




Mapping pressures on biodiversity: the contribution of thematic detail to decision making

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Abstract

Mapping pressures to species is key to identify where biodiversity is at risk and providing relevant information to direct conservation actions. Decision-making to minimise pressures requires the determination of specific target actions at a high level of detail. However, the trade-off between cost and effort to generate this information often leads to the production of generalised pressure maps, named coarse maps, covering the most relevant pressures and their proxies. Here we aimed to disentangle whether the cost and effort of mapping fine pressures is worthwhile to inform decision making, by comparing how fine and coarse maps identify “where” and “how” management actions should be derived. Comparing the extend of both map types as well as its capacity to identify risk areas. We focused on three main pressures: agricultural intensification, human intensification, and land abandonment. The study was carried out in Catalonia for local decision-making, but the results can be applied in other EU regions or elsewhere, also for local decisions-making. We found that the Jaccard’s similarity index between coarse and fine pressure maps was always below 0.3 indicating low overlap between fine and coarse maps. In particular, the coincidence between coarse and fine thematic maps within protected areas (PAs) was always below 50%. Both maps differed in the identification of risk areas inside three analysed PAs. Moreover, even when there was a total geographical overlap between coarse and fine maps, coarse maps lack information on which concrete pressure was actually present, making decision on actions needed difficult. Thus, we can conclude that fine maps can estimate more accurately both “where” and “how” to target concrete actions than coarser maps. Even in cases where the answer as to “where” to act is the same, fine maps provide more concrete information to provide guidance on “how” to act. Consequently, despite the high cost and effort involved in mapping pressures at a high level of detail, the final trade-off is positive.

Keywords Conservation management · Biodiversity · Decision-making · Drivers of change · Mapping pressures

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Introduction

Recent biodiversity reports confirm that the world has entered in the Anthropocene, characterized by unparalleled human impact on the global environment (Barnosky et al. 2011; Steffen et al. 2011). The global assessment report of the intergovernmental science-policy platform on biodiversity and ecosystem services (IPBES) describes as human actions threaten more species with global extinction now than ever before. This assessment calculates that about 25% of species assessed are threatened, suggesting that around one million species already face extinction, many within decades, unless action is taken to reduce the intensity of drivers of biodiversity loss (IPBES 2019). In this same line, the *State of Nature in the EU* (European Environment Agency 2020) that summarises the results from the reporting under the Nature Directives (Habitats and Birds Directives) for the period 2013–2018 depicts that less than a half of all bird species have a good population status, while almost 40% have poor or bad status (European Environment Agency 2020; Röschel et al. 2020). Also, less than a 30% of other species have a good conservation status and 75% of the assessed habitats are in a poor or bad status (European Environment Agency 2020; Röschel et al. 2020).

The main pressures reported behind this biodiversity loss are land use change, human intensification as well as leisure activities, overexploitation, unsustainable forest practices, invasive species, and climate change. Identifying and mapping pressures and threats to biodiversity is key to address the decline of biodiversity (Tulloch et al. 2015). Once these pressures and threats are mapped, and given that resources to address them are limited, decisions on how to best address them can benefit from structured decision making to evaluate potential management actions in a cost-effective way (Tulloch et al. 2015; Allan et al. 2019; Hermoso et al. 2022).

In recent years, several efforts have been made to map threats and pressures at a different spatial scale including the global scale (Ridley et al. 2020). The availability of large-scale information from remote sensors and large databases has made it possible to map proxies of the main pressures and threats driving the biodiversity loss at a global scale (Venter et al. 2016a; Moran and Kanemoto 2017; Bowler et al. 2020). Some of them incorporating species and pressures interactions (Allan et al. 2019; Harfoot et al. 2021; Ostwald et al. 2021) providing a more robust foundation for prioritising threat abatement strategies (Ostwald et al. 2021). However, the spatial resolution of global-scale maps as well the use of proxies, could be a limitation for guiding regional and local conservation actions (Warman et al. 2004; Hermoso and Kennard 2012; Harfoot et al. 2021). Mapping pressures and threats at high detailed spatial and thematic level is a priority to inform specific biodiversity conservation actions.

Since 2011 the European Commission has adopted its Biodiversity Strategy aimed at ‘halting the loss of biodiversity and the degradation of ecosystem services in the EU by 2020’, the EU’s nature and biodiversity policy relies on the Birds (2009/147/EC) and Habitats (92/43/EEC) Directives (Hermoso et al. 2019). Both Directives aims to ensure that habitats are maintained or restored to a favourable conservation status, and birds are subject to special conservation measures concerning their habitat to ensure survival and offspring in their breeding area. To achieve this, Member States of the EU must report to the European Commission on the conservation status of a set of habitats and species of community interest. These periodical reports include the detailed description of habitats and species state, as well as the pressures and threats affecting them, and the actions taken improve their conservation status. To carry out this assessment, the European Commission

provides to the Member States a detailed list of 220 pressures and threats describing very precisely the whole pressures affecting the EU.

Despite of the very concrete EU guidelines to assess biodiversity conservation status and to propose conservation actions, decision-makers often face budget constraints and information availability for mapping these pressures and threats at this fine thematic level of detail needed to inform decision-making. These limitations lead to a common practice of producing general pressure maps encompassing different individual pressures or their proxies. For example, pressure from agricultural intensification can be mapped by integrating information on the spatial aggregation of crops (a proxy for land consolidation) with fertiliser use (Morán-Ordóñez et al. 2018), as well as based on the IUCN threat classification scheme that includes 14 specific threats related to agriculture and aquaculture (Harfoot et al. 2021). But do these general maps provide us with sufficient information for decision-making at the level of detail we expect, or could they be biasing decision-making? Or, seen from another perspective: given the trade-off between cost and effort of mapping pressures and threats at a high thematic level, what are the advantages of mapping a list of pressures and threats as thematically comprehensive as, for example, the list of pressures and threats in the EU Directives? The aim of this work is to answer this question by means of finding the benefits and opportunities of thematical fine pressure maps, as well as the possible constraints of the thematically generalization of pressures maps, and its consequences on the decision-making, in the EU or elsewhere. We assume both that decision-making to minimise pressures requires the determination of specific target actions at a very high level of detail and that the combination between fine biodiversity distribution maps with fine thematic pressures maps are the most accurate and truthful description of the real pressures affecting a territory. Focusing on pressures mapping we must also assume that the trade-off between the cost and effort of fine thematic mapping of pressures often leads to the use of thematically coarse maps covering more than one pressure and/or proxies. Thus, based on the two main questions that the pressure maps should contribute to answer: “where” and “how” to target actions, we compare the thematically coarse pressures maps, hereafter coarse maps, with the thematically fine pressures maps, hereafter fine maps, and their capacities to define where and how target actions for biodiversity conservation. Ideally, we expect that coarser maps should explain a pressure in the same way as the corresponding combined fine pressures maps would do. For this reason, the coarse map should have the same extent as the combined set of corresponding fine maps (scenario A in Fig. 1). However, due to the trade-off between the cost and effort of accurately mapping all the fine pressures involved, coarse maps may end up being an oversimplified representation of the real pressures. In consequence, we also expect that in some cases that the coarse maps should occupy a different extend than the one formed by the whole fine maps set, as well underestimating or overestimating pressures (scenario B and C respectively in Fig. 1). Both situations would be especially caused by oversimplification of the fine maps due to limitations in the availability of base maps and in the cost/time effort to produce them.

