

Urban sprawl into Natura 2000 network over Europe

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Abstract: Urban growth is a major threat to biodiversity conservation at the global scale. Its impacts are expected to be especially detrimental when it sprawls into the landscape and reaches sites of high conservation value due to the species and ecosystems they host, such as protected areas. I analyzed the degree of urbanization (i.e., urban cover and growth rate) from 2006 to 2015 in protected sites in the Natura 2000 network, which, according to the Habitats and Birds Directives, harbor species and habitats of high conservation concern in Europe. I used data on the degree of land imperviousness from COPERNICUS to calculate and compare urban covers and growth rates inside and outside Natura 2000. I also analyzed the relationships of urban cover and growth rates with a set of characteristics of Natura sites. Urban cover inside Natura 2000 was 10 times lower than outside (0.4% vs. 4%) throughout the European Union. However, the rates of urban growth were slightly higher inside than outside Natura 2000 (4.8% vs. 3.9%), which indicates an incipient urban sprawl inside the network. In general, Natura sites affected most by urbanization were those surrounded by densely populated areas (i.e., urban clusters) that had a low number of species or habitats of conservation concern, albeit some member states had high urban cover or growth rate or both in protected sites with a large number of species or habitats of high conservation value. Small Natura sites had more urban cover than large sites, but urban growth rates were highest in large Natura sites. Natura 2000 is protected against urbanization to some extent, but there is room for improvement. Member states must enact stricter legal protection and control law enforcement to halt urban sprawl into protected areas under the greatest pressure from urban sprawl (i.e., close to urban clusters). Such actions are particularly needed in Natura sites with high urban cover and growth rates and areas where urbanization is affecting small Natura sites of high conservation value, which are especially vulnerable and concentrated in the Mediterranean region.

Keywords: 2030 Agenda Sustainable Development Goals, Aichi targets, Birds and Habitats Directives, conservation priority areas, Convention of Biological Diversity, EU Biodiversity Strategy, priority species and habitats, urbanization

Expansión Urbana dentro de la Red Natura 2000 en Europa

Resumen: El crecimiento urbano es una amenaza importante para la conservación de la biodiversidad a escala global. Se espera que los impactos de este crecimiento sean especialmente perjudiciales cuando se expande por el paisaje y alcanza sitios de alto valor para la conservación por las especies y ecosistemas que albergan, como lo son las áreas protegidas. Analicé el grado de urbanización (cobertura urbana y tasa de crecimiento) entre 2006 y 2015 dentro de los sitios protegidos de la red Natura 2000, la cual, de acuerdo con las Directivas de Aves y Hábitats, alberga especies y hábitats de alto interés para la conservación en Europa. Usé información sobre el grado de impermeabilidad del suelo tomados de COPERNICUS para calcular y comparar coberturas urbanas y tasas de crecimiento dentro y fuera de la red Natura 2000. También analicé las relaciones de la cobertura urbana y las tasas de crecimiento con un conjunto de características de los sitios Natura. La cobertura urbana dentro de la red Natura 2000 fue diez veces más baja que afuera (0.4% vs. 4%) a lo largo de la Unión Europea. Sin embargo, las tasas de crecimiento urbano fueron ligeramente más altas dentro de la red Natura 2000 que fuera (4.8% vs. 3.8%),

Article impact statement: Incipient urban sprawl into Natura 2000 makes it necessary stricter legal restrictions and controls on urbanization in these protected areas.

Paper submitted June 17, 2020; revised manuscript accepted December 14, 2020.

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lo cual indica una expansión urbana incipiente dentro de la red. En general, los sitios Natura más afectados por la urbanización fueron aquellos rodeados por áreas densamente pobladas (es decir, conglomerados urbanos) que tenían un número bajo de especies o hábitats de interés para la conservación, aunque algunos estados miembros de la UE tuvieron una cobertura urbana o una tasa de crecimiento alta o ambas en sitios protegidos con un número elevado de especies o hábitats de alto valor para la conservación. Los sitios Natura pequeños tuvieron mayor cobertura urbana que los sitios más grandes, pero las tasas de crecimiento urbano fueron más altas en los sitios Natura grandes. La red Natura 2000 está protegida contra la urbanización hasta cierto punto, pero todavía se puede mejorar mucho más. Los estados miembros de la UE deben promulgar una protección legal más estricta y controlar la aplicación de la ley para detener la expansión urbana hacia las áreas protegidas más cercanas a los conglomerados urbanos. Dichas acciones son necesarias en sitios Natura con una cobertura urbana extensa y tasas de crecimiento altas y en áreas en donde la urbanización está afectando a espacios Natura pequeños con un valor alto de conservación, los cuales son especialmente vulnerables y se encuentran concentrados en la región mediterránea.

Palabras Clave: áreas prioritarias para la conservación, Convenio sobre la Diversidad Biológica, Directivas de Aves y Hábitats, especies y hábitats prioritarios, Estrategia de la UE sobre Biodiversidad, Objetivos de Desarrollo Sostenible de la Agenda 2030, objetivos de Aichi, urbanización

Introduction

Urban expansion is a key component of land-use change that severely threatens ecosystem and biodiversity conservation worldwide (Sala et al. 2000; Grimm et al. 2008; IPBES 2019). Global urban growth over the last 3 decades has considerably exceeded forecasts and that which was necessary to sustain world population growth (80% vs. 52%) (Liu et al. 2020). As human demand for land for settlements and infrastructures continues to climb, urbanization increasingly goes beyond consolidated urban areas and their surroundings, which results in urban sprawl (EEA 2016). New urbanized areas have mostly replaced agricultural land (70%), followed by grasslands and forests (12% and 9%, respectively) (Liu et al. 2020).

