Area prioritization for insect pollinator communities on an Oceanic Island

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Conservation studies usually assess the effectiveness of protected areas and draft proposals on the inclusion of new areas to gain legal protection status, paying little attention to the unprotected surrounding matrix of the respective protected areas network. By combining species distribution modeling and a site selection method, we aim to quantify the contribution of different land uses to insect pollinator conservation on a small oceanic island i.e. Terceira Island (Azores, Portugal). Our results showed that, in addition to well preserved and protected native forest in Terceira, other land uses, such as naturalized vegetation areas, exotic forests, and semi-natural pastures, could serve as a continuum for the protected areas network. This result suggests that protecting marginal non-natural areas may also be important, especially when areas with well- preserved natural habitats are scarce. This spatial planning approach can be easily applied to other islands in the archipelago and any similar island systems, to better plan conservation efforts (such as habitat restoration) and to design specific buffer zones around a protected areas network.

Key words: Land-use planning, insect pollinator representation, spatial conservation planning, Zonation, species distribution modeling.

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INTRODUCTION

Spatial conservation planning methods have been strongly influenced by the Island Biogeography Theory (IBT) of MacArthur & Wilson (1967), which has played a pivotal role in the establishment of the concept of natural reserves (Triantis & Bhagwat 2011). IBT-based approaches usually make the assumption, which is often invalid, that reserves are isolated habitat islands embedded in a matrix of unfavorable terrain (Franklin & Lindenmayer 2009). Despite affording some insights into reserve network design, the guidelines provided by IBT offer little explicit guidance for decision-makers who face specific choices about how many and which sites or which spatial configuration have to be incorporated in a reserve network.

There is currently a broad consensus that managing the landscape matrix also matters, because standard reserve systems will never cover more than a small fraction of the globe; and human-induced habitats dominate most terrestrial ecosystems (Vitousek et al. 1997; Pereira & Daily

2006; Newbold et al. 2013). Therefore, proper conservation planning should take into consideration not only the human-perceived native habitat patches, but also the extensive areas that surround them (Franklin & Lindenmayer 2009). For this reason, reserve selection shifted its focus to systematic conservation planning framework developed to efficiently identify conservation areas, with its emphasis on quantitative targets, that guarantee species representation and persistence, the two most important conservation planning objectives (Margules & Pressey 2000; Moilanen et al. 2009; Fattorini et al. 2012). Representation refers to the targets defined to achieve the number of each species that should be contained within a system of conservation areas, and persistence refers to long-term survival of the species achieved by maintaining the ecological and evolutionary processes that sustain them (Carvalho et al. 2010; Margules & Pressey 2000). In the last decade, with the aim of promoting the persistence of biodiversity and other natural values (Pressey et al. 2007), reserve selection has advanced to spatial conservation prioritization (Kukkala & Moilanen 2013). This has been carried out with the application of statistical modeling techniques and numerical methods and also with the assistance of decision-making theory to inform the rational allocation of resources that are available for conservation planning (Moilanen et al. 2009). Biodiversity concerns have also to be incorporated into the policies and practices of sectors such as agriculture, tourism and transport that operate outside protected areas, rendering essential the development of conservation planning products that are accessible and useful for local decision-makers in land-use planning (Pierce et al. 2005; Primack 2006). Unprotected land or alternative land uses make different contributions to the conservation of biodiversity, and have different implementation and management costs (Wilson et al. 2010).

