Research Article

Are road-kills representative of wildlife community obtained from atlas data?

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Abstract

Systematic road-kill surveys are useful to study the impact of roads on wildlife. However, they are time-and budget-consuming, so the use of non-systematic data in road ecology is currently gaining popularity (for instance, by environmental consultants). Some data sources such as atlases (i.e., compilations of species records from a given region), which can include non-systematic and citizen-science data, can entail several intrinsic biases, mostly due to uneven sampling effort and uneven species detectability. Here, we tested this prediction by verifying if data from the Spanish Atlas of Terrestrial Mammals mirror the road-kill patterns obtained from our own systematic road-kill surveys. We focused on the Mediterranean mesocarnivore guild due to its easy identification by citizens involved in atlas-data collection. We tested if the relative abundance of each species, their richness and diversity obtained from Atlas and our systematic surveys were related, using linear models, while controlling for human population and road density (potentially confounding effects). We further compared the patterns of species abundance obtained from both sources. Our results highlight that road-kill patterns do not mirror the Atlas patterns for the three metrics evaluated. This is probably due to survey biases in typical data from wildlife atlases. When analysing species individually, we found that some species are road-killed more (or less) than expected in relation to their abundance in atlas records. These results are probably due to species-specific ecological or behavioural traits such as species morphology or species behaviour when facing the road. We suggest that abundance from atlas data should not be used as a proxy for road-kill rates.

Introduction

Anthropic structures, such as roads, have several impacts on wildlife, including different kinds of disturbance, habitat loss and fragmentation (reviewed by Forman, 2003; Benítez-López et al., 2010; van der Ree et al., 2015). Road-kills are one of the most noticeable traffic impact for the public, because carcasses remain on the road visible to drivers (Hobday and Minstrell, 2008; Santos et al., 2011). Road-kills can have a considerable impact on population viability, causing population crashes in some species (Row et al., 2007; Beaudry et al., 2008; Roger et al., 2011). Furthermore, wildlife-vehicle collisions implying large species, such as ungulates or large carnivores, can compromise driver safety (Conover et al., 1995; Seiler, 2005). For all these reasons, road-kill is the most studied impact in road ecology (Forman, 2003; van der Ree et al., 2015; D'Amico et al., 2018; Pinto et al., 2020).

Typical road-kill surveys are performed by car, driving slowly along a given itinerary, implementing a certain survey periodicity (for example, daily or weekly), and recording any road-killed individual of the target species (e.g., Costa et al., 2015; Canal et al., 2019). This kind of survey is time consuming and usually implies relatively high economic costs (Costa et al., 2015). In order to reduce these costs, in the last decades several road ecologists investigated road-kill patterns using other sources of data, such as for example the data included into wildlife atlases.

A wildlife atlas is the result of a data-gathering effort on a certain taxon in a certain area (usually an administrative region). In an atlas, all occurrence records (from a variety of sources) of a species are compiled and structured in a geographical net (sometimes also providing information on seasonal presence, or even abundance and long-term population changes; see for example the Southern African Bird Atlas Project or the European Bird Census Council). Atlas have been used for studying demographic trends (Fuller et al., 1995; Telfer et al., 2002; Lee et al., 2017) and the factors behind these trends (Allan et al., 1997; Trzcinski et al., 1999; Gil-Tena et al., 2007; Pascual-Hortal and Saura, 2008). Other studies used atlas to assess changes in species distribution (Kouba et al., 2014), and species range projections for future scenarios (Virkkala et al., 2008; Morueta-Holme et al., 2010). The popularity of atlas as a source of data relies on their data-gathering nature, usually focused on a specific taxon in a certain region. However, this typical data collection for wildlife atlases usually implies a mixture of data sources (Ozolins and Pilats, 1995; Palomo et al., 2007), such as specific surveys carried out by professionals, contributions from expert knowledge, voluntary surveys, questionnaires to authorities of protected areas, bibliographic search, specimens from collections and museums, or citizen-science projects. Consequently, this variety of sources may imply low data quality and uneven sampling effort especially in case of specimens from museums, voluntary surveys or citizen-science projects (Crall et al., 2011). Furthermore, data from wildlife atlases are typically represented at a large scale and, for this reason, they should not be implemented for investigating patterns at a lesser scale, as downscaling may produce some errors, especially in poorly sampled regions (Böhning-