Although some biodiversity is sustained in urban areas, urbanization of natural or seminatural land drives large changes in ecosystems and species assemblages that result in biotic homogenization (McKinney 2002, 2006; Aronson et al. 2014; La Sorte et al. 2014). Most studies on urbanization impacts on biodiversity and ecosystems still focus on particular towns or metropolitan areas, whereas the impacts of urban sprawl (i.e., replacement of natural or seminatural covers with artificial land) are likely more damaging and have been little explored (but see, e.g., Meynard et al. 2011; Concepción et al. 2015, 2016, 2017). Results of these few available studies have shown that urban sprawl mostly relates to the replacement of native specialist species with more common and generalist species, many of them non-native species, and thus to the homogenization of species assemblages in the affected areas. Accordingly, in the event that urban sprawl takes place in areas of high conservation value due to their species or ecosystems, its impacts are expected to be especially harmful.

Natura 2000 of the European Union is the largest network of protected areas in the world. Its main objective is the effective conservation of biodiversity and traditional land uses. It was conceived to safeguard

the most valuable and threatened species and habitats in Europe, according to the Birds and Habitats Directives (Council Directives 79/409/EEC and 92/43/EEC, respectively), through the designation of a coherent network of priority conservation areas throughout the European territory (EEA 2012). Member states must guarantee the legal protection of priority species and habitats through the appropriate regulation and management of land uses in the sites included in the EU Natura 2000 network in their territories (Martínez-Fernández et al. 2015; Simeonova et al. 2017). Natura 2000 implementation should be accompanied by the development of suitable conservation measures, controls, and financial instruments (Hermoso et al. 2017, 2018a, 2018b, 2019). Maintaining the delicate equilibrium between biodiversity conservation and compatible land uses is especially relevant and timely now in the frame of the 2030 Agenda for Sustainable Development Goals, in particular goal 15 (“Protect, restore and promote sustainable use of terrestrial ecosystems [...] halt and reverse land degradation and halt biodiversity loss”) and the new EU Biodiversity Strategy launched as part of the EU Green Deal (https://ec.europa.eu/environment/nature/biodiversity/strategy/index_en.htm). This strategy includes an ambitious nature restoration plan aimed at improving the condition of existing and new protected areas (up to 30% of the land and the sea) to reverse current biodiversity loss by 2030. This involves reducing pressures on habitats and species, ensuring the sustainable use of ecosystems, and supporting the recovery of nature by, among other methods, limiting impervious surface area and urban sprawl.

Although others report that protected areas in Natura 2000 tend to undergo less land-cover change than areas outside the network, they also report that over 20% of the land in the network has been affected by some kind of land-cover change, related to either naturalization (land abandonment) or anthropization (agricultural intensification and urbanization) (Kallimanis et al. 2015; Martínez-Fernández et al. 2015;

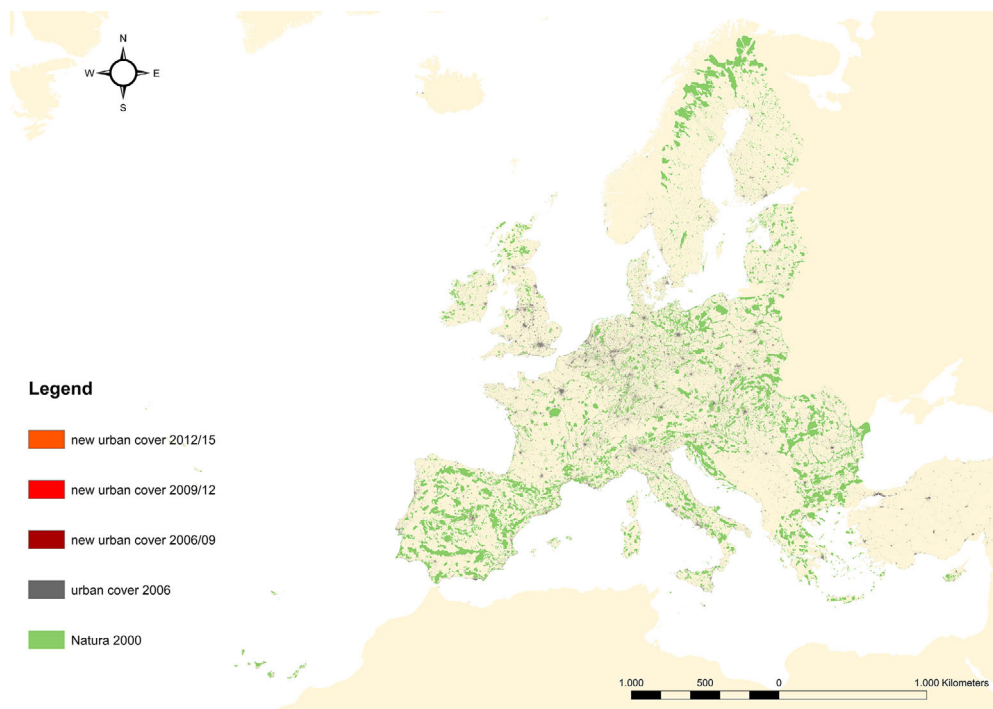


Figure 1. Distribution of Natura 2000 protection network and Copernicus Pan-European High Resolution Layers (HRLs) on urban land in 2006, 2009, 2012, and 2015 across the 28 member states of the European Union.