Among the most threatened ecosystems on Earth, oceanic islands are probably the places where the damage induced by the current global changes is most apparent (Whittaker & Fernández-Palacios 2007). Since human colonization, most oceanic islands have undergone a dramatic human mediated habitat changes and massive species introduction driven by the development of local agriculture and urbanization, the increase in seaborne world trade routes (for which oceanic islands form a strategic node) and recently by the growing popularity of oceanic islands as world-class tourist destinations (Walker & Bellingham 2011). Hence, there is an urgent need to improve the conservation of island ecosystems to better preserve their unique biota and the services that they may supply for human communities (Walker & Bellingham 2011). Several policy conservation action strategies have already been produced for islands, namely The CBD Global Island Partnership (GLISPA http://www.cbd.int/island/glispa.shtml; visited Nov 2 2016), the Samoa Pathway (see http://www.sids2014.org/samoapathway) and the BEST initiative (http://ec.europa.eu/environment/nature/biodiversity/best/index_en.htm), which mobilizes local stakeholders to identify priority areas for action and channels funding from different sources to research and conservation projects. However, little effort has been devoted specifically to island ecological networks, and in particular, to pollinating insects. Insects are responsible for 78 to 94% of pollination across all flowering plants and 75% of global food crops worldwide (Klein et al. 2007; Ollerton et al. 2011; Winfree et al. 2011). Therefore, maintaining the diversity of pollinators is of critical importance to preserve gene flow and community stability in plant communities (Steffan-Dewenter & Westphal 2008; Cranmer et al. 2012). Oceanic islands usually feature less complex networks with lower numbers of pollinator species, a high number of generalist species and less redundancy in comparison with continental settings (Olesen et al. 2002; Whittaker & Fernández-Palacios 2007). Hence, pollinator networks on oceanic islands have been considered highly vulnerable to any kind of disturbance (Traveset 2002), making them a priority target for future conservation planning on islands (Kaiser-Bunbury et al. 2017; Kaiser-Bunbury & Blüthgen 2015).

The Azorean archipelago, which was mostly covered by several types of semi-tropical evergreen forest (e.g. Laurisilva; *Juniperus* mountain woodlands) prior to human settlement, has suffered a massive land-use change since

human settlement 600 years ago, resulting in the destruction of native habitats and introduction of many exotic species (Borges et al. 2000, 2005a, 2013; Silva et al. 2008; Triantis et al. 2010; Gaspar et al. 2011). As a consequence, the region has already experienced a high number of species extinctions (Borges et al. 2000; Martín et al. 2008; Alcover et al. 2015; Terzopoulou et al. 2015) while recent estimations suggest that more than half of the extant forest arthropod species might eventually be driven to extinction in the near future (Triantis et al. 2010). However, previous studies have shown that some Azorean native and endemic arthropod species can persist and adapt in non-natural areas surrounding natural forest (Borges et al. 2000; Cardoso et al. 2008; Gaspar et al. 2011; Fattorini et al. 2012; Vergílio et al. 2016). Furthermore, Picanço et al. (2017) have demonstrated that Azorean endemic and native non-endemic insect pollinator species are widespread on the islands and are being able to occur in non-native habitats. This supports the idea that there might be an opportunity to avoid biodiversity loss of pollinating insect species not only through the preservation of Azorean native forest but also by implementing better management of anthropogenic areas (Borges et al. 2008; Jackson et al. 2009).

In this study, we use an extensive dataset of spatial distribution of pollinator insects on Terceira Island in the Azores (see also Picanço et al. 2017) in order to develop and apply a different spatial planning approach that explicitly accounts for the contribution of a diverse range of land uses to achieve conservation goals for the insect pollinator communities on the island.

MATERIAL AND METHODS

To identify high representation areas of insect pollinator communities, we followed two steps: (i) use of species distribution models (SDMs) to estimate the potential distribution of insect pollinator species; and (ii) identification of areas of high priority for conservation in different land uses besides the island's protected areas network, i.e. Terceira Island Natural Park. By combining SDMs and priority areas (PA) selection method, our goal is to contribute to an optimal island PA

design that promotes insect pollinator preservation and monitoring plans.

STUDY AREA

The Azores archipelago is located in the Central North Atlantic Ocean (37 - 40º N latitude, 25 – 31º W longitude), between Southern Europe (Portugal) and the east coast of North America. The Azores is a relatively recent archipelago comprising nine islands and several additional islets (França et al. 2005). At the time of human colonization, in the 15th century, the archipelago was almost totally covered by native forest consisting of *Laurisilva* forest i.e. a humid evergreen broadleaf laurel forest and other types of forest (e.g. mountain *Juniperus* woodlands) (see Elias el al. 2016). In 600 year human activities have led to the destruction of 95% of the original native forest (Gaspar et al. 2008) and presently, only seven out of the nine Azorean islands still have native forest fragments.