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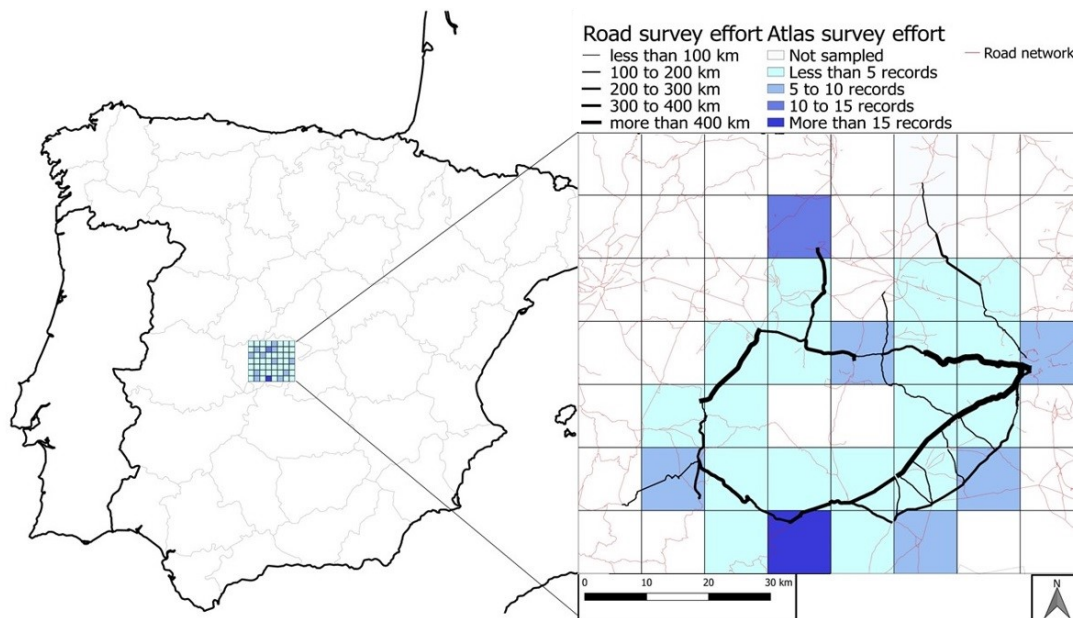
Figure 1 – Survey effort in the study area, both for the road-kill survey and the Atlas. Black lines thickness represents the number of kilometers surveyed in a particular road segment. The blue gradient in the UTM squares represent the number of Atlas records per square.

Gaese, 1997; Araujo et al., 2005). Nevertheless, this kind of data has been used for investigating road-kill patterns, both employing the occurrence of road-kills (Battisti et al., 2012) and developing road-kill risk models from atlas datasets (Visintin et al., 2016). Whereas some authors have found a positive association between species abundance and road-kills (e.g., Gehrt, 2002; D'Amico et al., 2018; Visintin et al., 2016; Canova and Balestrieri, 2019), this relationship seems to blur when abundance is based on atlas data (Battisti et al., 2012). As publicly available atlas data are being used, for example, by environmental consultants and stakeholders to select the least impacting alternative among those competing for the construction of a new road, we think the relationship between atlas data and field-based road-kill patterns deserves further exploration.

The aim of this study is to test if datasets from wildlife atlases are suitable for investigating road-kill patterns. Considering that both species occurrence and abundance have been described as some of the main drivers of road-kill risk (Gehrt, 2002; D'Amico et al., 2018; Visintin et al., 2016; Canova and Balestrieri, 2019), we tested if road-kills are representative of the wildlife community based on the atlas data for a given species guild. For this purpose, we compared the data accumulated until 2016 in the Spanish Atlas of Terrestrial Mammals (last edition; Palomo et al., 2007, then updated; henceforward Atlas) in an area of central Spain with our own road-kill survey. We selected carnivores as the study group because they are relatively more reported than other species in citizen-science platforms (Kosmala et al., 2016), and their medium-large carcasses are easier to detect and persist for longer times on the road than smaller ones (Barrientos et al., 2018). Also, this guild undergoes high road-kill rates in Mediterranean road networks (Grilo et al., 2009, 2015). We expect that road-kills are not representative of the wildlife community obtained from Atlas data (Battisti et al., 2012), mainly due to the intrinsic limitations of Atlas data regarding survey biases (Isaac et al., 2014; Vercayie and Herremans, 2015); but also due to the existence of species traits affecting differential road-kill risk among species (D'Amico et al., 2018; Jacobson et al., 2016). Consequently, we also expect that some species are road-killed above or below their occurrence in Atlas data.