We aim at disentangling whether the cost and effort of mapping fine pressures is worthwhile to inform decision making, in identifying where and how management actions should be prescribed. For this purpose, we analysed the geographical extent of the mapped pressures and threats following both approaches at two different levels: across the study area and only within protected areas (PAs). In addition, a very important issue is that to target concrete conservation measures it is necessary to identify which species and habitats are at risk due to the negative pressures that may affect them. Therefore, the identification of risk areas is key for decision making. Considering that risk occurs when pressures overlap with the distribution of a species sensitive to those

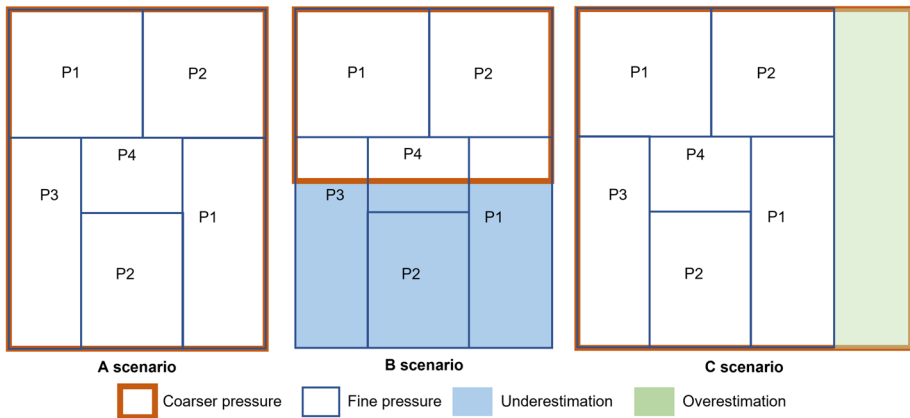


Fig. 1 Three distinct overlap scenarios that could occur between coarse and fine thematic pressure maps. The coarse pressure map is symbolized by an orange frame and the distribution of the different fine thematic pressures maps that correspond to the coarse pressure map, by a dashed blue line polygon. On the left, scenario A shows when the coarse map includes all the related thematic fine pressure maps, both maps having the same extend. In the centre, scenario B depicts when the coarse pressure map does not include all the fine pressures and occupies less extend than fine maps, underestimating (in blue) pressures. On the right, scenario C shows when the coarse pressure map occupies more extend than the fine pressures maps, in consequence overestimating (in green) pressures

pressures, methods for mapping pressures are important (Tulloch et al. 2015; Ostwald et al. 2021). Thus, we analysed the ability of fine and coarser maps to determine risk areas within PAs. We hypothesise that fine maps can estimate more precisely where and how to target concrete actions than coarser maps. We discuss about the consequences of our findings for conservation action in the EU, and elsewhere facing similar problems.

Methodology

The present work considers the thematically fine pressures maps, here and after “fine maps”, as maps depicting a concrete and unique pressure affecting a territory. Besides, the thematically coarser pressures maps, here and after “coarser maps”, as maps that represents a broader pressure concept that includes different concrete pressures. For example: a commonly used coarse agricultural intensification map would consider the land consolidation and the use of fertilisers and pesticides as main proxies of agricultural intensification; while, for another hand, according the EU Directives list there would be five fine pressure maps explaining the individual pressures producing agricultural intensification separately: the conversion to agricultural land, the conversion from mixed farming to specialised production, the removal of small landscape features for agricultural land parcel consolidation, the application for synthetic fertilisers and finally and finally, the application of plant protection chemicals. In this work we compare the fine maps with the coarser maps, analysing the geographical extent of both types of maps (regionally and within PAs). We also quantify the sensitive species risk areas derived by both types of maps within three PAs.

Study area

The study was conducted in Catalonia, at the north-east of the Iberian Peninsula in western Mediterranean Sea, with an area of about c. 32,000 km². The region comprises two different EU biogeographical regions: the Mediterranean region in the most part of the study area, and the Alpine concentrated in the north corresponding to the west Pyrenes range. There is an important agricultural area in the central west of the study area, called Lleida plain. The most part of population is concentrated in the coast, especially in the central coast region, concretely in Barcelona and its metropolitan area. The rest of the study area is dominated by forested land uses.

In accordance with global and European reports, the State of Nature 2020 report for Catalonia (Brotons et al. 2020), has determined that in the last 20 years 25% of biodiversity has decreased due to human impact. The Catalan PAs that form part of the Natura 2000 network cover more than 1 million ha, corresponding to 33% of the region, of which 977,230 ha are terrestrial and 85,141 ha marine.