Hermoso et al. 2018a; Anderson & Mammides 2020). The actual magnitude of these land-cover changes inside Natura 2000 is probably greater because some of these changes may have been unnoticed due to the use of available categorical data on land-use covers and the small size of many Natural 2000 protected sites in comparison with the spatial resolution of land-cover data (i.e., 100 x 100 m in the best of cases, based on CORINE Land Cover) (Martínez-Fernández et al. 2015; Anderson & Mammides 2020). As a result, and despite the increasing urban sprawl into the European countryside in the last decades (EEA 2016) and its relevance for biodiversity conservation, there is a lack of awareness of the degree of urbanization inside priority conservation areas in this protected-area (PA) network.

I conducted a comprehensive analysis of the degree of urbanization in Natura 2000 sites relative to unprotected areas based on high resolution data (20 x 20 m) on the degree of land imperviousness throughout the European Union from 2006 to 2015. I considered whether urban land covers and growth rates differ inside versus outside Natura 2000 sites, what characteristics of Natura 2000 sites are associated with high levels of urbanization, and whether urbanization patterns vary over time and across EU member states. Gathering this information is the first step in the evaluation of the conservation measures taken to halt ongoing urban sprawl into European PAs and determining whether the EU member states should pay

more attention and provide more legal protection to halt urban sprawl inside the Natura 2000 network.

Methods

Copernicus Pan-European High Resolution Layers (20 x 20 m) on the degree of land imperviousness (i.e., artificial sealed soil) in different years (harmonized data for 2006, 2009, 2012, and 2015) (<https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness>) were intersected with the distribution of Natura 2000 protected sites across the 28 member states of the European Union (<https://www.eea.europa.eu/data-and-maps/data/natura-10/natura-2000-spatial-data/natura-2000-shapefile-1>) using ArcGIS (ESRI 2018) (Fig. 1). Then, urban covers (i.e., proportion of impervious land) and growth rates (i.e., proportional increase in urban cover with respect to the initial urban cover) were calculated for each year from 2006 to 2015 inside and outside the Natura network. In doing so, the year of incorporation in the European Union of each member state and the year of designation of each Natura site were accounted for to accurately calculate urban covers and growth rates inside and outside Natura 2000 sites in each year (i.e., considering protected areas only when they were officially part of the Natura 2000 network). Bulgaria and Romania joined the European Union on 1 January 2007 and

were considered only for the years 2009, 2012, and 2015. Croatia joined the European Union on 1 July 2013 and was considered only for 2015.

To compare urban covers and growth rates inside and outside Natura 2000 across member states from 2006 to 2015, linear mixed-effects models were run (Bates et al. 2015). Dependent variables were urban cover (transformed to the arcsine square root) and growth rate (log transformed) inside and outside Natura 2000 in each member state and year (2006, 2009, 2012, and 2015 for urban cover) or period (2006–2009, 2009–2012, and 2012–2015 for urban growth). Member state was included as a random factor in models, and year or period and Natura 2000 protection (inside vs. outside) were included as fixed factors. The total area (log transformed) of land inside or outside Natura 2000 in each member state and year or period were also included as explanatory variable in analyses to control for the generalized unbalanced proportion of protected and unprotected land (18% and 82%, respectively, in the whole European Union).

To evaluate which Natura sites with specific characteristics were affected most by urban sprawl throughout the European Union and in individual member states, the relationships of urban cover and growth rates in Natura 2000 sites with a set of characteristics of such sites were also analyzed by means of linear mixed-effects models. Dependent variables were urban cover (transformed to the arcsine square root) and growth rate (log transformed) in each Natura site and year (2006, 2009, 2012, and 2015 for urban cover) or period (2006–2009, 2009–2012, and 2012–2015 for urban growth). Natura site was included as a random factor, and year or period was included as a fixed factor together with member state and the following set of characteristics of Natura 2000 sites: type (protected by Birds Directive, Habitats Directive, or both), area (log transformed), conservation value (normalized variable accounting for the number of species or habitats of conservation concern present in each site corrected for size [details below]), and the amount of densely settled territories (i.e., urban clusters) in Natura sites' surroundings.

The interactions between the factor member state and the rest of predictors were included in models to test the likely varying relationships of these explanatory variables and urban cover and growth rates in Natura sites across member states. After proving the generalized significance of interactions between the factor member state and the rest of explanatory parameters, separate models were performed for each member state. All models' residuals were graphically explored to test for linear mixed-model assumptions (i.e., residuals' normal distribution, independence, and homoscedasticity).

Urban clusters are defined by Eurostat-GEOSTAT as contiguous urban areas (1-km² grid) with a total population of at least 5000 inhabitants and a density

of ≥ 300 inhabitants/km², respectively (<https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/geostat>). Overall amount (log transformed) of urban clusters within a 25-km radius around Natura sites' centroids at the beginning of the analyzed period (2006) was included in models as a potential driver of urban sprawl into these protected sites.

To estimate the conservation value of each Natura 2000 site, I considered the total number of habitats or species of conservation concern present in each site. The total number of habitats and species of conservation concern were those present in each site according to the European Environment Agency. Habitats had to be included in Annex I of the Habitats Directive, and species had to be listed in Article 4 (1 and 2) of the Birds Directive and Annex II of the Habitats Directive. I also included other important species in a site (i.e., species listed in the Annexes IV and V of the Habitats Directive, national red lists, Bern Convention on the Conservation of European Wildlife and Natural Habitats, Bonn Convention on the Conservation of Migratory Species of Wild Animals, and endemic and other important species specified by member states). Both the total number of habitats and species in Natura sites were normalized and corrected for the effect of site size (i.e., large sites hosted more species and habitats than small sites). Specifically, they were normalized to range from 0 to 1: $normalized\ N_i = (N_i - N_{min}) / (N_{max} - N_{min})$, where i is the site, and subsequently corrected by the normalized area of the site (also ranging between 0 and 1): $corrected\ N_i = normalized\ N_i \times (normalized\ area_{max} - normalized\ area_i) / (normalized\ area_{max} - normalized\ area_{min})$. Conservation value was estimated by means of the corrected number of species in the case of Natura 2000 sites protected under the Birds Directive and the greatest value between the two estimates (i.e., the corrected number of species or habitats) in the case of sites protected under the Habitats Directive or both directives (i.e., so as not to underestimate any of the conservation values associated with the species or habitats in these sites).

