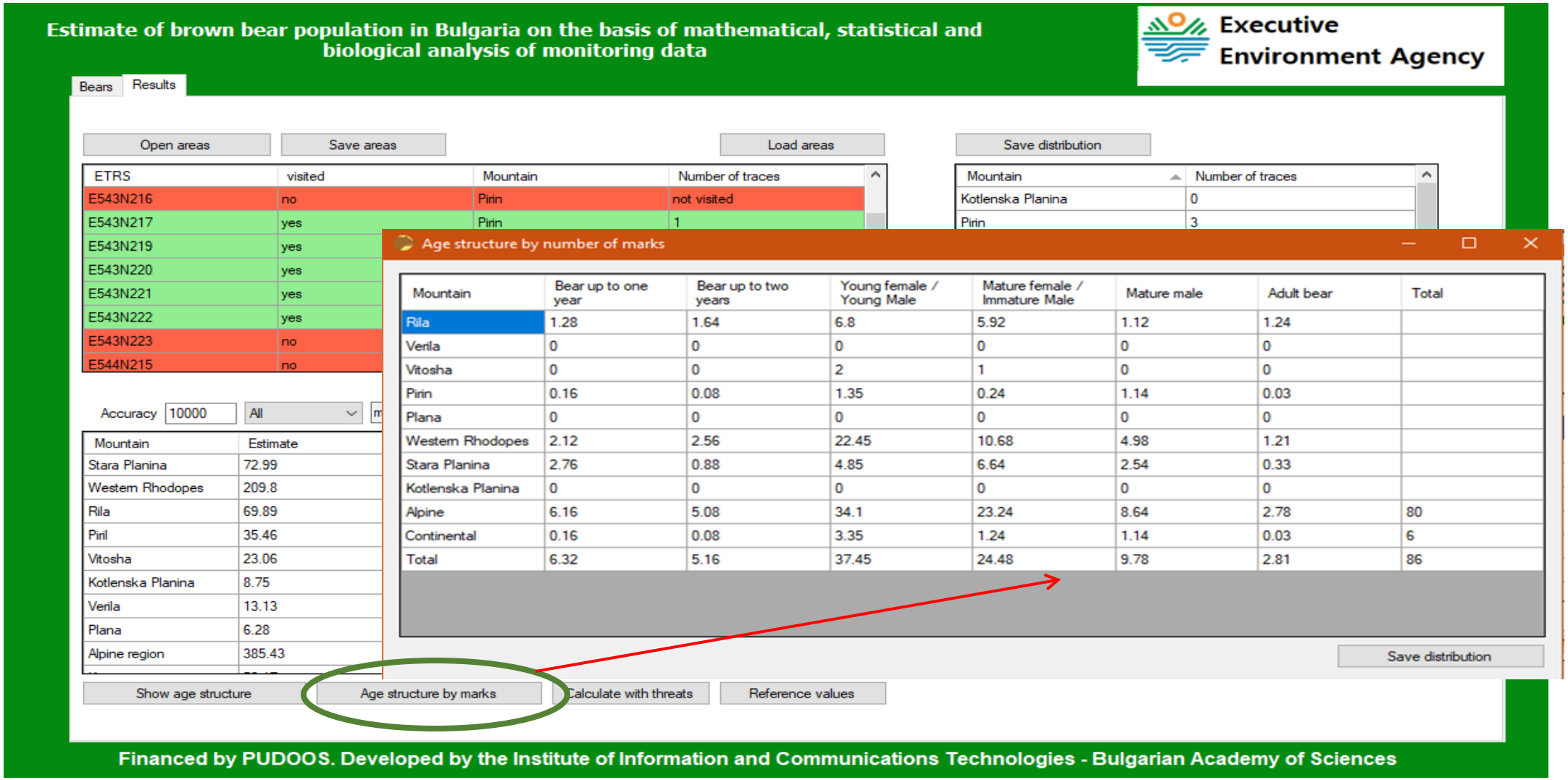