Coarse and fine pressures mapping

We focus on three main groups of pressures: agricultural intensification (AI), human intensification (HI), and land use abandonment (AB). They are among the most relevant pressures according to the Habitats and Birds Directives in the period 2013–2018 report and the State of Nature in Catalonia 2020 report (Sainz de la Maza et al. 2019; Brotons et al. 2020; European Environment Agency 2020), and they can be addressed through local management actions. We have not considered the pressures of climate change and invasive species, although they are also very important pressures in the study area, because they need actions beyond local management to be addressed, for example involving deeper social transformation. We have mapped both map types according to the Habitats and Directives 2013–2018 reporting period in order to consider the same time frame for both map types. In line with EU recommendations, some pressures describe pressures over the reporting period, so we used information from 2013 to 2020. On the other hand, other pressures (i.e. land use pressures) required quantifying the effect of pressures over a longer time frame, so we used land use maps from 1987 to 2012. Further information regarding the elaboration of each pressure map in the Online Resource 1 (Tables S1, S2, and S3).

We mapped these three coarse pressures accordingly to the most commonly process used by biodiversity managers and planners, which are based on scientific and technical reports (Venter et al. 2016a; Morán-Ordóñez et al. 2018) since there are no defined guidelines from the EU. Further information regarding the elaboration of each pressure map in the Online Resource 1 (Tables S1, S2, and S3).

We mapped the corresponding fine pressures based on the comprehensive EU list provided to Member States for regular reporting of Birds and Habitats Directives. According to the results of the last period reporting of both Directives in the study area (Sainz de la Maza et al. 2019; Röschel et al. 2020), we first defined the list of fine pressures present in the study area and related to the respective coarser pressures analysed. This EU list contains 220 pressures and threats with a high detailed thematic level, grouped into 19 main types (i.e., agriculture, forestry, climate change, pollution), without a thematic hierarchical relation. After a thorough analysis, we selected the fine pressures present in the study area related to each of the three main pressures, we founded 13 fine pressures (Table 1).

Table 1 Selected fine pressures and its corresponding coarse pressure: abandonment (AB), agricultural intensification (AI) and human intensification (HI)

Fine pressure	Description	Coarse pressure
A06	Abandonment of grassland management (e.g., cessation of grazing or mowing)	AB
A07	Abandonment of management/use of other agricultural and agroforestry systems (all except grassland)	AB
A10	Extensive grazing or under grazing by livestock	AB
B01	Conversion to forest from other land uses, or afforestation (excluding drainage)	AB
A01	Conversion into agricultural land (excluding drainage and burning)	AI
A03	Conversion from mixed farming and agroforestry systems to specialised (e.g., single crop) production	AI
A05	Removal of small landscape features for agricultural land parcel consolidation (hedges, stone walls, rushes, open ditches, springs, solitary trees, etc.)	AI
A20	Application of synthetic (mineral) fertilisers on agricultural land	AI
A21	Use of plant protection chemicals in agriculture	AI
E01	Roads, paths, railroads, and related infrastructure (e.g., bridges, viaducts, tunnels)	HI
F01	Conversion from other land uses to housing, settlement, or recreational areas (excluding drainage and modification of coastline, estuary, and coastal conditions)	HI
F03	Conversion from other land uses to commercial/industrial areas (excluding drainage and modification of coastline, estuary, and coastal conditions)	HI
F07	Sports, tourism, and leisure activities	HI

We have mapped these 13 fine pressures using available official cartography and ancillary data, specifically using population and tourist statistics as well official admissible fertilisers thresholds. Further information regarding the elaboration of each pressure map in the Online Resources 1 (Tables S1, S2, and S3). We assume that the fine thematic pressure maps are the best attainable information that can be achieved, regardless potential uncertainties associated with the data sources used for mapping them.

Both coarse and fine maps were geometrically unified at the 1×1 km UTM grid squares since this is the resolution used for monitoring species conservation status and reporting pressures and in consequence a widely used grid for planning and management in the study area. We measured the intensity of each pressure and scaled them between 0 and 1 within all 1 km grid cells.

We identified pressure hotspots for each fine and coarse map (Halada et al. 2017; Riera et al. 2021) using Getis-Ord (G_i^*) statistic. The G_i^* statistic compares the value of a variable in a specific location and its neighbourhood within a specified distance, to the global mean of that pressure across the study region, to identify locations with values significantly higher to those expected at random (Getis and Ord 1992). The G_i^* is conceptualized as a Z-score where positive values imply high local relationships as well hotspots (Zen et al. 2019). In order to choose the best neighbourhood to be considered, we tested three different influence scopes: 5, 10 and 20 km and, after a qualitative analysis of the results, we selected the 5 km radius because we found that longer distances blurred the significance of the hotspots generating an unrealistic increase in the surface area of the hotspots. These hotspots maps were used for subsequent analyses as the basis for all the comparisons between fine vs. coarse maps.

Comparison between coarse and fine maps

To evaluate the opportunities and limitations of coarse pressures maps to identify where to prescribe management actions, we evaluated the similarity between each coarse map with the aggregated distribution of the whole set of corresponding fine maps associated with the coarse pressure (Table 1). We used the Jaccard similarity index (Jaccard 1912; Chung et al. 2019), assuming that the more overlap between the coarse and the fine maps, the more accurate the coarse map would be. This index ranges between 0 and 1, the closer to 1, the more similar the two maps are. Given that the coarse map ideally conveys all the fine maps (Fig. 1A), we first aggregated all the fine thematic maps related to each coarse pressure in a single map (Table 1) and then measured the spatial overlap between both (coarse and merged fine resolution maps). We also compared the spatial overlap between the merged fine maps with the correspondent coarse map with a random overlap. Each random coarse maps were generated by randomly distributing across the study area the same number of 1×1 km UTM cells previously identified as pressures for each coarse map. This process was replicated 1000 times, and we calculated the mean Jaccard index across those replicates for each of the three random coarse maps individually. If the observed overlap between the merged fine maps and the coarse map is similar or lower than the similarity with the random coarse map, it means that the coarse map explains as little as a random map.

High similarity between fine and coarse maps indicates that we are probably closer to scenario A, while low similarity indicates that we are probably closer to scenarios B or C. We, therefore, further calculated the overestimation or underestimation of the true distribution of pressures derived from each of the three coarse pressure maps. Considering that

overestimation occurs when an area is represented in the coarse map but not in the fine map, and underestimation occurs when an area is represented at least in a fine map but not in the coarse map.