Statistical analyses were performed in R (R Core Team, 2019) with the packages lme4 (Bates et al. 2015), lmerTest (Kuznetsova et al. 2017), and visreg (Breheny & Burchett 2017).

Results

Overall, Natura 2000 network covered around 18% of EU land (1,218,641 km²) and came to a total of 25,791 protected sites in 2015 (22,243 sites and 862,169 km² in 2006; 24,391 sites and 1,078,839 km² in 2009; and 24,900 sites and 1,128,296 km² in 2012) (Fig. 1). Member states with the greatest proportion of territory in

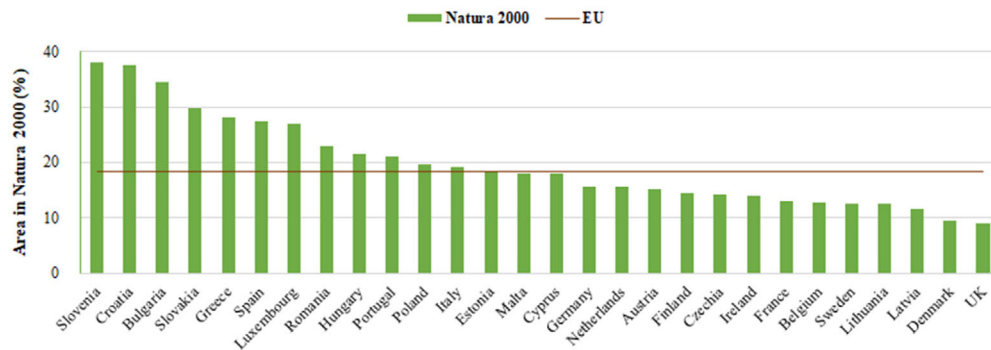


Figure 2. Percent area covered by the Natura 2000 network in the 28 member states of the European Union (EU) in decreasing order of Natura cover (horizontal line, overall value for the EU). Reference year is 2015.

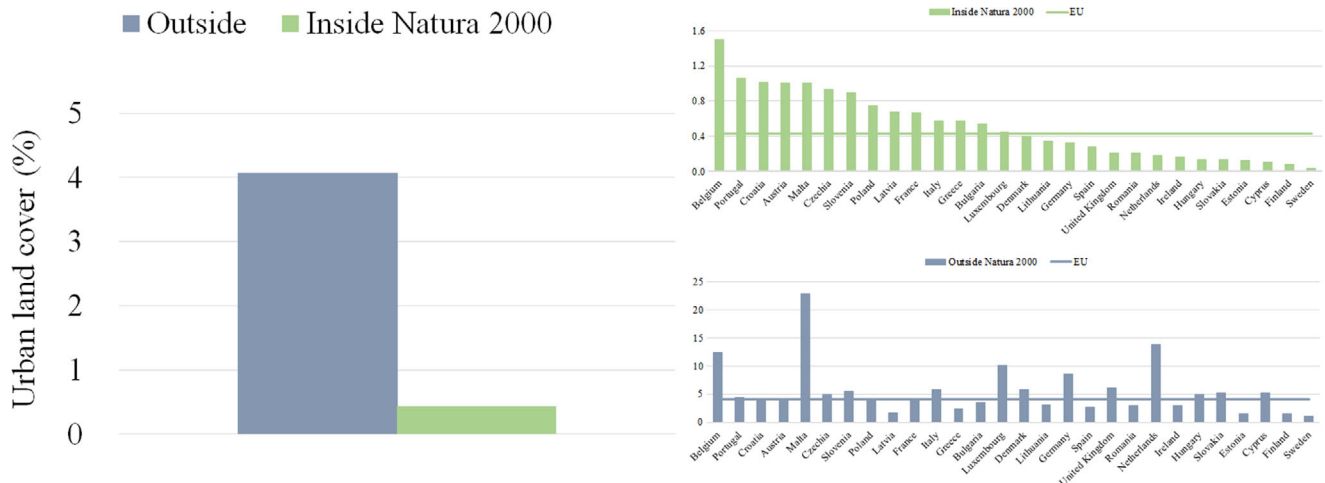


Figure 3. Percent area covered by urban land in 2015 inside and outside Natura 2000 network in the European Union as a whole (left) and in each of the 28 member states (EU 28) (right) in decreasing order of urban cover inside Natura 2000.

the network were Slovenia, Croatia, Bulgaria, Slovakia, Greece, Spain, and Luxembourg (Fig. 2). Member states with the lowest proportion of territory under protection were United Kingdom, Denmark, Latvia, Lithuania, Sweden, Belgium, and France.

