Landscape Changes in Protected Areas in Poland

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Land-Use Cover Changes (LUCCs) are one of the main problems for the preservation of landscapes and natural biodiversity. Protected Areas (PAs) do not escape this threat. Poland is among the European leaders in terms of the variety of landscapes and the share of an area designated as a protected area. However, as many as 78% of the habitats have poor or bad conservation status based on EEA reports. The changes in PAs were usually smaller than in the surrounding buffer zones, which may indicate their effectiveness. The scale of land-cover flows (LCFs) changed within particular forms of protected areas, though afforestation and deforestation predominating in all area types. National reserves and parks were the most stable in terms of land cover structures. However, human settlements increased around the protected areas, potentially increasing threats to their ecological integrity.

landscape change protected area urban pressure deforestation land use CORINE land cover Poland

1. Introduction

Protected areas (PAs) are the cornerstone of global biodiversity conservation strategies [1][2]. They are a key for mitigating climate change, providing ecosystem services, and fostering human well-being [3][4]. There is considerable evidence that well-managed protected areas are effective in reducing biodiversity loss [5][6][7][8][9][10][11]. However, not all protected areas are fulfilling their conservation objectives [12][13][14][15]. As the human population increases, pressures on habitats are intensifying with unknown consequences for protected area effectiveness [16][17][18][19][20], and recent work has identified a range of drivers of biodiversity loss in protected areas [18][19][20][21][22].

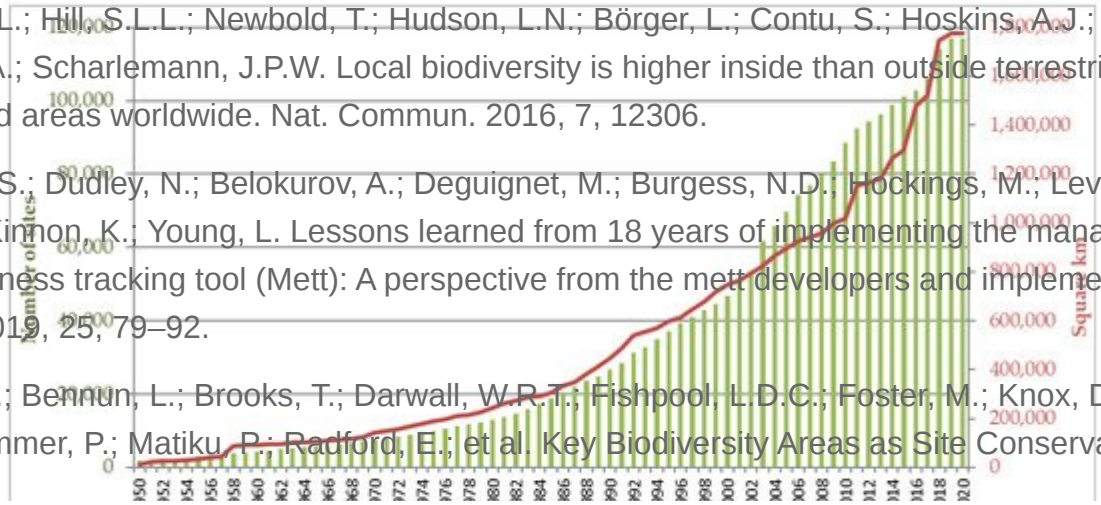
The inception and growth of a protected area network are one of the major global responses to rapid habitat loss and fragmentation, to counter the threats of the propagation of invasive species, deforestation, climate change, and urban and agricultural pressure. In 1990, PAs covered 8.6% of the Earth's surface [23], and now occupy 16.44% of the Earth's land surface, and 7.73% of the marine area [23]. According to the World Database of Protected Areas (WDPA) [23], they have expanded from 84,577 individual sites in 2003 to 258,133 in 2021, covering 245 countries and territories. The highest coverage of protected areas is in the Polar region (over 41% terrestrial and 44% marine) (**Table 1**). Europe has the largest number of sites, but they cover only 13% of the land area and 8% of the marine area [23].

Table 1. Protected areas in the world.