We further analysed the capacity of coarse maps to identify the pressures that would need management actions within PAs, focusing on the 109 terrestrial PAs of the Natura 2000 network in the study area. We measured the proportion of correct classification associated with each of the three coarse pressures and their fine thematic pressures within PAs. We counted as correct classification those areas where the coarse pressure overlapped with at least one of the fine thematic pressure maps that it should cover. We then classified the overlap within the protected area and, therefore, the surrogacy of the coarse map as no overlap (overlap between 0 and 5%), low (5–50%), high (50–99%) and full (100% overlap). High proportion of correct classification values indicate that coarse maps would represent the pressures distribution as well as fine maps inside a PAs and, in consequence, it would indicate that coarse maps can answer “where” to act as well as fine maps, inside PAs. We counted the number of PAs in each level to quantify the number of PAs with high and full overlap between coarse and fine maps, where the coarse maps would be contributing to decide where to target conservation actions as well as fine maps. In the other hand, also quantifying the number of PAs with low or null overlap between coarse and fine maps, where the coarse maps would be insufficient to direct concrete conservation actions.

We also analysed the coarser and fine capacity to map the areas at risk inside three PAs, considering as a risk area where a pressure overlaps with the distribution of a species sensitive to that pressure. We have focused in three PAs, each particularly affected by some of the pressures analysed. Concretely, we analysed the Plans de Sió Natural Park, which is specially impacted by Agricultural Intensification pressures, the Aigüestortes National Park affected by Human Intensification pressures and, the Prades Mountains Natural Park impacted by Abandonment pressures. We sourced the list of all species present inside the PA boundaries from the Standardized Data Forms (SDF) of each PA and we determined the sensitivity to each one of the analysed pressures with expert knowledge (Sainz de la Maza et al. 2019). To determine the distribution of the species we used the suitability habitat distribution models of each species developed by CARTOBIO (Villero et al. 2017; CARTOBIO 2023). The distribution maps of those species define three types of zones according to the habitat suitability of each 1 km² grid cell within the PAs: optimal, good, and suitable zones; indicating from highest to lowest suitability respectively (Arcos et al. 2009; Villero et al. 2017). We focused on the optimal areas because, being the most suitable for each species, they may be considered as priority areas for their conservation. We compared the risk zones within the three PAs identified by fine maps versus those identified by coarser maps.

Results

At first glance, each of the three coarse maps (Figs. 2, 3, 4) did not represent the distribution of the merged fine resolution pressures related to them, as indicated by the low values of the Jaccard's similarity index (Table 2). The highest similarity value was 0.30 for agricultural intensification. In the case of abandonment, the similarity between the fine thematic map with its coarse map was 0.20, concretely the same value than between fine and the correspondence random coarse map. Human intensification showed a Jaccard value of 0.21 between fine maps and its coarse map and a similarity value of 0.11 between fine

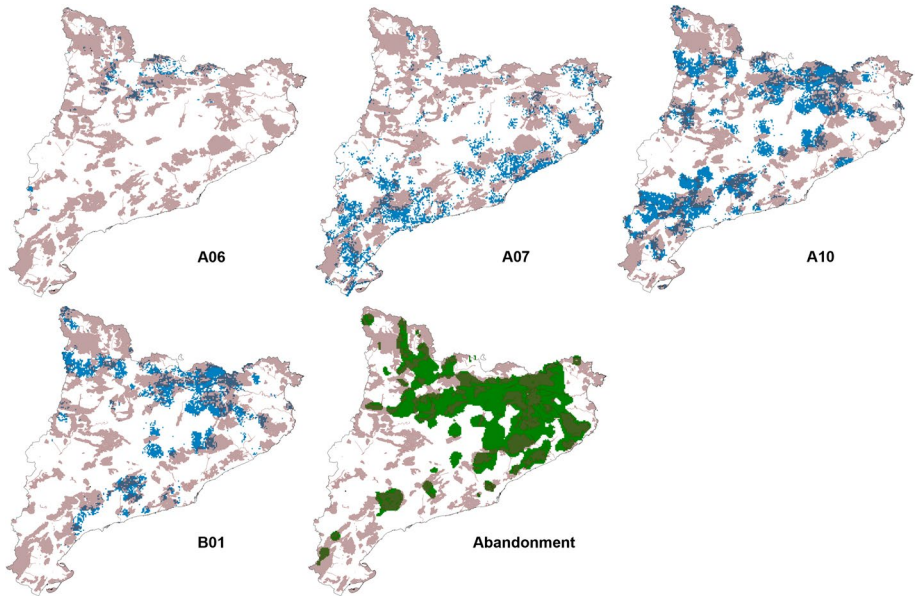


Fig. 2 In blue fine abandonment hotspots maps: abandonment of grassland management (A06), abandonment of management/use of other agricultural and agroforestry systems (A07), extensive grazing or under grazing by livestock (A10) and conversion to forest from other land uses, or afforestation (B01) and in green the coarse abandonment map. Terrestrial Protected Areas into Nature 2000 network in grey

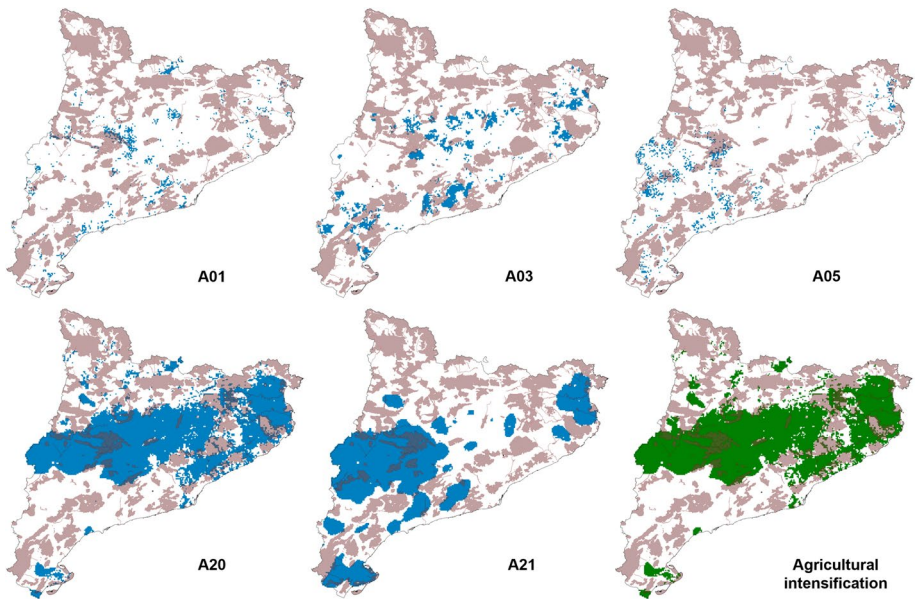


Fig. 3 Fine Agricultural Intensification hotspots maps (in blue): conversion into agricultural land (A01), conversion from mixed farming and agroforestry systems to specialised production (A03), removal of small landscape features for agricultural land parcel consolidation (A05), application of synthetic (mineral) fertilisers on agricultural land (A20), use of plant protection chemicals in agriculture (A21); and coarse agricultural intensification map (in green). Terrestrial Protected Areas into Nature 2000 network are shown in grey