Results of the linear mixed model testing the differences in urban cover inside versus outside Natura 2000 from 2006 to 2015 showed that it was 10-fold greater outside than inside Natura 2000 sites in the entire European Union (4% vs. 0.4%; $F_{1, 87.65} = 413.15$, $p < 2.2e-16$) (Fig. 3 [detailed results in Appendix S1]). Malta, Netherlands, Belgium, Luxembourg, and Germany had the highest overall urbanization levels outside Natura 2000 among the member states (Fig. 3). However, urban cover inside the network remained moderate, especially in the Netherlands and Germany, whereas Belgium and secondarily Malta were among the member states with the largest amounts of urbanized areas inside Natura 2000 sites, followed by Portugal, Croatia, Austria, Czechia, and Slovenia (Fig. 3). The low-

est levels of urbanization inside Natura 2000 sites were in Sweden, Finland, Cyprus, Estonia, Slovakia, Hungary, and Ireland (Fig. 3 top right), all of which also had low urbanization levels outside Natura 2000 sites (Fig. 3 bottom right).

Results of the linear mixed model for urban growth from 2006 to 2015, however, showed that it was slightly higher inside than outside Natura network throughout the European Union (4.8% vs. 3.9%; $F_{1, 80.52} = 3.92$, $p = 0.051$) (Fig. 4 [detailed results in Appendix S1]). Overall, both outside and inside Natura 2000, urban growth increased from 2009 to 2012 and slowed down from 2012 to 2015 ($F_{2, 128.79} = 25.79$, $p = 3.794e-10$). The lowest urban growth rates inside Natura 2000 occurred in Latvia, Lithuania, Finland, Estonia, Czechia, Slovakia, and United Kingdom (Fig. 4). The highest urban growth within Natura 2000 was recorded in Cyprus, Hungary, Slovakia, Luxembourg, and the Netherlands, followed by Germany (Fig. 4 top right). These states also had the largest differences in urban growth between inside

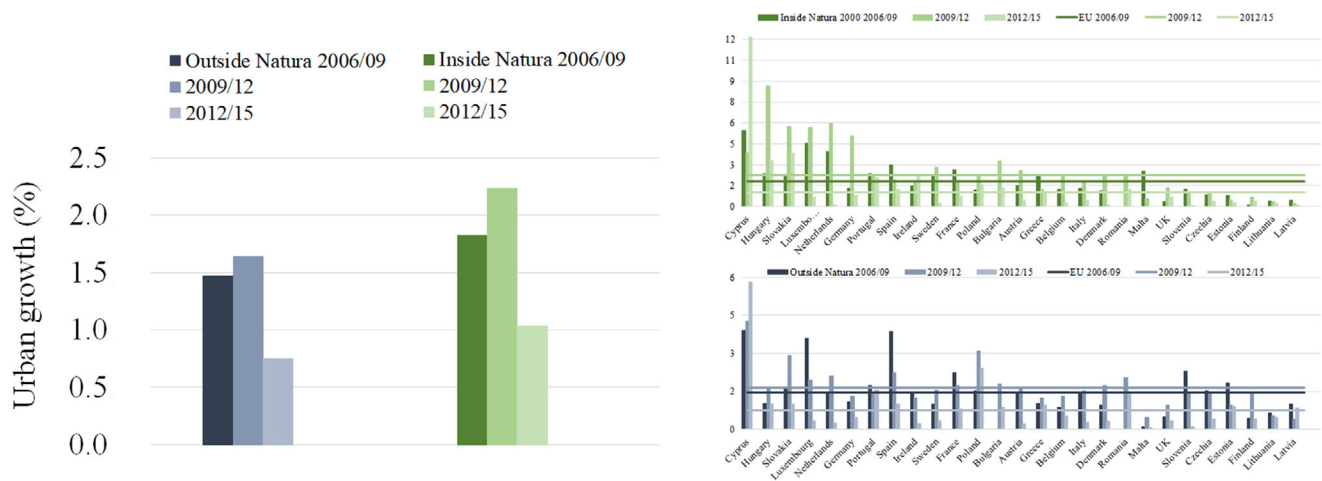


Figure 4. Urban growth, i.e., increase in urban cover (%) (shown by axis label) from 2006 to 2015 inside and outside Natura 2000 network in the European Union (EU) (left) and in the 28 EU member states (right) from 2006 to 2009, 2009 to 2012, and 2012 to 2015 in decreasing order of urban growth inside Natura 2000 over the entire period (2006–2015).

(higher) and outside (lower) Natura sites (Fig. 4). Most member states had higher urban growth rates inside than outside the Natura network, except Spain, Poland, Slovenia, Czechia, Estonia, Finland, Lithuania, and Latvia (Fig. 4).

Urban cover and growth rate inside Natura 2000 protected sites varied significantly across member states, year, and some site characteristics (i.e., type, area, conservation value, and urban clusters in their surroundings). These relationships in addition varied among member states (i.e., significant interactions between this factor and the rest of predictors) (Table 1). Member states that had the greatest urban cover in specific Natura 2000 protected sites were Bulgaria, Croatia, Czechia, Malta, and Portugal, whereas sites with the lowest urban cover were in Sweden, Estonia, Finland, Ireland, Hungary, Slovakia, Latvia, and Lithuania. Member states with Natura PAs with the highest urban growth from 2006 to 2015 were Bulgaria, Cyprus, Hungary, the Netherlands, Poland, Romania, and Spain. Detailed results for the European Union as a whole and for each member state are given in Appendix S2.

Urban cover inside Natura sites increased over the analyzed period in the European Union as a whole and in all member states except Malta and Croatia. In the case of Croatia, which joined the European Union in 2013, only data on urban cover in 2015 were considered. Overall in the European Union and in most member states, the highest urban growth occurred from 2009 to 2012, and growth lessened from 2012 to 2015 (Table 1). However, in some member states, such as Slovenia and Spain, urban growth deceleration began in 2009 and 2006–2009 was the period of greatest urban growth.