Region	Total Protected Areas	With Management Effectiveness Evaluations	Number of Countries	Terrestrial Protected Area Coverage %	Marine Protected Area Coverage %
Asia & Pacific	34,710	2821	56	15.37	18.56
Africa	8559	1000	58	14.11	12.35
Europe	158,452	15,719	62	13.14	8.44
Latin America&Caribbean	9971	1282	52	24.21	23.04
Polar	35	3	5	41.28	44.78
North America	45,272	117	3	11.85	16.51
West Asia	378	65	12	3.82	1.11

UNEP-WCMC (2021). Protected Area Profile from the World Database of Protected Areas, May 2021. Available at: www.protectedplanet.net, accessed on 5 May 2021.

These values may be slightly different from the national data. According to the European Environment Agency (EEA) in 2020, protected areas covered 26% of EU land, with 18% designated as Natura 2000 sites and 8% as other national designations [24]. The area and number of terrestrial protected areas in Europe has grown steadily over time, where the biggest increases were in the 1990s (**Figure 1**) [24][25]. In EEA-38 countries (plus the United Kingdom), this coverage is lower and amounts to 23%, in Poland—one of the biggest countries in the European Union (EU) selected as the study area for further detailed analyses—the number of PPA objects, according to WDPA is 3091, covering 39.54% of the land area [23]. National data indicate that there are 10,884 sites (surface forms of national legal nature protection) and 995 sites protected under the European Natura 2000 Network, covering a total of 43.88% of the country's land area [26][27].



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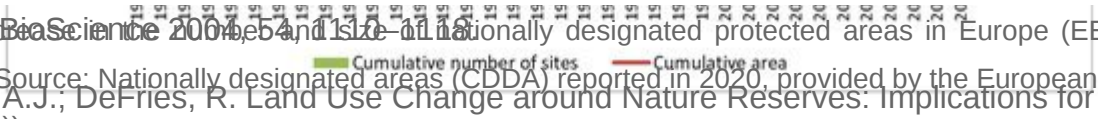

Figure 1. Trends in the number and size of nationally designated protected areas in Europe (EEA-38 + UK), 1950–2020 (Source: Nationally designated areas (CDDA) reported in 2020, provided by the European Environment Agency (EEA)).

To achieve the targets of the EU Biodiversity Strategy for 2030, Member States should designate additional protected areas in order to increase the share of protected areas in the EU, as well as to improve the ecological quality of existing protected areas [25]. However, a gradual decline in biodiversity conservation. Unfortunately, the increase in the number and area of protected areas does not directly transpose to the conservation status of habitats. At the EU level, only 23.87% of habitat assessments have good conservation status, with 72.39% having poor or bad conservation status [28]. Grasslands, dunes, and bog, mire, and fen habitats show strong deteriorating trends, while forests have the most improving trends. Intensive agriculture, urban sprawl, and pollution are the top reported pressures on habitats. Against this background, Poland (PL) looks even worse. As many as 78.26% of the habitats have poor or bad conservation status (**Figure 2**) [28]. Even though Poland is among the European leaders in terms of the share of an area designated as a terrestrial protected area (fourth place out of 32 EEA member countries [24]), it ranks only 16th in terms of the conservation status of habitats [28].

Figure 2. Conservation status of habitats at EEA Member State level (EU27+UK) and in Poland (PL), 2013–2018 (based on the conservation status of habitat type datasets from Article 17, Habitats Directive 92/43/EEC report provided by EEA).

Many protected areas may not be adequately safeguarding biodiversity from human activities on surrounding lands and global change. The magnitude of such change agents and the sensitivity of ecosystems to these agents vary among protected areas [29][30]. Thus, there is a need to assess vulnerability across networks of protected areas to determine those most at risk.

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2. Landscape Changes in Protected Areas in Poland

2.1. Area

According to the Nature Conservation Act, there are 10 forms of nature conservation in Poland (**Table 2**): 8 forms of surface protection and 2 forms of individual protection (objects or species) [31]. The Polish definitions of these areas do not always coincide with International Union for Conservation of Nature (IUCN) categories of protected areas (**Figure 3**). For example, according to the criteria used by the IUCN, none of the 1499 Polish nature reserves has been classified as a Strict Nature Reserve (category I), and only 1 is classified as Ib (Wilderness area). The remaining majority was classified into the "Not Reported" group. Furthermore, only 16 of 23 Polish national parks have the status of an "international" national park (category II), while the rest are classified as category V, a protected landscape area, or not reported [23].