Methods

Study area

We selected a homogeneous Mediterranean cropland mixed with abandoned fields where we could find a large and diverse carnivore guild, exposed to different road densities. The study area covers a total of 26 10×10 km UTM squares in the Tagus Valley, central Spain (Fig. 1). The altitude ranges between 350 m and 850 m above sea level, and the climate is Mediterranean with 340 mm of average annual rainfall, and average daily maximum temperatures between 27.1 °C (August) and 3.6 °C (December). Most of the surface is dedicated to dry crops (55%), including cereals and olive groves, but also fallow lands. Whereas 14% is occupied by irrigated lands, non-cultivated areas (dominated by xerophytic shrubs such as the broom *Retama sphaerocarpa* and the tussock grass *Stipa tenacissima*) cover 23% of the area. The remaining 8% is occupied by different land uses, including urban settlements. In terms of road infrastructure, secondary roads are the main type of road, with densities that range from 0.12 km to 0.74 km per km^2 (mean=0.4 km/km^2), a medium road density compared to the rest of Spain. We focused on secondary (i.e., regional) roads because they are the most representative road type in our study area (Barrientos and Bolonio, 2009).

The study area hosts a rich community of medium-sized carnivores, including most common species of the Mediterranean landscapes of Iberian Peninsula (e.g., Grilo et al., 2009; Soto and Palomares, 2015). This carnivore guild is composed by one canid (red fox *Vulpes vulpes*), one felid (European wildcat *Felis silvestris*), one viverrid (small-spotted genet *Genetta genetta*), one herpestid (Egyptian mongoose *Herpestes ichneumon*), and four mustelids (European badger *Meles meles*, Eurasian otter *Lutra lutra*, Stone marten *Martes foina* and European polecat *Mustela putorius*). As they have similar body masses, carcass detectability and persistence rates are expected to be homogeneous (Barrientos et al., 2018).

Data collection

The road-kill surveys were carried out between September 2014 and August 2016, by repeating exactly the same sampling schema carried in a previous work (Barrientos and Bolonio, 2009), in the framework of a long-term research project. We worked on the same 330 km-long road network during the two years, in which we carried out a total of 41 biweekly samplings (Barrientos and Bolonio, 2009). However, the distance covered in each survey was variable within those 330 km, and totalled ≈5300 km (Fig. 1). We drove at 40–50 km/h searching for carcasses on the road surface. Once a carcass was detected, we stopped the car to identify the species and locate it with a GPS device. This method has proven to be highly cost-effective for carnivore carcass detection, as the survey could be performed by just one researcher (Barrientos and Bolonio, 2009). Recorded carcasses were removed from the road in order to avoid re-sampling in successive surveys.

Table 1 – Carnivores' Abundance Model (in which we tested if the abundance in the Atlas is a potential predictor of the abundance of road-kills), Species richness model (in which we tested if the species richness in the Atlas is a potential predictor of the species richness of road-kills) and Species diversity model (in which we tested if the species diversity in the Atlas is a potential predictor of the species diversity of road-kills). Each model had Human and Road densities as additional predictors. Coefficient Estimates, Standard Error (SE), 95% Confidence interval (95% CI) and *p*-value (*p*) are provided; "Observations" represents the number of our 10×10 km study units.