Natura sites protected by the Birds Directive tended to have greater urban covers than those protected by the

Habitats Directive or by both directives in the European Union as a whole and in most member states (Belgium, Bulgaria, Czechia, Denmark, Germany, Poland, Romania, and Spain). No overall pattern in this respect was found for urban growth in the entire European Union, although Natura sites protected by the Birds Directive had higher urban growth in the Netherlands and Slovakia, whereas sites protected by both directives showed higher urban growth in Hungary (Table 1).

Overall, small Natura sites showed greater urban cover than large ones at the EU level; this varied considerably among member states. This general pattern applied to Cyprus, Czechia, Germany, Italy, Malta, Poland, and Spain. In Belgium, Denmark, Latvia, Lithuania, Slovenia, and Sweden, large Natura sites showed greater urban covers than small sites. In contrast, urban growth was greater in large Natura sites than it was in small sites in the European Union as a whole and in most member states (Table 1).

Conservation value of Natura sites (i.e., number of species and habitats of conservation concern normalized and corrected with respect to site area) showed more variable relationships with urbanization (Table 1). In general, Natura sites of low conservation value showed greater urban cover (Fig. 5). This was the case for the European Union overall and most member states: Croatia, France, Poland, and Sweden. However, in some member states (i.e., Latvia and Spain), Natura sites with high conservation value also had high urban covers. In the case of urban growth, there was not an overall relationship with conservation value of Natura sites at the EU level. Nonetheless, some member states showed greater urban growth in Natura sites of high conservation value (Cyprus, Greece, Italy, and Malta) than in sites of low conservation value; only Bulgaria and Czechia showed

Table 1. Results of the linear mixed-effects models testing the relationships of urban cover and growth rates inside Natura 2000 sites throughout the European Union and in member states (MS)^a from 2006 to 2015 with a set of characteristics of Natura 2000 sites.^a

Urban cover				Urban growth							
MS	Year	type ^b	Area	conservation value	surrounding urban cluster	MS	period	type ^b	area	conservation value	surrounding urban cluster
$F_{27, 25637} = 8.80^{***}$	$F_{3, 71460} = 48.45^{***}$	$F_{2, 25628} = 15.35^{***}$	$F_{1, 25639} = 21.60^{***}$	$F_{26, 25637} = 9.13^{**}$	$F_{1, 25638} = 3.70^{***}$	$F_{26, 24297} = 1.49^{(*)}$	$F_{2, 46911} = 36.57^{***}$	$F_{44, 25993} = 1.83^{***}$	$F_{1, 25716} = 19.57^{***}$	$F_{26, 24362} = 1.47^{(*)}$	$F_{25, 24244} = 2.74^{***}$
x MS	$F_{76, 71459} = 2.99^{***}$	$F_{45, 25631} = 5.53^{***}$	$F_{27, 25639} = 32.63^{***}$	$F_{27, 25637} = 1.44^{(*)}$	$F_{26, 25637} = 3.70^{***}$	x MS	$F_{50, 46819} = 2.97^{***}$				
European Union	2006<09<12<15***	A>(B<C)***	-***	-***	+	AT	(2006/09<09/12)>12/15***		+		+
Austria (AT)	2006=09<12=15***				+	BE	(2006/09=09/12)>12/15*		+		
Belgium (BE)	2006=09<12=15***	A>B>C***	+			BG	2006/09=09/12>12/15*				
Bulgaria (BG) +**	2009<12<15***	A>(B=B)C*			+	BG	2009/12>12/15*			*	+
Croatia (HR) +*				-*		HR					
Cyprus (CY)	2006=09<12=15**	A=B<C*	- ^(*)			CY		A<B ^(*)	+	+	+
Czechia (CZ) +***	2006=09<12=15 ^(*)	A>B***	-***	+		CZ	2006/09<09/12>12/15*		+	*	+
Denmark (DK)	2006=09<12=15***	A>(B=B)C*	+			DK	2006/09<09/12>12/15**		+		+
Estonia (EE) -**	2006<09<12=15***				+	EE			+		+
Finland (FI) -***	2006<09<12=15***				+	FI	2006/09<09/12>12/15*		+		+
France (FR) + ^(*)	2006<09<12=15***			-**		FR	2006/09=09/12>12/15***		+		+
Germany (GE)	2006<09<12=15***	A>(B=B)C***	-***	- ^(*)		GE	2006/09<09/12>12/15***	A>B ^(*)	+	+	+
Greece (GR)	2006<09<12<15***				+	GR	2006/09<09/12>12/15**	A=B<C*	+		
Hungary (HU) -**	2006<09<12=15***		+		+	HU	2006/09<09/12=12/15 ^(*)		+		+
Ireland (IE) -*	2006<09<12=15***				+	IE			+		+
Italy (IT)	2006<09<12=15***		-**		+	IT	(2006/09<09/12)>12/15***		+		
Latvia (LV) -**	2006=09<12=15*		+	+	+	LV			+	+	+
Lithuania (LT) -**	2006<09=12=15**		+		+	LT				+	
Luxembourg (LU)	2006=09<12=15***					LU	(2006/09<09/12)>12/15***		+		+
Malta (MT) +**			-*			MT		A>(B=B)C)**		+	
Netherlands (NL)	2006<09<12=15***					NL	2006/09=09/12>12/15***				+
Poland (PL)	2006<09<12=15***	A>B*	-***	-*	+	PL	2006/09=09/12>12/15*				+
Portugal (PT) +***	2006=09<12=15***				+	PT					
Romania (RO) - ^(*)	2009<12=15***	A>B*		- ^(*)		RO	2009/12>12/15*	A>B*			
Slovakia (SK) -***	2006=09<12=15**				+	SK	2006/09>(09/12=12/15)**				
Slovenia (SI)	2006<09=12=15***		+	+	+	SI	2006/09>09/12=12/15*		+		+
Spain (SP) + ^(*)	2006<09<12<15***	A>(B=B)C***	-***	+	+	SP	2006/09>09/12=12/15*		+		
Sweden (SE) -***	2006=09<12=15***	A=B>C ^(*)	+	-**	+	SE	2006/09<09/12>12/15***		+		
United Kingdom (UK)	2006<09<12=15***			- ^(*)	+	UK	2006/09<09/12>12/15***				