Our study was conducted on Terceira Island (Fig. 1). Terceira Island is the third largest island in the archipelago, after São Miguel and Pico with an area of 402 km^2 and with four main volcanic complexes (Cinco Picos, Guilherme Moniz, Pico Alto and Serra de Santa Bárbara). The Terceira climate is marked by heavy and regular precipitations, particularly in winter and autumn, often associated with strong winds. The average annual precipitation exceeds 3400 mm on "Serra de Santa Bárbara" summit (1023 meters), and reaches almost 1000 mm per year everywhere in the island. The average annual temperature varies between 9º C in "Serra de Santa Bárbara", to 17º C on the coast. Minimum temperature in winter varies between 4º and 12º C while the maximum summer temperature varies between 14º and 26º C (Azevedo et al. 2004). In Terceira, only five native forest fragments survived the severe deforestation, and now occupy less than 6% of the island surface (i.e. 23 km^2) (Gaspar et al. 2008). Even so, a few of these forest fragments still harbor a substantial number of endemic species and were considered priority areas for biodiversity conservation in the Azores (Borges et al. 2005b; Gaspar et al. 2011; Fattorini et al. 2012). They are now included in a recently created protected area – the Terceira Island Natural Park (INP). Terceira INP (Fig. 1) is

formed by 20 components including three nature reserves, two natural monuments, seven PAs for habitat/ species management, one protected landscape and seven PAs for resource management. The INP is regulated by Regional Legislative Decree no. 11/2011/A of 20th April,

which applies a new juridical regime that classifies, manages and administrates the protected areas of Azores, according to the International Union for Conservation of Nature (IUCN) management categories system.
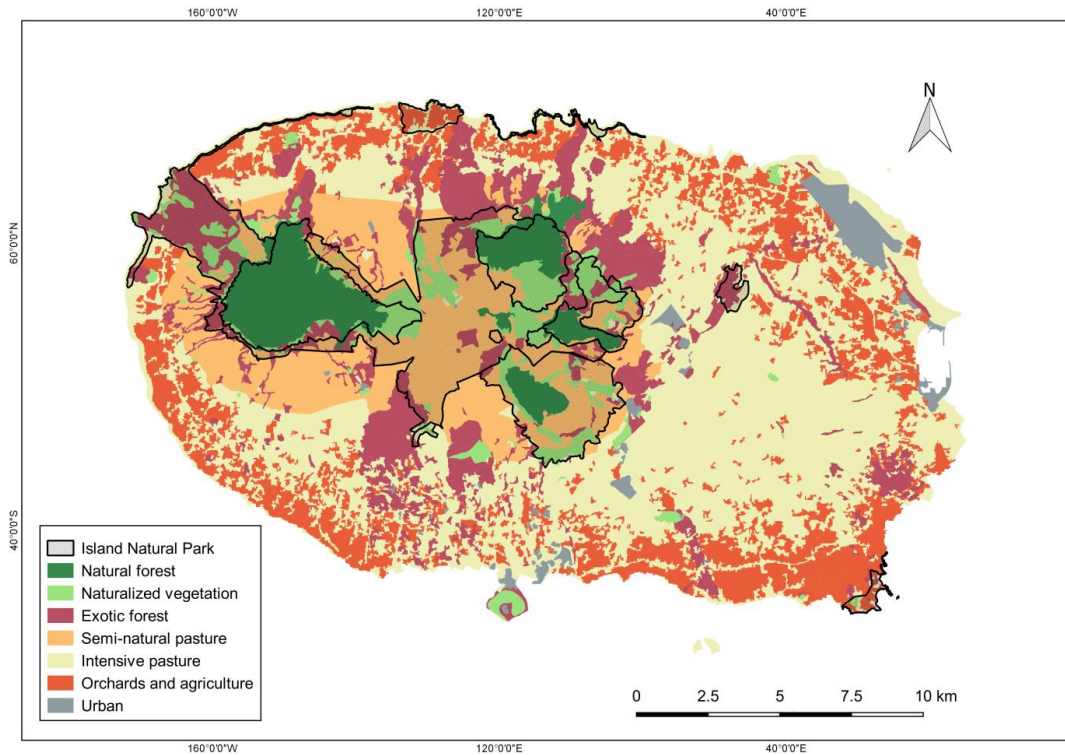

Fig. 1. Terceira Island with respective land-use distribution, including the island protected areas network – Terceira Island Natural Park.