Predictors	Abundance Model				Species richness Model				Species diversity Model			
	Estimates	SE	95% CI	*p*	Estimates	SE	95% CI	*p*	Estimates	SE	95% CI	*p*
Carnivores' Abundance in the Atlas	0.18	0.15	−0.13–0.49	0.235								
Carnivores' Species richness in the Atlas					0.02	0.02	−0.03–0.06	0.462				
Carnivores' Species diversity in the Atlas									0.01	0.01	−0.02–0.04	0.689
Human density	0.00	0.01	−0.02–0.02	0.716	0.00	0.00	−0.01–0.01	0.810	0.00	0.00	0.00–0.00	0.930
Road density	4.83	4.05	−3.58–13.23	0.247	0.93	1.55	−2.29–4.16	0.554	-0.63	0.38	−1.43–0.17	0.117
Observations	26				26				26			
R^2 / R adjusted	0.111/-0.111				0.029/-0.103				0.137/0.019			

We obtained species occurrence data from the database of the Spanish Society of Mammalogists (Sociedad Española para la Conservación y Estudio de Mamíferos, SECEM). The SECEM compiled this database with the aim of generating the Spanish Atlas of Terrestrial Mammals (last edition; Palomo et al., 2007), in collaboration with the Atlas of European Mammals (Mitchell-Jones et al., 1999). Data incorporated into the Atlas is a heterogenous set of sources (both systematic and opportunistic) which includes regional atlas, bibliographic data, museum collections, technical reports or information provided by local administrations, data from collaborators and citizen-science data, which is the only source of the constant updates carried from 2007 to date. We used the original database employed to draw the maps, not the maps themselves (based on presence/absence outputs). So, every occurrence (positive UTM cell) could be composed of more than one record, similar to a standard census.

Our study units were those UTM squares (26) in which we performed road-kill surveys (Fig. 1). We extracted all the Atlas data (any carnivore record of any kind since the beginning of the Atlas) from those squares and weighted both the atlas and the road-kill dataset to control for the sampling effort, in order to make them comparable. Namely, we divided the Atlas metrics (abundance of records, species richness and species diversity) of all carnivore species combined in every square by the total number of mammal records in that square. By controlling for sampling effort, we tried to mitigate one of the most important bias related to the Atlas data (Isaac et al., 2014; Vercayie and Herremans, 2015). Similarly, we divided the road-kill figures (road-kill abundance, species richness and species diversity) of all carnivore species combined in each square by the accumulated km surveyed in that square. Note that road-kill abundance by km is usually denominated *road-kill ratio*, but in this work we will keep it as *abundance*, in order to preserve the analogy between *abundance of road-killed carnivores* and *carnivores' abundance in the Atlas*.

We further collected information on *human density* (inhabitants per square) and *road density* (kilometres of roads per square) as these variables can influence data-gathering in citizen science projects as *human density* determines the potential number of collaborators and *road density* determines how accessible is the landscape for those potential collaborators (Geldmann et al., 2016). Finally, we confirmed that none of the final explanatory variables we used in our linear models were correlated by using the function `cor` in R (package `stats`).

Data analyses

We fitted three Linear Models (Tab. 1) using the `lm` function in R. In our first model, the response variable was the abundance of road-killed carnivores, and the explanatory variables were: carnivores' abundance in the Atlas, human density and road density. In our second model, the response variable was the species richness of road-killed carnivores, and the explanatory variables were: carnivores' species richness in the Atlas, human density and road density. In our third model, the response variable was the species diversity of road-killed carnivores (assessed with Shannon index), and the explanatory ones were: carnivores' species diversity in the Atlas, human density and road density.

As we expected that density-independent species traits (e.g., hunting behaviour, habitat selection, etc.) of some species may influence road-kill rates, we also analysed the differences in the observed proportion of road-kills compared to their expected occurrence from Atlas data with species-specific 2×2 chi-squares with the Yates correction. Statistical analyses were performed with R (R Core Team, 2017), and spatial analyses with Quantum GIS (Quantum GIS Development Team, 2018).

Results

In our 26 UTM study units, we found 146 carcasses during our two-year road-kill survey (Tab. 2): 29 foxes, 12 wildcats, 3 genets, 13 mongooses, 1 stone marten and 88 polecats, whereas no badgers or otters were found. On the other hand, the Atlas contained 119 records (Tab. 2): 24 foxes, 5 wildcats, 3 genets, 5 mongooses, 5 stone martens, 42 polecats, 3 badgers and 32 otters.

First, none of the explanatory variables used in the linear models were correlated. Most importantly, in the three Linear Models comparing road-kill survey data and Atlas data, we did not find any significant predictor (Tab. 1). However, we found hints of a negative relation between road density and the diversity of road-killed carnivores in our

Table 2 – Number and percentage of road-kills and Atlas record for each species. Chi-squared statistics are also shown (Chi-square value; χ^2 and *p*-value), with significant differences between road-kills and Atlas data for European otter and European polecat in gray.