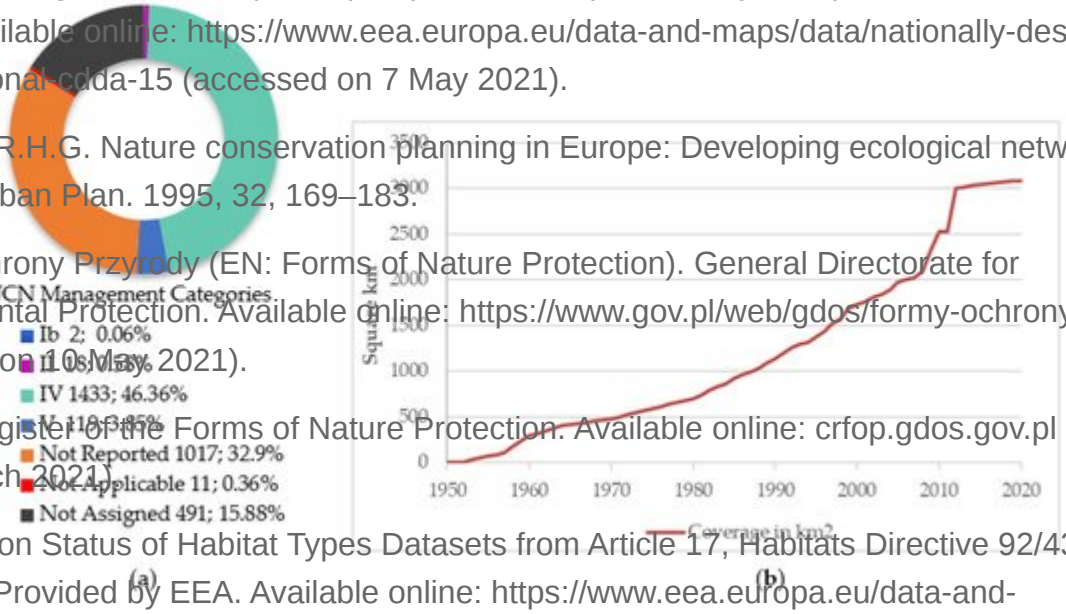

Figure 3. Protected areas in Poland according to the International Union for Conservation of Nature (IUCN). (**a**) Management categories, (**b**) growth of protected area coverage in Poland (data years 1950–2020) (source: https://www.protectedplanet.net/country/POL, accessed on 5 May 2021). Graphic: T. Kostecka, J. Bacmaga, WCMC, May 2021).

Table 2. List of nature conservation forms in Poland.

No.	Nature Conservation Form	Number of Sites		Area [Thousand Hectares] *	
		2000	2020	2000	2020
1.	Nature reserves	1307	1499	148.7	169.6
2.	National parks	22	23	306.5	315.1
3.	Landscape parks	120	124	2446.9	2531.8
4.	Natura 2000 areas	x	145 (SPAs) 849 (SACs)	x	4911.4 (SPAs) 3491.3 (SACs)

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No.	Nature Conservation Form	Number of Sites		Area [Thousand Hectares] *	
		2000	2020	2000	2020
5.	Protected landscape areas	407	407	7137.7	6925.6
6.	Landscape-nature complexes	170	263	78.1	118.8
7.	Ecological areas	6113	7654	44.9	55.4
8.	Documentation sites	103	178	1.0	1.0
9.	Monuments of nature	33 094	34 890	x	x
10.	Plants, animals, and fungi species protection	715 plants species 322 fungi species 801 animals species		x	x