SPECIES DATA

Distribution data from insect pollinator species were collected from June to September 2013 and from July to October 2014 in five distinct land uses covering a large percentage of the total island area, from the least to the most disturbed: natural forests mainly characterized by *Juniperus-Ilex* montane forests and *Juniperus* woodlands; naturalized vegetation areas formed by exotic and native species; exotic forests with *Criptomeria japonica* and *Eucalyptus* sp.; semi-natural pastures with *Lotus* sp., *Holcus* sp. and *Rumex* sp.; and intensively managed pastures with

Lolium spp. and *Trifolium* spp.. In each land-use, 10 sites were sampled making a total of 50 transects located across the entire island. Within each land-use, sites were selected to maximize environmental diversity following the method developed by Jiménez- Valverde and Lobo (2004) and Aranda et al. (2011) (for more details see Picanço et al. 2017). In each site, a 10 meter linear transect with 1 meter width was established (Pollard & Yates 1993) and transect surveys were carried out for 180 minutes once per year and repeated in the following year in a randomized order. Each flower along every 10 m transect was

surveyed for 4 minutes to guarantee effective contact of the insect; therefore, only insects probing for nectar or eating/collecting pollen (foraging) were recorded. Each record includes information on location precision usually UTM point (Universal Transverse Mercator coordinate system) data. The specimens collected were identified to species-level but when species-level identification could not be resolved, individuals were identified to the lowest taxonomic unit possible and classified as morphospecies. All species were classified as indigenous or exotic species. Indigenous species may be endemic (i.e. found only in the Azores) or native non- endemic (i.e. species that colonized the Azores by natural long-distance dispersal mechanisms). Exotic species are those whose original distribution range did not include the Azores and are believed to have arrived as a consequence of human activities; these species often have a cosmopolitan distribution (see Borges et al. 2010). A total of 54 species/morphospecies belonging to Coleoptera, Hymenoptera, Lepidoptera, Syrphidae and other Diptera were collected (Picanço et al. 2017). Hoverflies (Syrphidae) were studied separately, due to the great importance of these dipteran insects for pollination (Jauker & Wolthers 2008; Rader et al. 2015) and relatively high number of species observed. In the present study, we selected only species identified to species-level, totaling around 461 records of 45 species (Appendix I). The 45 species comprise three beetle species (Coleoptera), 10 bees and wasps (Hymenoptera), five butterflies and moths (Lepidoptera), 12 hoverflies (Diptera, Syrphidae) and 15 other flies (Diptera). These species include: (i) Azorean endemics occurring on Terceira Island (four species); (ii) native but non-endemic species (34 species); and (iii) exotic species (seven species), according to Borges et al. (2010).

S<small>PECIES DISTRIBUTION MODELING</small>
For the following analysis, we used only incidence data (i.e. presence/absence data). We modeled the potential distribution of the 45 insect species (Appendix I) using Maximum Entropy modeling implemented in the software MaxEnt version 3.3.3

(http://www.cs.princeton.edu/~schapire/maxent). MaxEnt has been identified as one of the most accurate methods for species niche modeling since it combines ease of use with proven predictive ability (Moilanen et al. 2009). The method combines data of species incidence (presence-only data) with environmental grid data to estimate the probability of distribution of a species, subjected to the set of constraints provided by environmental characteristics of grid cells where the species has been recorded (Phillips et al. 2004, 2006; Elith et al. 2006). The environmental variables selected for the SDM procedure were the following: annual averages for maximum annual temperature (tmax), minimum annual temperature (tmin), annual range of temperature (trange), minimum annual humidity (rhmin), maximum annual humidity (rhmax), annual range of humidity (rhrange), maximum annual precipipation (ppmax), minimum annual precipitation (ppmin), and annual range of precipitation (pprange). These variables were obtained from the CIELO model for the Azores (Azevedo 1999), which models local scale climate variables. The geographical variables selected altimetry and land-use were based on maps provided by Cardoso et al. (2009; 2013) and the Azorean Government agencies (DROTRH 2008), respectively. For all models, MaxEnt algorithm was used with default settings to randomly select 20% points of occurrence records for testing, with the remaining 80% for training (Philips et al. 2006). The models were tested with receiver operating characteristics (ROC), which plot the true-positive rate against the false-positive rate and with the average area under the curve (AUC) of the ROC plot as a measure of the overall fit for each model. In this context, the AUC could also serve as an index of habitat suitability ranging between 0 (highly unsuitable) and 1 (highly suitable) and it displays the probability that a randomly chosen presence site will be ranked above a randomly chosen absence site (Phillips et al. 2006). Models with AUC values above 0.7 were considered potentially useful (Pearce & Ferrier 2000; Elith 2002; Carvalho et al. 2010).