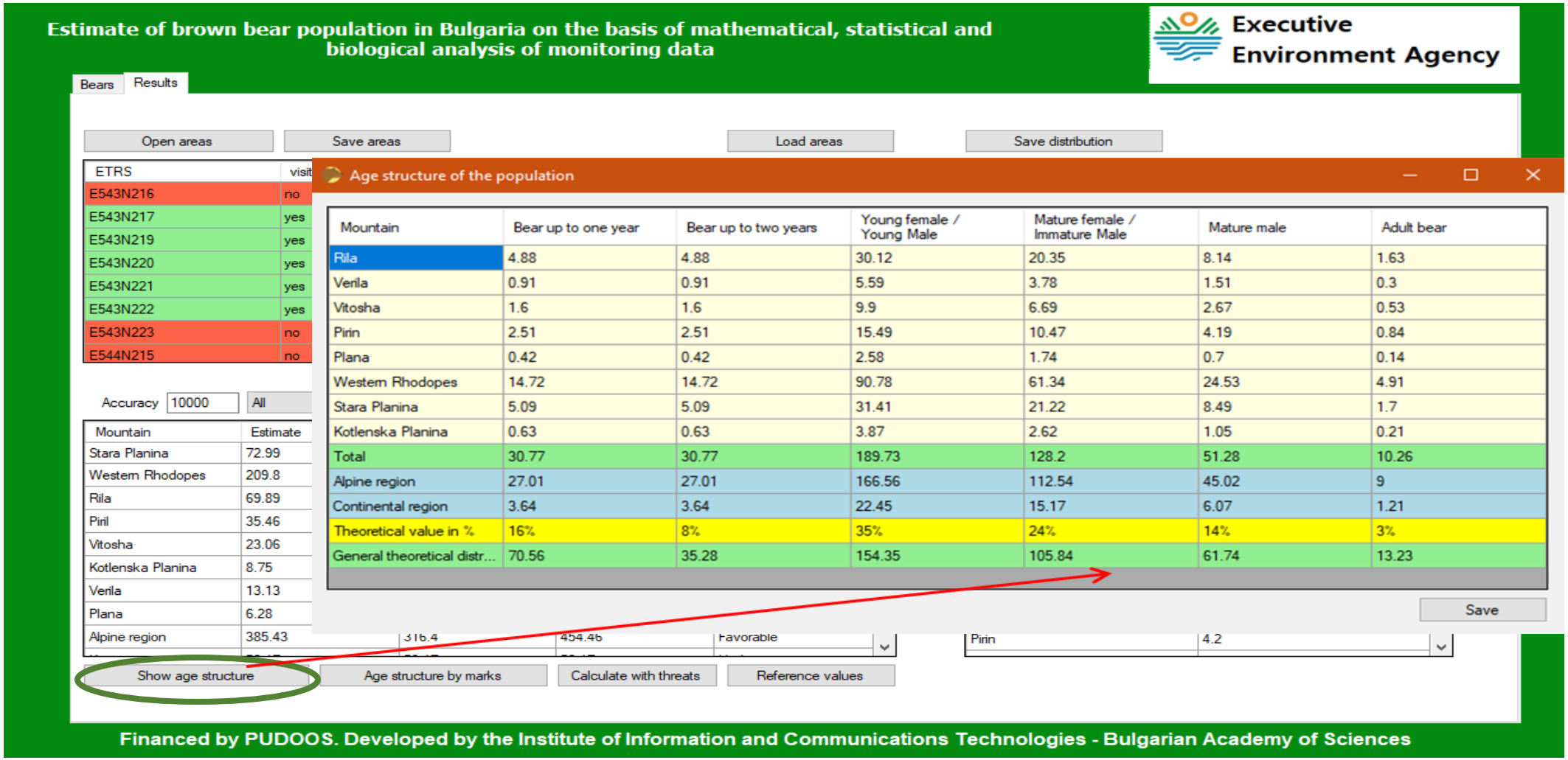