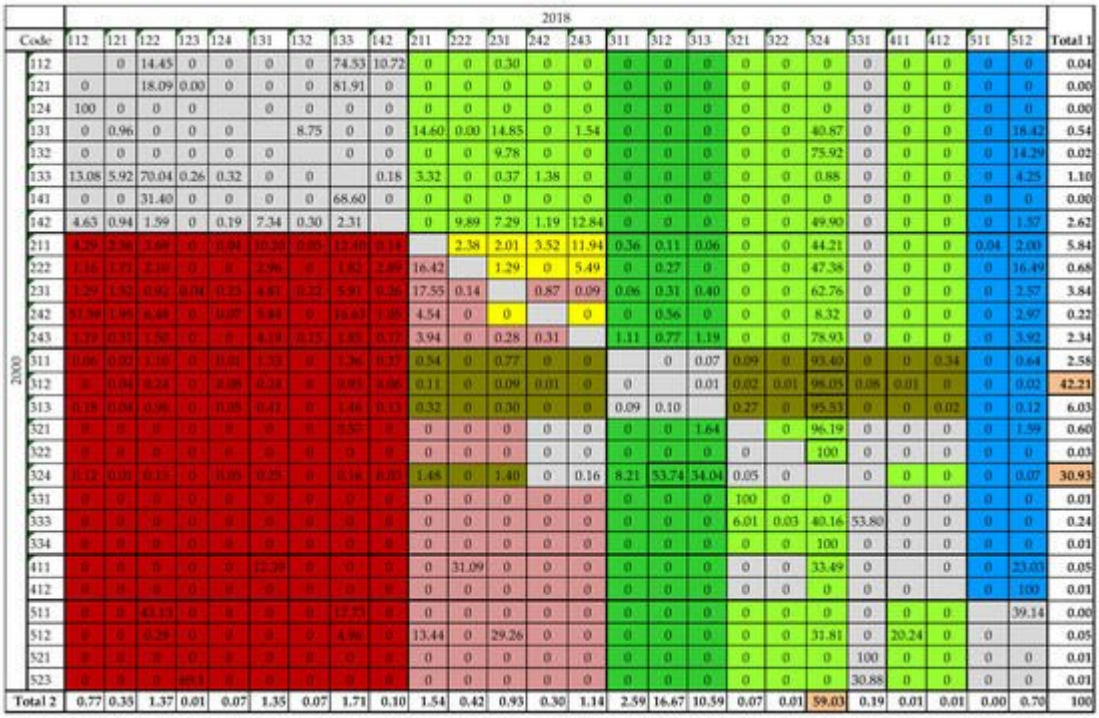
SPAs—special protection sites (Birds Directive) (PLB). SACs—special sites of conservation (Habitats Directive) (PLH). * Terrestrial area only (do not include information about marine areas), due to the overlapping of the boundaries of various forms of nature conservation, the areas do not correspond to the sum of the total area designated as a terrestrial protected area. x—not applicable. Data in points 1–9—Source: Central Register of the Forms of Nature Protection, crfop.gdos.gov.pl (3 March 2021, regularly updated data); data in points 10—Source: General Directorate for Environmental Protection (January 2015)—data refer to native species.

2.2. Landscape Changes

In the analyzed period of 2000–2018, the share of nature conservation areas in the territory of Poland increased from 38% to almost 44%, mainly due to the implementation of a new form of nature protection (European Ecological Network Natura 2000 sites) and the establishment of a new national park in 2001 (Ujscie Warty).

The land cover structure on PAs underwent slight changes. Out of 44 land cover classes identified at level 3 CLC, 32 classes were identified in Poland, including 28 different classes of land cover forms in protected areas. They are dominated by forests (classes 312 and 313) and arable land (class 211), together covering about 92% of the PAs area in 2000. The matrix of transformations between land cover classes in PAs is presented in **Figure 4**. From 2000 to 2018, the most frequently transformed CLC class was 312 (coniferous forest). It was transformed into class 324 (transitional woodland shrubs). Slightly less intense but also quite frequent were transformations in the opposite direction—from class 324 to classes 312 and 313 (mixed forest). However, the area covered by such flows was almost 35% smaller than that of flows 312–324. Even so, the total forest area increased by 2.43% between 2000 and 2018 (**Table 3**). Besides artificial surfaces (group 1 in level 1 CLC), water bodies (group 5) were the most stable over time. Small changes were also observed in classes 411 (inland marshes) and 412 (peatbogs). They constituted, respectively, 0.05% and 0.01% of all transformations and covered 0.1% of the areas in class 411 and 0.3% of areas classified as 412. As for the transformations towards anthropogenic areas (classes 1xx), they mainly concerned agricultural land, in particular classes 211 (non-irrigated arable land) and 242 (complex

cultivation patterns). The area of urbanized areas increased by as much as 85% and agricultural land decreased by 16%, including the reduction of the area of meadows, pastures, and mixed crops by almost 10% (**Table 3**).