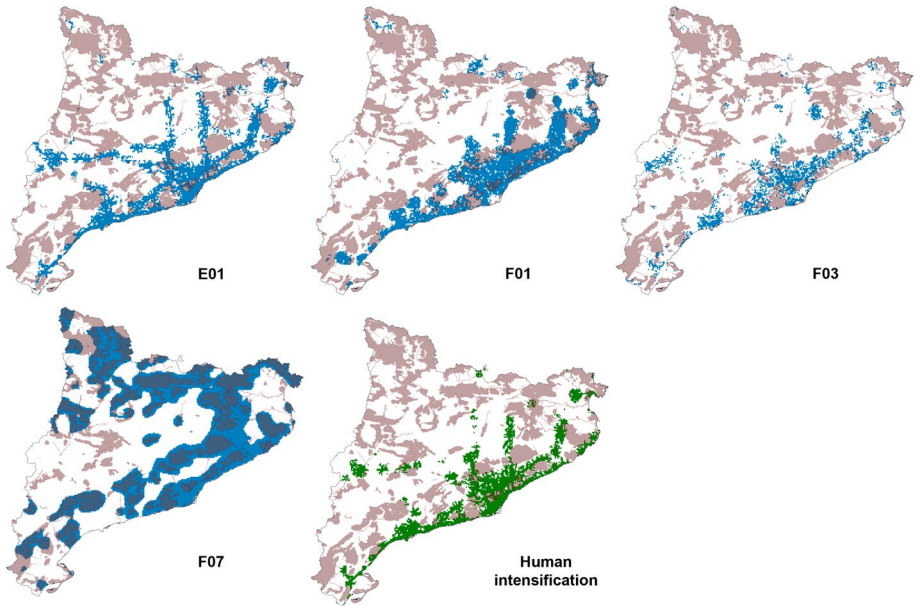


Fig. 4 Fine Human Intensification hotspots maps (in blue): roads, paths, railroads, and related infrastructure (E01), conversion from other land uses to housing, settlement or recreational areas (F01), conversion from other land uses to commercial/industrial areas (F03), sports, tourism and leisure activities (F07); Coarse human intensification map (in green). Terrestrial Protected Areas into Nature 2000 network are shown in grey

Table 2 Jaccard Similarity index between coarse maps or coarse random maps and corresponding aggregated fine maps

Pressure type	Coarse map	Coarse random map
Abandonment	0.20	0.20
Agricultural intensification	0.30	0.25
Coarse human intensification	0.21	0.11

maps and random coarse map. Moreover, fine thematic maps are as similar to its correspondent coarse map as to a random coarse map.

This low Jaccard index similarity values indicate that the three analysed pressure types are closer to scenario B and C than scenario A (Fig. 1). For all three analysed pressures, the coarse maps either overestimated or underestimated the areas affected by the pressures. The overlapped area between coarse and fine maps were smaller than the area with overestimation or underestimation (Table 3). The areas occupied by the coarse maps for abandonment and agricultural intensification pressures were quite similar, concretely 10,553 km² and 12,169 km² respectively. But in both cases, there was a low overlap: 3636 km² and 5942 km² respectively. In the case of abandonment, the coarse maps overestimated or underestimated greater areas than the overlapped area: 6917 km² and 6346 km² respectively. In the case of agricultural intensification, the overlapped area is near the 50% of the coarse and fine areas, and the overestimation and underestimation are slightly higher: 6227 km² and 7276 km² respectively. Human intensification

Table 3 For each pressure and map type (“Coarse” and “Fine”) it is described the Area occupied (considering the map type “Fine” as the combination of all the correspondence fine maps), the overlapped area between coarse and fine maps, the overestimated area when there is coarse map but not fine map, and the underestimated area when there is fine map but not coarse map

Pressure	Map type	Area (km ²)	Overlapped area (km ²)	Overestimated area (km ²)	Underestimated area (km ²)
Abandonment	Coarse	10553	3636	6917	6346
	Fine	9982			
Agricultural intensification	Coarse	12169	5942	6227	7276
	Fine	13218			
Human intensification	Coarse	4037	4017	20	14769
	Fine	18786			

All areas in km²

had the peculiarity that the fine thematic maps occupy an area four times greater than the correspondent coarse map with an overlap area similar to the coarse map area. In addition, the coarse map overestimates a very little area but underestimates a large area, concretely 20 km² and 14,769 km² respectively.

Table 4 Spatial area (km²) occupied for each coarse and fine pressure for the three pressures groups (abandonment, agricultural intensification, human intensification), and area of overlap between each fine map and the corresponding coarse map (km²)

Code	Pressure	Area (km ²)	Overlapped area (km ²)
<i>G-AB</i>	<i>Coarse abandonment</i>	10627	
A06	Abandonment of grassland management	577	213
A07	Abandonment of management/use of other agricultural and agroforestry systems	4048	812
A10	Extensive grazing or undergrazing by livestock	6766	2945
B01	Conversion to forest from other land uses, or afforestation	4047	2431
<i>G-AI</i>	<i>Coarse agricultural intensification</i>	12169	
A01	Conversion into agricultural land	951	620
A03	Conversion from mixed farming and agroforestry systems to specialised production	2075	1173
A05	Removal of small landscape features for agricultural land parcel consolidation	948	489
A20	Application of synthetic mineral fertilisers on agricultural land	12008	11674
A21	Use of plant protection chemicals in agriculture	9076	5596
<i>G-HI</i>	<i>Coarse human intensification</i>	4084	
E01	Roads, paths, railroads and related infrastructure	5159	3813
F01	Conversion from other land uses to housing, settlement or recreational areas	5677	2956
F03	Conversion from other land uses to commercial/industrial areas	2666	1759
F07	Sports, tourism and leisure activities	14455	1812