Species	Road-kills		Atlas		χ^2	df	*p*
	%	n	%	n			
Stone marten (*Martes foina*)	0.68	1	4.20	5	2.25	1	0.13
European wildcat (*Felis silvestris*)	8.22	12	4.20	5	1.16	1	0.28
Small-spotted genet (*Genetta genetta*)	2.05	3	2.52	3	0.03	1	0.87
Egyptian mongoose (*Herpestes ichneumon*)	8.90	13	4.20	5	1.61	1	0.2
Eurasian otter (*Lutra lutra*)	0.00	0	26.89	32	42.16	1	<0.0001
European badger (*Meles meles*)	0.00	0	2.52	3	1.81	1	0.17
European polecat (*Mustela putorius*)	60.27	88	35.29	42	15.39	1	<0.0001
Red fox (*Vulpes vulpes*)	19.86	29	20.17	24	0.01	1	0.93

third model, which we further analysed with a correlation test between both variables (t=-1.89, df=24, *p*=0.07).

Species-specific comparisons showed that whereas some species are road-killed more than expected given the Atlas data, others are road-killed less than expected (Tab. 2). Namely, polecats were road-killed more often (25%) than expected from their abundance, whereas otters were road-killed less than expected. Foxes, wildcats, genets, mongooses, stone martens and badgers were road-killed on average to their occurrence in the Atlas records.

Discussion

The present findings suggest that road-kills were not representative of abundance, species richness and species diversity obtained from Atlas data. This is likely due to two factors: i) limitations of the Atlas data; ii) the fact that some species are intrinsically more (or less) prone to be road-killed than expected regarding their abundance.

In regard to wildlife-atlas data, Isaac et al. (2014) pointed out the potential of non-systematic data to swamp trends or to produce spurious patterns and described the types of biases inherent to citizen science data: (i) uneven recording intensity over time, (ii) unequal spatial coverage, (iii) heterogeneous sampling effort in every visit, and (iv) different detectability of the sampled species. Moreover, both the spatial and temporal scales of wildlife atlases may influence their suitability to be mirrored by road-kill patterns. Furthermore, Atlases spatial scale can affect how useful atlases are as conservation tools, as their scale could have a profound effect on model predictions based on them (Böhning-Gaese, 1997; Araujo et al., 2005) and could, therefore, affect conservation planning (Bombi et al., 2012). On the other hand, temporal scale is usually overlooked or poorly controlled, which could affect road-kill risk assessment, as wildlife populations are not static over the time (Delibes-Mateos et al., 2008; Carminatto et al., 2020; Gaüzère et al., 2020).

Factors mismatching road-kill probability with species occurrence are likely influenced by morphological, ecological, life-history or behavioural traits. For example, Mata et al. (2017) found that foxes, stone martens and genets usually used the road proximities during foraging, whereas badgers and wildcats tended to avoid roads. In this sense, we found a negative trend of road density on road-killed species diversity. This could suggest that when road-kill risk is low (i.e., lower road density), no species is particularly affected as they all have low road-kill rates. On the contrary, when such risk increases, more susceptible species are disproportionately road-killed (see Jacobson et al., 2016). However, further investigations are needed to confirm this pattern.

The most road-killed species, relative to its occurrence in the Atlas data, was the European polecat (Tab. 2). Polecats in the Iberian Peninsula are specialists in European rabbit (*Oryctolagus cuniculus*) hunting, with lagomorphs (mainly rabbits) forming up to 87% of consumed biomass in Mediterranean habitats (Santos et al., 2009). Polecat distribution overlaps with that of rabbits (Barrientos and Miranda, 2012; Santos et al., 2009), and rabbit abundance is the most important driver of polecat road mortality (Barrientos and Bolonio, 2009; Barrientos and Miranda, 2012), because this predator searches for rabbits breeding in road embankments. Thus, repeated visits to road embankments, together with its particular body morphology (poorly-adapted to run), could increase the road-kill rates of polecats (Barrientos and Bolonio, 2009).