		2018																							
	Code	112	121	122	123	124	131	132	133	142	211	222	231	242	243	311	312	313	321	322	324	331	411	412	511	512	Total 1
2000	112		0	14.45	0	0	0	0	74.53	10.72	0	0	0.30	0	0	0	0	0	0	0	0	0	0	0	0	0.04
	121	0		18.09	0.00	0	0	0	81.91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
	124	100	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
	131	0	0.96	0	0	0		8.75	0	0	14.60	0.00	14.85	0	1.54	0	0	0	0	0	40.87	0	0	0	0	18.42	0.54
	132	0	0	0	0	0	0		0	0	0	0	9.78	0	0	0	0	0	0	0	75.92	0	0	0	0	14.29	0.02
	133	13.08	5.92	70.04	0.26	0.32	0	0		0.18	3.32	0	0.37	1.38	0	0	0	0	0	0	0.88	0	0	0	0	4.25	1.10
	141	0	0	31.40	0	0	0	0	68.60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
	142	4.63	0.94	1.59	0	0.19	7.34	0.30	2.31		0	9.89	7.29	1.19	12.84	0	0	0	0	0	49.90	0	0	0	0	1.57	2.62
	211	4.29	2.36	3.69	0	0.04	10.20	0.05	12.40	0.14		2.38	2.01	3.52	11.94	0.36	0.11	0.06	0	0	44.21	0	0	0	0.04	2.00	5.84
	222	1.16	1.73	2.10	0	0	2.96	0	1.82	2.89	16.42		1.29	0	5.49	0	0.27	0	0	0	47.38	0	0	0	0	16.49	0.68
	231	1.29	1.52	0.92	0.04	0.23	4.81	0.22	5.91	0.26	17.55	0.14		0.87	0.09	0.06	0.31	0.40	0	0	62.76	0	0	0	0	2.57	3.84
	242	31.39	1.95	6.48	0	0.07	3.84	0	16.63	7.05	4.54	0	0		0	0	0.56	0	0	0	8.32	0	0	0	0	2.97	0.22
	243	1.79	0.31	1.50	0	0	8.19	0.15	1.85	0.12	3.94	0	0.28	0.31		1.11	0.77	1.19	0	0	78.93	0	0	0	0	3.92	2.34
	311	0.06	0.02	1.10	0	0.01	1.33	0	1.36	0.37	0.54	0	0.77	0	0		0	0.07	0.09	0	93.40	0	0	0.34	0	0.64	2.58
	312	0	0.04	0.24	0	0.08	0.24	0	0.95	0.08	0.11	0	0.09	0.01	0	0		0.01	0.02	0.01	98.05	0.08	0.01	0	0	0.02	42.21
	313	0.18	0.04	0.96	0	0.05	0.41	0	1.46	0.13	0.32	0	0.30	0	0	0.09	0.10		0.27	0	95.53	0	0	0.02	0	0.12	6.03
	321	0	0	0	0	0	0	0	0.52	0	0	0	0	0	0	0	0	1.64		0	96.19	0	0	0	0	1.59	0.60
	322	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		100	0	0	0	0	0	0.03
	324	0.12	0.03	0.13	0	0.03	0.25	0	0.16	0.03	1.48	0	1.40	0	0.16	8.21	53.74	34.04	0.05	0		0	0	0	0	0.07	30.93
	331	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0		0	0	0	0	0.01
	333	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.01	0.03	40.16	53.80	0	0	0	0	0.24
	334	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0.01
	411	0	0	0	0	0	12.20	0	0	0	0	31.09	0	0	0	0	0	0	0	0	33.49	0		0	0	23.03	0.05
	412	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	100	0.01
	511	0	0	43.13	0	0	0	0	17.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		39.14	0.00
	512	0	0	0.29	0	0	0	0	4.96	0	13.44	0	29.26	0	0	0	0	0	0	0	31.81	0	20.24	0	0		0.05
	521	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0.01
	523	0	0	0	99.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30.88	0	0	0	0	0.01
	Total 2	0.77	0.35	1.37	0.01	0.07	1.35	0.07	1.71	0.10	1.54	0.42	0.93	0.30	1.14	2.59	16.67	10.59	0.07	0.01	59.03	0.19	0.01	0.01	0.00	0.70	100