^a After proving the significance of interactions between member state and the rest of explanatory parameters (x MS) in the overall model (first 2 rows below each primary column heading), separate models were run for the European Union as a whole and for each member state. The MS estimates relative to Austria from the model for the entire European Union without interactions: +, positive; -, negative. Significance: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

^b Site type: A, Birds Directive; B, Habitat Directive; C, both Birds and Habitat Directives.

Detailed results are given in Appendix S2.

Conservation Biology

Volume 35, No. 4, 2021

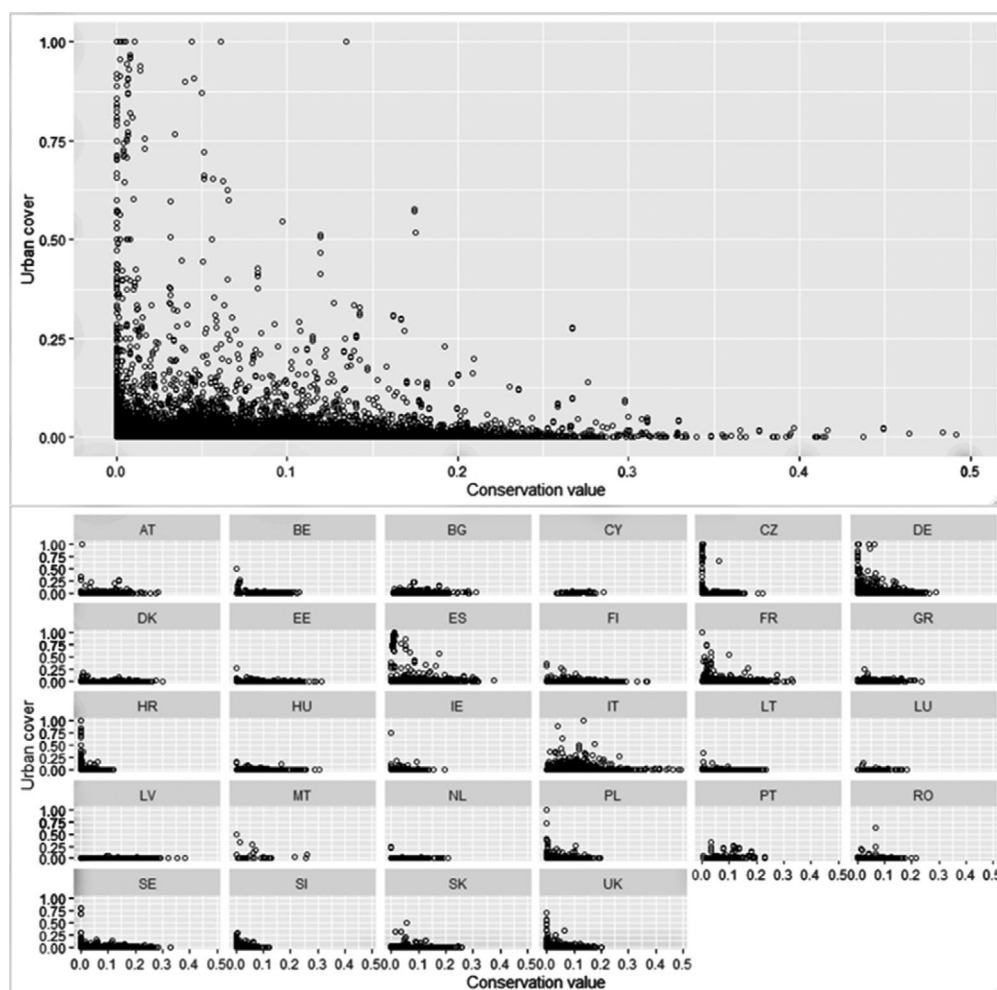


Figure 5. Relationships between urban cover (i.e., proportion of impervious land) and the normalized conservation value of Natura 2000 sites in the European Union as a whole (top) and in individual member states (bottom). The normalized conservation value accounts for the number of species or habitats of conservation concern in each Natura site corrected by its size.

the opposite pattern (i.e., greater urban growth in Natura sites of low conservation value than in sites of high conservation value). Natura sites surrounded by large urban clusters (i.e., densely populated areas) showed greater urban cover and growth rates in the European Union as a whole and in most member states (Table 1) than sites that were surrounded by a small clusters.

Discussion

This study evinces that urban sprawl is already affecting protected areas in Europe as a consequence of an increasing demand for land for building outside consolidated urban cores and periurban areas (EEA 2016). Although total urban cover inside EU Natura 2000 network was still low compared with the level reached outside this protection network (0.4% vs. 4%) (Fig. 3), the rates of urban growth from 2006 to 2015 were higher inside than out-

side Natura network (4.8% vs. 3.9% in all 28 EU member states) (Fig. 4). Furthermore, even though rates of urban growth slowed after 2012 (after the peak of financial crisis) (Fig. 4), the economic recovery is likely to increase demand for urban land. Member states affected most by urban sprawl inside Natura 2000 network and that ought to pay more attention to control this phenomenon are those that showed the greatest urban covers or growth rates inside these protected sites. This was the case of some member states in western (Belgium and the Netherlands), central (Luxembourg, Austria, Czechia, Hungary, Croatia, Slovakia, Slovenia, and Poland), and southern Europe (Portugal, Spain, Malta, Romania, Bulgaria, and Cyprus).