Deeping to each fine pressure map (Table 4), it is noteworthy that in the case of the coarse map of agricultural intensification pressure overlaps almost entirely with the fine map “Application of synthetic mineral fertilisers on agricultural land”, and both maps have similar areas and distribution (Fig. 3). In relation to human intensification pressures, the coarse map is very similar in area (Table 4) and spatial distribution (Fig. 4) to the fine maps related to roads and human settlements. It is remarkable the fine map of “Sport, tourism, and leisure activities” is 75% larger than the coarse pressure map (Table 4) and the overlapped area is below 10%. This fine map extends to practically all areas of the Nature 2000 network while the coarse map is underestimating this large area (Fig. 4).

Focusing on coarse and fine maps overlap within PAs (Table 5), we found that only 25 PAs were close to scenario A, and most of the PAs showed an overlap below 50% (Table 5). There were 15, 12 and 17 PAs without pressures hotspots for abandonment, agricultural and human intensification pressures respectively (Table 5). Therefore, in most of the PAs the coarse maps could overestimate or underestimate fine thematic pressures in more than a half of its area.

The overlap between coarse and fine thematic pressures within PAs and its geographical distribution (Fig. 5), in the case of abandonment pressures, the few PAs with a correct classification above 50% were concentrated in northern forested areas. In agricultural intensification pressure, the PAs characterized for its agricultural landscape situated in the centre-west of the study area, showed a total overlap. The PAs with overlaps between 50% and 99% corresponded both to PAs with an important agricultural area within the PA limits or important agricultural area surrounding the PA (Fig. 5). The human intensification pressure stood out as there was almost no overlap (0–5%) within most of PAs, and when it occurred at low values (5–50%), it happened in PAs near the most populated areas in the study area (Fig. 5).

Inside the analysed PAs the species sensitive distribution areas to human intensification, abandonment, and human intensification, occupied respectively 376 km² in Aigüestortes National Park, 259 km² in Prades Mountains Natural Park and 34 km² in Plans de Sió Natural Park (Table 6). In the case of Plans de Sió Natural Park the whole sensitive area, scattered throughout the PA (Fig. 6A), was determined at risk according both types of maps (Table 6). In the case of Aigüestortes National Park (Fig. 6B) the 49.2% of the area had no risk and the 50.8% was at risk according to fine pressure maps, coarser maps did not determine human intensification risk inside the PA. The risk is concentrated in the lower altitude areas of the park, in the east and west. The sensitive species to human intensification, concretely to the fine pressure of sport, tourism, and leisure activities (F07) are distributed throughout the PA, while the fine pressures map identifies risk in the lower altitude areas of the PA. In the case of Prades Mountains Natural Park, the sensitivity species to abandonment pressures are distributed throughout the park (Fig. 6C), the 6.6% of areas

Table 5 Number of protected areas (PAs) in different overlap proportions (0–5%, 5–50% 50–99% and 100%) for each pressures type

	No pressure	Overlap			
		0–5%	5–50%	50–99%	100%
Abandonment	15	47	38	5	4
Agricultural intensification	12	30	33	15	19
Human intensification	17	58	26	6	2

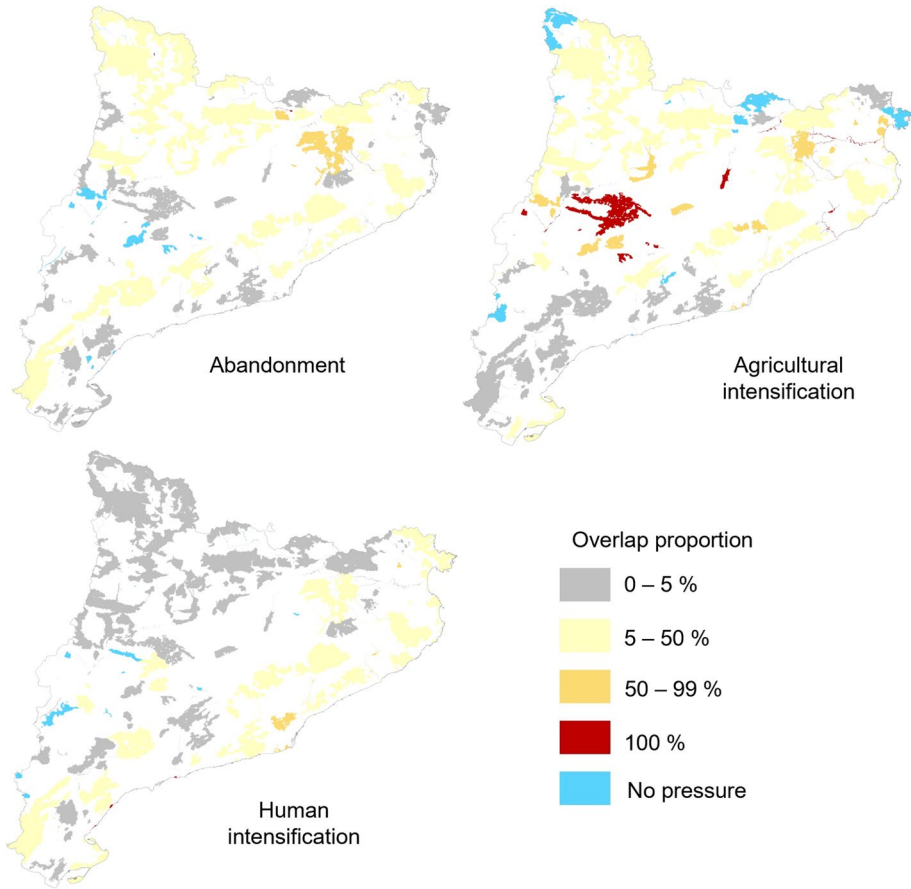


Fig. 5 Terrestrial protected Areas (PAs) conforming the Nature2000 network. Colour indicates the proportion of overlap within each PA: below 5% in grey, from 5% to 50% in yellow, from 50% to 99% in orange, and 100% in red. The blue colour represents PAs without abandonment, agricultural intensification or human intensification pressures