Figure 4. Matrix for Land Use-Cover Changes in PAs between two dates (2000–2018), in line with Level 3 of CORINE Land Cover (CLC) with the classification of major change processes: urbanization (red), afforestation (green), deforestation (brown), intensification of agriculture (orange), extensification of agriculture (yellow), formation of water bodies (blue) and naturalization or land reclamation (yellow-green), and non-classified changes (grey). In the rows are the CLC classes for the starting year (t1, 2000). In columns, the CLC classes for the final year (t2, 2018). The meaning of the codes for the CLC classes can be consulted in Jager et al., 2012 [32]. Values in italics mean the percentage share of transformations of individual pairs of classes between 2000 and 2018 (rows sum up to 100). The “Total” value shows the percentage of the area transformed from a given CLC class (Total 1) or into a given CLC class (Total 2) in the total area undergone transformation between 2000 and 2018.

Table 3. Changes in selected area-edge metrics between two dates (2000–2018) calculated at the class level for protected areas (PAs) and 1 km buffer zones (PABs).

Land Cover Type	CA [ha] (%)		PLAND [%]		AREA_MN [ha]		TE [m]	
	PAs	PABs	PAs	PABs	PAs	PABs	PAs	PABs
Urban areas	+188,517 (85.3)	+158,290 (49.0)	1.41	2.98	2.3	−4.83	+20,840,050	17,308,300
Urban greenery	+8020 (61.5)	+4804 (25.5)	0.06	0.09	0.54	−1.62	+691,700	+607,600

Land Cover Type	CA [ha] (%)		PLAND [%]		AREA_MN [ha]		TE [m]	
	PAs	PABs	PAs	PABs	PAs	PABs	PAs	PABs
Arable land	−244,672 (−6.5)	−132,426 (−5.1)	−1.83	−2.93	0.99	−2.63	−12,651,400	−6,680,300
Pastures [1]	−250,453 (−9.5)	−127,760 (−13.9)	−1.87	−2.58	−4.14	−2.01	−14,049,450	−13,180,100
Forests	+145,255 (2.4)	+83,128 (7.0)	1.09	1.41	−1.4	1.04	+6,282,250	+5,323,100
Shrubs and scrub	+143,136 (66.1)	+50,960 (97.2)	1.07	0.97	−8.4	−0.71	+12,803,300	+5,295,800
Open spaces	−2529 (−18.4)	−895 (−22.2)	−0.02	−0.02	20.39	−0.79	−228,700	−126,700
Wetland	+2680 (2.8)	−386 (−6.2)	0.02	−0.01	−7.13	−2.73	+372,400	−22,800
Water	+10,047 (2.2)	+5872 (7.3)	0.08	0.1	2.82	1.9	+529,750	+357,400

[1] Pastures and mixed crops.

The increase in the urbanized areas observed in the protected areas was even greater than in the surrounding buffer zone (**Table 3**). In contrast to the buffer zone (PABs), in the protected areas (PAs) the average area of urbanized patches (AREA_MN) increased, while the Splitting Index (SPLIT) value decreased, which indicates that these areas are more consolidated. At the same time, the increases in Total Core Area (TCA) and Core Area Percentage of Landscape (CPLAND) shown in **Table 4** revealed a 77.4% increase in urban core areas in PAs and 44.9% in PABs. In addition, the mean size of urban core areas (CORE_MN) increased by 0.35 ha in PAs and decreased by 4.15 ha in PABs. The rate of increase of urban core areas in PAs and PABs was lower than the rate of increase for the total urban area (**Table 3**), suggesting that the emergence of isolated urban areas contributes to urban expansion more than the sprawl from existing urban areas. The phenomenon is more intense in the buffer zone. This is also confirmed by the increase in the value of the Landscape Shape Index, which indicates a more irregular shape of built-up areas compared to 2000.

Table 4. Changes in selected core area and aggregation metrics between two dates (2000–2018) calculated at the class level for protected areas (PAs) and 1 km buffer zones (PABs).