Table for Age Structure

Table: Size of the footprints of the brown bear from Bulgaria and Eastern Europe. Correlation between the length of the footprint of the hind paw, the width of the fore one, and the size, the sex and the age of the bear.

Feature Category bear	Width of the fore pow footprint	Width of the hind pow footprint	Length of the hind pow footprint
1. A bear cub – 1st year	5-7 cm	-	6-11 cm
2. A bear cub – 2nd year, up to ~ 50 kg.	~ 8-9 \10	0-0.5 cm narrower than the anterior one	12-15
3. Young females (3 and 4 years'old) and young males ~ 3 years' old (small bear: ~ 50-100 kg)	10/11-12 cm. (the most frequent in the field) In the young individuals with 12 cm are most possibly young males because 12 cm is normal size for a mature female)	0-0.5 cm. narrower than the anterior	16-19/20
4. Adult females and subadult (4-5 years old) males (average-sized bear - 100 ~ 200 kg.)	12/13-13.5/14; (extremely rarely 14 cm – for a female but most frequently for a young male)	~ 0.5-1 cm Narrower than the anterior	19/20-23/24 cm; (23/24 – only male individuals)
5. Mature males more than 5 years old (large bear ~ 200-250 kg)	14.5-17	It could be up to 1-1.5 cm narrower	24-26/27
6. Very big, old males, usually more than 10 years' old and more than 250 kg (records – above 350 kg)	17 and more	Up to 1-2 cm narrower	27-30 (31?) cm

Age structures of the estimated population



List of pressures and threats

Pressures and Threats	weight	Favorable	Unfavorable - unsatisfactory	Unfavorable - bad
Derogation of problematic bears	L	0 - 25%	25 - 40%	Over 40%
Conflicts with farmers and local people	H	0-10%	11-30%	Over 30%
Poaching	H	0-10%	11-30%	Over 30%
Disturbance (human activities)	M	0 - 20%	21 - 50%	Over 50%
Destructions of bio-corridors	H	0-10%	11-30%	Over 30%
Natural threats (survival of bears up to two years of age)	L	0 - 60%	60-70%	Over 70%
Forest management for reduction (reduction of the area) of old forests	H	0-10%	11-30%	Over 30%
Sports infrastructure and tourism infrastructure	M	0 - 20%	21 - 50%	Over 50%
Climate change	M	0 - 20%	21 - 50%	Over 30%

Formula for computing the accumulated tread

- Justification for the choice of certain parameters: reflects the adverse effects on the condition and threats to the species in the studied habitats.
- Method of calculation:

$$F(\%) = \frac{n * (1 - \mu)}{N} * 100,$$

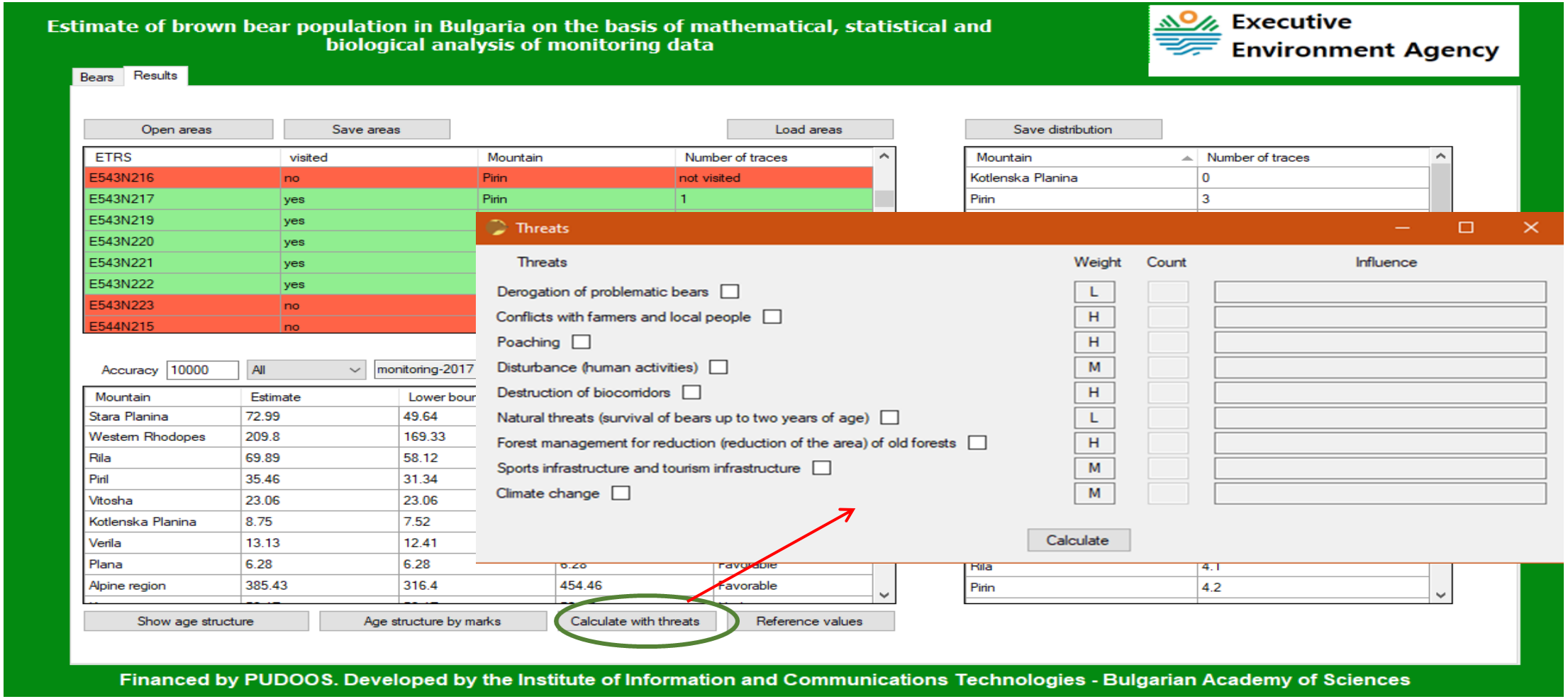
where n - means the number of sample areas (grids 10x10 km) in which the threat/impact is registered, and N - total number of sample areas in the studied habitats for a given level of analysis, and μ is an weight parameter depending on the degree of significance of the threat (L = low significance, M = medium significance, H = high significance. μ is belong to (0,1).

For example: when we have H (high significance), $\mu \approx 0{,}90$; if we have M , $\mu \approx 0{,}50$, and when we have L (low significance), $\mu \approx 0,20$.

- The integrated threat is calculated in percentages according to the formula:

$$F(\%) = \sum_{i=1}^{k} \frac{n_i * (1 - \mu_i)}{N} * 100.$$

Calculate with threats



Created unique traces using the data of given monitoring

Mountain	Number of unique traces 2017	Number of unique traces 2018	Number of unique traces 2019	Number of unique traces 2020
Central Balkan	10	8	11	7
Western Rhodopes	38	49	50	47
Rila	11	11	9	21
Pirin	6	2	3	5
Kotlen mountain	1	0	1	0
Plana, Verila, Vitosha	2	1	3	1
Alpine area	60	68	71	75
Continental area	8	3	6	6
Total	68	71	77	81

Evaluation results using HPDA service

Mountain	2017	2018	2019	2020
Central Balkan	61	61	58	77
Western Rhodopes	200	185	185	229
Rila	70	84	59	93
Pirin	37	40	41	35
Kotlen mountain	6	2	8	5
Plana, Verila, Vitosha	27	2	46	18
Alpine area	368	369	339	438
Continental area	33	5	58	19
Total	401	374	397	457

Conclusion

The HPDA service was created for the needs of the ENVIRONMENTAL EXECUTIVE AGENCY (EIA), which is under the Ministry of the Environment and Water (MOEW) with the financial support of the ENTERPRISE FOR MANAGEMENT OF ENVIRONMENTAL PROTECTION ACTIVITIES (PUDOOS).

Thank you!

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