Overall, the proximity to densely settled territories (i.e., urban clusters) was confirmed to be a major driver of urban sprawl into Natura 2000 protected areas; sites affected by the highest degree of urbanization (urban cover and growth rates) were those surrounded by larger

urban clusters in the European Union as a whole and in the majority of member states (Table 1). These results are in accordance with previous studies that show that land-cover changes that occurred inside this network over the last decades were mainly related to two contrasting patterns: land abandonment and naturalization in steep and remote areas and anthropization in accessible and populated areas (e.g., Kallimanis et al. 2015; Martínez-Fernández et al. 2015; Anderson & Mammides 2020).

These results highlight that, besides legal protection and controls, the implementation of management plans in Natura 2000 sites should be accompanied by appropriate financial instruments that guarantee the economic viability and thus the maintenance of traditional land uses compatible with conservation that otherwise will be abandoned or converted to more profitable covers (Hermoso et al. 2017, 2018a, 2018b, 2019). The effective conservation of Natura 2000 network also requires a close collaboration and coordination among the different administrations involved in spatial development and environmental management, from European to local levels (Simeonova et al. 2017).

Natura sites under the protection of the Birds Directive showed greater urban cover than those protected by the Habitats Directive or both directives in the European Union as a whole and in most member states. However, there were no differences in urban growth between Natura sites under the protection of the Birds or the Habitats Directives. These results are probably related to the fact that Natura sites under the Habitats Directive require an initial management plan prior to official designation as a PA. However, these initial plans have to be implemented to be effective, and only 30% of Natura sites under the Birds Directive and 41% of sites under the Habitats Directive had management plans in place in 2012 (WWF 2017). These slight differences in the level of implementation of management plans between Natura sites protected under the Birds and the Habitats Directives would explain the lack of significant differences in urban growth rates between both types of sites.

Moreover, low levels of implementation of management plans in Natura 2000 sites reveal a low capacity of the current protection framework to halt ongoing urban sprawl into these PAs. This was also evinced by Martínez-Fernández et al. (2015), who found low urbanization only in nationally designated PAs (i.e., those with specific and upper-level legal protection). The rest of Natura 2000 sites had even greater increases in artificial land than unprotected areas in Spain from 1987 to 2006. Urban development in protected sites should be effectively halted through an integrated protection framework that includes appropriate regulation, effective management plans, and subsequent controls of law and plans' enforcement.

In general, Natura sites affected by the highest degree of urbanization had low conservation value; that is, they contained few species or habitats of conservation concern in relation to their size (Fig. 5). However, some member states had high urban covers or growth rates in Natura sites with high conservation value (i.e., high number of species or habitats). This was the case for Latvia, Spain, Cyprus, Greece, Italy, and Malta. Firmer legal protection and vigilance against urban development in these cases is mandatory, especially in Spain, Cyprus, and Malta, which were also among member states with the highest urban covers or growth rates inside Natura 2000 over the analyzed period (Table 1).

Small Natura sites had high urban covers throughout the European Union and in most member states. These results are in accordance with previous studies that show smaller Natura sites have undergone more land-cover changes over the last two decades (Hermoso et al. 2018a). However, I found greater urban growth rates in large Natura sites, which indicates that high urbanization rates in small Natura sites likely occurred before 2006–2015 and are now concentrated in large Natura sites, where more land is available for building. Special attention should be paid to small Natura sites of high conservation value with high urban cover or growth rates, given their high vulnerability. Such special attention is even more important considering that these cases were concentrated in the Mediterranean basin (i.e., Cyprus, Italy, Malta, and Spain), one of the 25 world biodiversity hotspots, which is considered especially vulnerable to global change and where substantial habitat loss is linked to high anthropic pressure (Myers et al. 2000; Martínez-Fernández et al. 2015).

Overall, Natura 2000 network seems to be protected against urban sprawl to a certain degree, but not completely. I identified an incipient urban sprawl inside Natura 2000 areas, likely as a result of an increasing demand by people to reside and recreate closer to nature (EEA 2016). Stricter legal measures, effective management plans, observance controls, and adequate financial instruments have to be put in place, with close coordination among the different administrations involved, to ensure the preservation of traditional land uses compatible with conservation and to halt the spread of built areas inside Natura 2000 PAs.

Member states that showed high urban cover or growth rates inside the Natura network must put more effort into avoiding further urban sprawl into their PAs, especially in sites subject to high urban pressure (i.e., close to highly populated areas). More urgent actions must be put in place in those member states that showed both high urban cover and growth rates (Bulgaria) and where high urban cover or growth rates affected Natura sites of high conservation value (Spain, Cyprus, and Malta). These latter cases are in the highly diverse and vulnerable Mediterranean region, which also concentrates member

states with high urban cover or growth rates in small Natura sites of high conservation value (i.e., Cyprus, Italy, Malta, and Spain), which are worthy of special protection, given their high vulnerability to habitat loss and degradation.

Acknowledgments

I am a recipient of a Juan de la Cierva - Incorporación postdoctoral fellowship (IJCI-2016-30964) from the Spanish Ministry of Science and Innovation. I wholeheartedly thank L. Barrios for the statistical advice, and three anonymous reviewers and the editors for their detailed review comments and suggestions that have considerably enhanced the initial manuscript.

Supporting Information

Additional Information

Additional information is available online in the Supporting Information section at the end of the online article. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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