Land Cover Type	TCA [ha]		CPLAND [%]		CORE_MN [ha]		NP		SPLIT		LSI	
	PAs	PABs	PAs	PABs	PAs	PABs	PAs	PABs	PAs	PABs	PAs	PABs
Urban areas	+53,952	+99,985	0.4	1.88	0.35	−4.15	6 078	4 252	−2,786,047	−100,039	54.23	38.73

Land Cover Type	TCA [ha]		CPLAND [%]		CORE_MN [ha]		NP		SPLIT		LSI	
	PAs	PABs	PAs	PABs	PAs	PABs	PAs	PABs	PAs	PABs	PAs	PABs
Urban greenery	+3431	+2846	0.03	0.05	0.17	−1.35	271	250	−29,208,137	−1,661,509	7.68	5.96
Arable land	−157,168	−110,277	−1.18	−2.43	0.68	−2.29	−2 365	−644	2212	2403	−10.45	−4.63
Pastures [1]	−148,921	−83,988	−1.11	−1.7	−2.77	−1.32	−1 428	−2 306	10,274	43,977	−12.93	−17.89
Forests	+87,605	+64,426	0.66	1.09	−2.77	0.81	450	1 312	21	−3085	5.54	5.54
Shrubs and scrub	+58,284	+33,493	0.44	0.63	−7.62	−0.71	2 650	1 858	203,713	−2,027,190	36.72	24.97
Open spaces	−1000	−537	−0.01	−0.01	12.41	−0.45	−54	−68	2,151,017	−7,603,132	−3.13	−2.59
Wetland	180	−274	0	−0.01	−6.15	−1.77	67	56	−24,042	2,601,001	2.21	0.04
Water	+4919	+4557	0.04	0.08	1.41	1.47	−7	36	486	−808	1.03	1.27

[1] Pastures and mixed crops.

The core area and aggregation metrics reveal that although the total forest area increased between 2000 and 2018, the average area of the patches (AREA_MN) and the average area of the core (CORE_MN) decreased in PAs. Furthermore, the number of patches increased by 450 within the PAs and by 1312 in the PABs. In addition, the 20.7 increase in Splitting Index shows that there is now more forest patches as compared to 2000, a sign of fragmentation. In the buffer zone, the mean patch and core size increased. Coupled with the declining Splitting Index, this indicates a lesser fragmentation problem.

In contrast to forest areas and urban areas, agricultural areas experience decreases in their core and total area. This is the case both within the protected areas and in the buffer zone. Metrics pertaining to aggregation (**Table 4**) reveal that arable areas and pastures did not only shrink between 2000 and 2018, but it also became more fragmented. It is true that the number of patches (NP) decreased as a result of a reduction in the total arable land area of 6.5% (in PAs) and 5.10% (in PABs), and of pastures, meadows, and mixed crops by 9.5% and 13.8%. However, the splitting index, which increases with more fragmented patches, rose by more than 2000 for arable land and more than 10,000 for pastures and mixed crops in PAs. In the PABs, the splitting index of pastures and mixed crops increased by over 43,000 from 2000 to 2018. These changes in value suggest an increasing fragmentation of these areas.

Overall, land cover changes within protected areas were less frequent than outside (**Figure 5**), although they still amounted to 143,859 hectares (1.24% of all national forms of protected areas) from 2012 to 2018. In some parts of Europe, urbanization and intensification of agriculture still accounted for up to 25% of land cover changes within protected areas [21]. There is no such problem in Poland. Urbanization and intensification of agriculture accounted only for 5.6%, 7.2%, and 5.3% of land cover changes within protected areas in three analyzed periods.

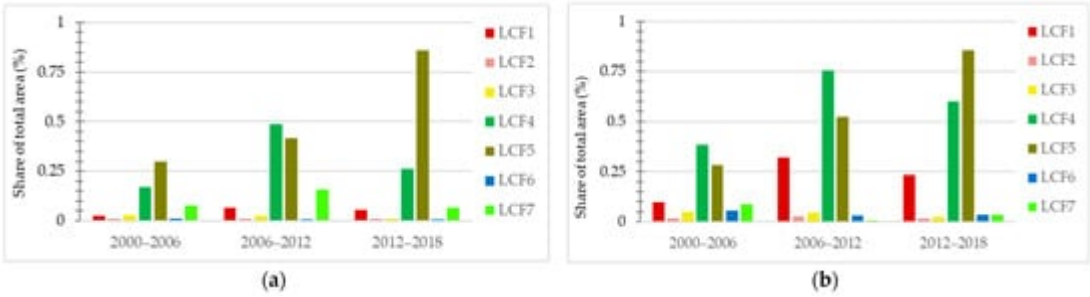


Figure 5. Land cover flows (LCFs) in protected areas (PAs) (**a**) and 1 km protected area buffers (PABs) (**b**) as shares of total areas. LCF1 = Urbanization, LCF2 = Intensification of agriculture, LCF3 = Extensification of agriculture, LCF4 = Afforestation, LCF5 = Deforestation, LCF6 = Formation of water bodies, LCF7 = naturalization or land reclamation.