Table 6 Sensitive species area in km² for each analysed protected area

Protected area	Sensitive species area (km ²)	No pressure and no risk (%)	Risk proportion area		
			Fine maps (%)	Coarser maps (%)	Overlapped maps (%)
Aigüestortes National Park	376	49.2	50.8	0	0
Prades Mountains Natural Park	259	6.6	4.2	49.8	39.4
Plans de Sió Natural Park	34	0	0	0	100.0

The last four columns explain the proportion (%) of sensitive areas with no risk because there is no pressure, risk determined by fine maps, coarser maps and both maps

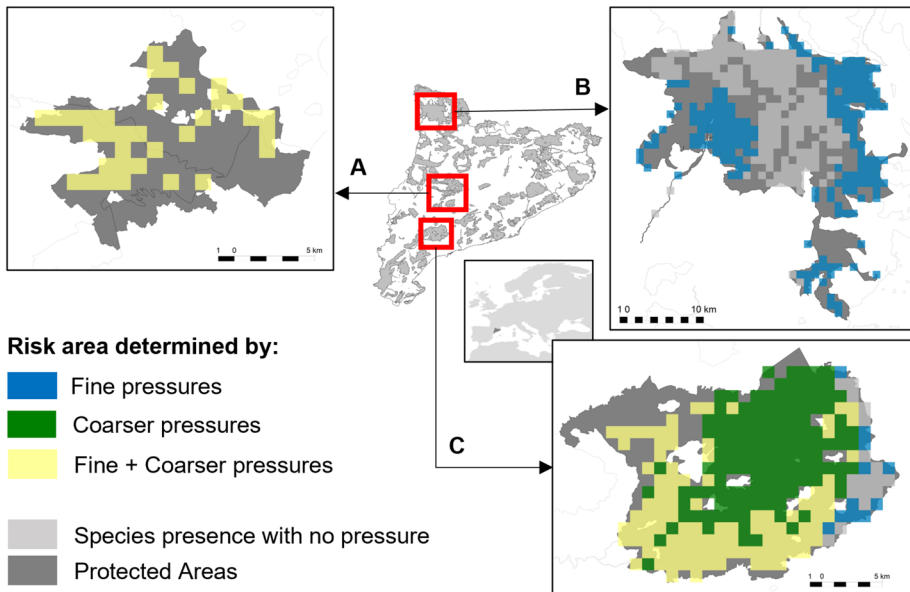


Fig. 6 Risk areas determined by fine (blue), coarser (green) or both pressures maps (yellow) inside three protected areas (dark grey): Plans de Sió Natural Park with agricultural intensification pressures (A), Aigüestortes Natural Park with human intensification pressures (B) and Prades Mountains Natural Park with abandonment (C). The areas with no pressure (light grey) are areas with sensitive species but without respectively analysed pressures

with sensitive species had no risk, 4.2% was at risk according to fine pressure maps, 49.8% was at risk according to coarser maps and 39.4% according both map types. The coarser maps determine risk in almost entirely PA, while fine maps determine risk in areas close to edges, except in the north (Fig. 6C). Only in the case study of the Plans de Sió Natural Park did the fine and coarse maps fully coincide (Fig. 6A). Both fine and coarser maps identify different risk areas.

Discussion

This work complements previous work demonstrating sensitivity to special resolution in conservation decision making (Warman et al. 2004; Hermoso and Kennard 2012), but now focusing on the thematic resolution of pressures as drivers of change that directly impact on conservation. Here, we show that there is very low similarity between coarse pressures maps and the corresponding merge of fine thematic pressures maps. Considering the fine thematic pressures maps as the true distribution of pressures, we observe that for the analysed pressures coarse maps mostly overestimate and/ or underestimate pressures, in both analysed areas: the whole study area and inside PAs. The low similarity of the Jaccard index values in the three addressed pressure groups confirm that coarse maps can show very different picture of pressure distribution to fine maps. Furthermore, in the three analysed main pressures, the coarse maps can explain as little as a random map compared to the true distribution of each fine thematic pressure. Consequently, we were closer to

scenario B and C and for the three main analysed pressures, the area occupied by the aggregation of fine maps did not correspond to area occupied by the corresponding coarse maps. The results regarding the proportion of correct classification of pressure incidence within PAs show that coarse maps can both overestimate and/or underestimate the incidence of fine pressures within the PAs boundaries, with values below 50%. In more than half of the PAs in the study area, the coarse maps would not be as suitable as fine maps to determine where to direct management actions.

Our results show that coarse maps are often biased towards what would appear to be the most relevant fine pressures and/or the easiest to gather information and represent geographically. For example, the most human intensification pressure coarse maps in the literature describe pressures related to human infrastructure, as well as human settlements and roads (Venter et al. 2016a; Di Marco et al. 2018; Allan et al. 2019) underestimating pressures on natural areas due to sports and leisure activities. It also occurs in agricultural intensification pressures maps, focus mostly on the effects of insecticides, and increased single crop production (Morán-Ordóñez et al. 2018), underestimating some fine pressures as well the decrease of features for agricultural land parcel consolidation, which contribute greatly to the decline of the species (Weissteiner et al. 2016). In both examples, gathering information to elaborate these thematic fine pressures maps should be a priority. For example, the pressure on natural areas due to sports and leisure activities is being mapped at a European scale (Zulian et al. 2014) but a major effort is required to adapt it to each region. In consequence, the usual budgetary and time constraints lead to use human intensification coarse maps and thus obviate these fine pressures despite of being a true pressure that is acting on the territory.