The higher-than-expected road-kill rates of the polecat is a good example of how density-independent species traits (such as hunting behaviour) can affect road-kill risk of certain species and makes road-kills do not reflect atlas data. In this sense, the polecat could be classified as a non-responder in the framework that Jacobson et al. (2016) developed, as they do not recognize or detect the threat of a moving vehicle, regardless of traffic volume. Thus, species like the polecat may have their road-kill rates affected not only by their local abundance, but also by their behavioural response to roads and traffic. Moreover, polecats are especially elusive, and they may had been underdetected in the Atlas data, which would help to explain the deviation from road-kill figures.

On the other hand, otters were road-killed less than expected from Atlas data (Tab. 2). Otters are semi-aquatic carnivores that feed in and displace by water courses, only rarely leaving them (Quaglietta et al., 2012, 2013, 2014), so they are expected to be less impacted than terrestrial carnivores (e.g., Grilo et al., 2009). However, they are not safe from being road-killed; for instance, their risk increases when they cannot cross the road under bridges or culverts because of high river flows (Philcox et al., 1999; Guter et al., 2006). Nevertheless, we think that the differences we found are associated to important biases in Atlas data. Our study area is a dry (annual rainfall of only 340 mm) Mediterranean area where otters are likely associated to the few rivers that have water throughout the year. Nonetheless, otter presence is easily detected by searching for their scats in protruding stones or in bridge foundations when infrastructures cross the rivers. In fact, there is a standardized method to detect this species in Europe (i.e., searches in 600 meters long surveys; Jefferies, 1986; Manson and McDonald, 1986), which has been employed in up to three national surveys in Spain (Jiménez et al., 2008), which has been able to train many amateur samplers to detect otters. Moreover, the Atlas 10×10 km square scale is known to overestimate otter abundance (Sales-Luís et al., 2012). Otter case is a clear example of how citizen-science data biases, such those described by Isaac et al. (2014), can make this source unsuitable to investigate road-kill patterns.

The remaining species in our study underwent road-kills rates on average to their abundances in the Atlas data, although in some cases the number of occurrences was low to obtain sound patterns. Nevertheless, some of these remaining species are known to be affected differently by the road. For example, the stone martens are known to suffer more road-kills is sinuous road sections (Grilo et al., 2011), a road topology that is scarce in our study area (Barrientos and Bolonio, 2009). Furthermore, road impact on badgers depends on traffic volume, as high traffic loads may discourage them from attempting to cross major roads, causing barrier effects and intermediate traffic flows can road-kill to those who dare to cross (Clarke et al., 1998). Therefore, research using more occurrences in both road-kills and Atlas data would be necessary in order to better understand how good of a predictor for road-kill patterns the Atlas is for the whole carnivore guild.

Although it falls out of the scope of present study, it is worth mentioning that some authors have tried to correct the limitations of citizen science-based data mainly by means of three ways: (i) by validating the species distribution models (SDMs) obtained with citizen science data using conventional fieldwork. For example, Bradsworth et al. (2017) and Coxen et al. (2017), found that the generated SDMs predicted with great success the fieldwork data; (ii) with methodological improvements applicable to citizen-science projects such as properly training the data collectors or assessing the scope of the given citizen-science project (Conrad and Hilchey, 2011; Dickinson et al., 2012). And, finally, (iii) establishing new statistical approaches that allow a better use of citizen-science data, better controlling the lack of systematic sampling effort both in time and space (Bird et al., 2014; Isaac et al., 2014).

Conclusions

To summarize, our findings suggest that wildlife atlas data does not always mirror road-kill patterns, likely due to both biases in Atlas data (including uneven recording intensity and detectability) and to species-specific responses to roads (such as morphological, ecological, life-history or behavioural traits). This mismatch is important while considering if road-kill data can be used (or not) for monitoring, not just road-kill rates but also population trends in general, as there are now numerous projects starting or operating across the globe on road-kill monitoring (Schwartz et al., 2020). Therefore, it is key to separate road-kill data (abundance and occurrence) from data obtained from other projects with less bias. Thus, to study road-kill rates and patterns, we suggest that classical road-kill surveys should be the first option, however, as these are time-and budget-consuming, other sources of data could be used as well, but always using correcting approaches to citizen-science datasets and other non-systematic data sources. More-

over, species' ecology and traits should be considered if the study aims to determine species' specific road-kill patterns. ✍

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Associate Editor: M. Musiani