The results of land cover flows (LCFs) in various forms of protected areas and 1 km protected area buffers (PABs) showed that land cover changes were the most frequent in Natura 2000 sites (altogether for bird and habitat sites, it was 3.8% of the area in the period 2012–2018 and 4.5% of the area in the period 2006–2012) (**Figure 6**). This is understandable to some extent, as economic and construction activities are permitted in these areas as long as it does not endanger the habitat or species for which they are established. It is worrying that these changes are greater than in unprotected (buffer) sites.

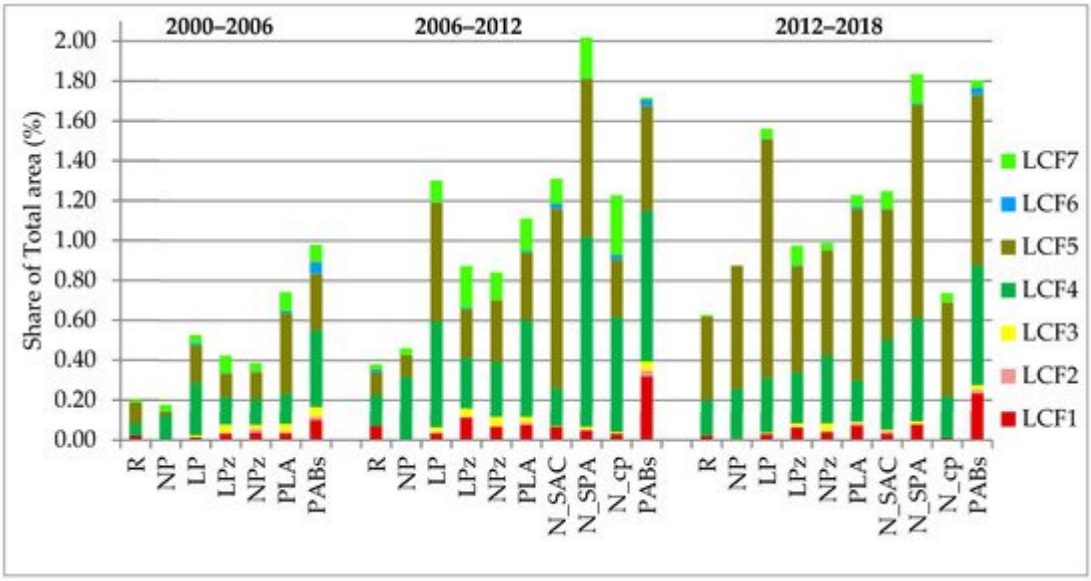


Figure 6. Land cover flows (LCFs) in various forms of protected areas and 1 km protected area buffers (PABs) as shares of total modeled areas. R = Nature reserves, NP = National parks, LP = Landscape parks, LPz/ NPz =

parks buffer zones, PLA = Protected landscape areas, N_SAC = Natura 2000 Habitats Special Areas of Conservation, N_SPA = Natura 2000 Birds Special Protection Areas, N_cp = Natura 2000 common part of Bird and Habitat Areas. LCF1 = Urbanization, LCF2 = Intensification of agriculture, LCF3 = Extensification of agriculture, LCF4 = Afforestation, LCF5 = Deforestation, LCF6 = Formation of water bodies, LCF7 = Naturalization/Land reclamation.

Nevertheless, the national forms of nature protection adopted in Polish law can be considered effective. National reserves, national parks, and landscapes are subject to slight urbanization changes (LCF 1). The transformations of agricultural and forest areas into anthropogenic areas are the greatest threat and the image of urbanization pressure. In this context, the greatest pressures were recorded in the buffer areas. However, on the other hand, human settlements increased around almost every protected area, potentially increasing human activity along the edges of protected areas and threatening their ecological integrity. Urban expansion around protected areas varied, but overall, their area increased by almost 49% between 2000 and 2018. In protected areas, this increase was even greater (85%), so that the share of urbanized areas in the structure of land use increased by almost 1.5%.