The risk area for sensitive species detected by the fine and coarse maps differs in the three PAs analysed. In Aigüestortes National Park (Fig. 6B) the human intensification coarser map does not identify risk areas inside PA boundaries, while the fine maps identify the sports and leisure activities (F07) pressure. It is consistent with the fact that this PA receives more than half a million visitors each year, being one of the most visited parks in Catalonia (Gordi i Serrat 1993). It is noteworthy that the more common coarser human intensification maps do not takes into account this specific fine pressures (Venter et al. 2016a; Di Marco et al. 2018; Allan et al. 2019). The fine maps allowed us to identify that sporting, tourism and leisure activities represent a risk to sensitive species inhabiting the mid and lower altitude areas of the park. This information is key to know where and how to direct actions to minimise this pressure. In this case, the trade-off of mapping this specific pressure is clearly positive. In the case study of Prades Mountains Natural Park, we can confirm that the coarse map of abandonment is more generalist, while the fine maps would allow targeting concrete actions where they are really needed. In the case of a limited budget to target conservation actions within the protected area, which is usually the case, coarse maps would require spreading the same efforts over a larger territory, which would probably diminish the effectiveness of the conservation measures taken. In addition, fine pressure maps allow the identification of the specific pressures causing risk in these areas: “Abandonment of management/ use of other agricultural and agroforestry systems” (A07), “Extensive grazing or under grazing by livestock” (A10) and “Conversion to forest from other land uses, or afforestation” (B01). This makes it possible to define more precisely how to act in order to minimise risk. Again, the trade-off of mapping such specific pressure is clearly positive. Finally, in the case of Plans de Sió Natural Park fine maps and coarse maps determine the same risk area, perfectly describing the scenario A (Fig. 1), both maps determine exactly where to target conservation actions. Notwithstanding, fine maps describes that

three different concrete pressures are acting: “Removal of small landscape features for agricultural land parcel consolidation” (A05), “Conversion from mixed farming and agroforestry systems to specialised production” (A03) and “Conversion into agricultural land” (A01), provide very concrete information to guide where and how to direct concrete management actions.

Thus, we can conclude that our hypothesis is true: fine maps can estimate more accurately both “where” and “how” to target concrete actions than coarser maps. Even in cases where the answer as to “where” to act is the same, fine maps provide more concrete information to provide guidance on “how” to act in each risk area. The trade-off between the cost and benefit of mapping pressures at a high level of detail is positive. The cost and effort involved in such mapping provides a greater ability to detect risks with high accuracy and provides key information for prioritising where and how to implement specific conservation measures. In consequence, we strongly recommend that conservation planners use fine pressure maps whenever available, and where this is the case, the use of coarse pressure maps should be avoided. For another hand, coarse maps are very useful to provide guidance on the importance of the main groups of pressures (Venter et al. 2016b; Moran and Kanemoto 2017; Bowler et al. 2020; Harfoot et al. 2021).

Going further, we consider the EU guidelines required to the Member States to report the state of biodiversity, based on the list of fine pressures, is suitable for biodiversity management, planning and prioritisation of actions at a regional scale. Despite this, the present study also has allowed us to detect some of the limitations of the EU fine pressures guidelines. In some cases, fine pressures are feasible to map and interpret at European scale, i.e.: the pressure “Roads, paths, railroads, and related infrastructures” (E01). In many other cases, due to Europe’s ecological and sociocultural heterogeneity, it may be necessary to make regional adaptations. For example, in order to inform local decisions on where and how to act to minimise the negative consequences of the sport, tourism and leisure activities (F03) it may be necessary to disaggregate the fine pressure into even more precise pressures. In some regions it should be necessary to be disaggregated into different sport activities, such as mountain running, speleology activities, mushroom gathering, etc. to guide concrete actions on where and how to minimise each pressure. In the same line, some pressures act differently between regions, i.e.: the pressure “Extensive grazing or undergrazing by livestock” (A10) where the extensive grazing by livestock in some regions can be related with a measure to avoid overgrazing (Mosquera-Losada et al. 2020), while in other regions, as well the study area of this work, extensive grazing is a measure to avoid undergrazing, which is one of the most important pressures causing grassland abandonments (Couto 2020). It is also important to note that some other fine pressures are still not possible to map because there is not available information. For example, gaps in the legislation of most Member States to report on the use of chemicals in agriculture make it impossible to map the pressure on the use of chemicals in agriculture, concretely the pressure “Use of plant protection chemicals in agriculture” (A21); both at regional scales, and even less at European scale. Besides, despite of the immense effort that is being made to obtain very accurate information at European scale, specially from remote sensing with high resolution products, there is currently no information available to map some pressures as well “Removal of small landscape features for agricultural land parcel consolidation (hedges, stone walls, rushes, open ditches, springs, solitary trees, etc.)” (A05). In consequence,

some of these relevant pressures must currently be represented by means of proxies or directly use coarser maps that include various related pressures. However, beyond the present work, further analysis is needed to draw precise conclusions on the appropriateness of the working scale of the EU guidelines for decision-makers and planners.

Focusing on the fact that the fine maps are the best option for decision-making, it is important to note that detailed information on large areas will not always be easy to obtain. However, it is worth noting the effort made for the European Union's Copernicus Land Monitoring Service (European Union), a valuable and increasingly important source of information at European level. This information is thematically compliant with European guidelines and, in addition, provides information up to 5 m spatial resolution at European scale. This allows to better answer the question of where to act. Thematically very interesting high-resolution layers, i.e.: "Impervious Built-up" or "Small Woody Features"; although currently, some of these products lack both a broader validation process at the European level and longer time series to provide a deeper understanding of the drivers of change affecting biodiversity. In addition to these products, is also important to point out other remote sensing sources as radar data (Bergen et al. 2009) or drone (Cardil et al. 2019; Ouattara et al. 2022; Perroy et al. 2022). Both provide information at an even higher spatial resolution, which, together with the growing science of cloud computing, makes valuable information available for decision making at regional or local scales. Although, like the information described above, it still requires further refinement, and it will not be available in the short-term making the use of coarse alternatives a potential way forward. Thus, all these improvements suggest that, in the medium to long term, the increasing use of cloud computing, the evolution of remotely sensed datasets and the products produced at regional and European level, could make it feasible to develop automatic procedures to regularly produce fine maps that contribute positively to decision-making on biodiversity conservation.

Finally, it is important to bear in mind that in some cases the trade-off between the cost and effort of fine thematic mapping of pressures will inevitably lead to the use of thematically coarse maps. Where this is the case, knowing and considering the constraints defined in our work, will help to make better decisions even from these coarse maps.

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Data availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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