CONTRIBUTION OF EACH LAND-USE AND INP TO
AREA PRIORITIZATION

The software for spatial conservation prioritization, ZONATION v4.0 (Moilanen et al. 2014), which is based on a more recent and sophisticated heuristic algorithm (Moilanen 2007; Moilanen et al. 2005), was used to identify priority areas for insect pollinator communities conservation. The Zonation algorithm produces a hierarchical prioritization of the landscape, by ranking cells on a scale from 0 to 1, starting from the selection of the whole planning region, and iteratively removing the area that causes the smallest marginal loss of conservation value, leaving the highest ranked with the highest conservation value (Moilanen, Wilson & Possingham 2009). Because Zonation does not aim to achieve specific representation targets, this process is repeated for every area, thus producing a hierarchy of conservation priorities for the entire landscape. The critical part of the algorithm is the definition of marginal loss (called the cell-removal rule), which also allows species weighting and species-specific connectivity considerations to be applied. The probability of a species' presence in each cell is obtained from the MaxEnt models and total representation for each species is the sum of all the probabilities. Different cell-removal rules can be applied to emphasize different objectives. To perform the analysis, the Core-area Zonation function was applied as a removal rule for the retention of high-quality core areas (Moilanen 2007) of different land-use (natural forest, naturalized vegetation areas, exotic forest, semi-natural pasture, intensive pasture) and INP, for all species and for each one of the five taxonomic groups: Coleoptera, Hymenoptera, Lepidoptera, Syrphidae and other Diptera species. The option "edge removal" was selected to generate spatial aggregation into the solution. The warp factor (i.e., the number of cells removed at each iteration) and the boundary length penalty strength were defined as 1 and 0.01, respectively (Moilanen et al. 2014). All species were weighted equally. With this analysis, we calculated: (1) the ranking of priority areas, (2) percentages of land-use area covered by each different taxonomic group and total set of insects, both inside and outside INP, (3) the percentage of INP area covered by each different taxonomic group and total set of insects and (4) and average of species presence probability in each land-use for each different taxonomic group and total set of insects. For this latter result, we applied Kruskal-Wallis following by post-hoc Dunn tests to test for significant differences between land uses.

RESULTS

SPECIES DISTRIBUTION MODELS

SDMs were performed for 45 species represented by 461 records (Appendix I). The most important variables that contribute to over 30% of the selected insect pollinators were land-use, annual ppmin, annual rhrange and annual trange. AUC values for test data varied between 0.517 (the hoverfly *Eristalis arbustorum*) and 0.945 (the moth *Tebenna micalis*) (Table 1). Only three species – *Ancistrocerus parietum*, *Colias croceus* and *Eristalis arbustorum*, from Hymenoptera, Lepidoptera and Syrphidae taxonomic groups, respectively, had AUC values lower than 0.7 (Table 1). These species were not used in further analyses since SDMs presented both lower AUC values and a small number of records.

Table 1. Species included in the SDMs analyses for modeling, AUC values of training and test data.

	Test data AUC	Training data AUC
Coleoptera		
Anaspis proteus	0.822	0.906
Meligethes aeneus	0.764	0.818
Stilbus testaceus	0.705	0.936
Hymenoptera		
Ancistrocerus parietum	0.631	0.679
Apis mellifera	0.733	0.843
Bombus ruderatus	0.774	0.833
Chrysis ignita ignite	0.755	0.929
Lasioglossum morio	0.808	0.848
Lasioglossum smeathemanellum	0.784	0.976
Lasioglossum villosulum	0.752	0.826
Lasius grandis	0.839	0.856
Megachile centuncularis	0.754	0.929
Vespula germanica	0.824	0.834
Lepidoptera		
Agrius convolvuli	0.786	0.845
Colias croceus	0.529	0.599
Hipparchia azorina azorina	0.921	0.983
Pieris brassicae azorensis	0.789	0.779
Tebenna micalis	0.945	0.963
Syrphidae, Diptera		
Episyrphus balteatus	0.839	0.846
Eristalis arbustorum	0.517	0.579
Eristalis tenax	0.709	0.732
Eupeodes corolla	0.796	0.840
Meliscaeva auricollis	0.773	0.849
Myathropa florea	0.717	0.755
Sphaerophoria nigra	0.837	0.894
Sphaerophoria scripta	0.819	0.824
Syritta pipiens	0.753	0.793
Xanthandrus azorensis	0.850	0.887
Xanthandrus comtus	0.910	0.947
Xylota segnis	0.850	0.897

Other Diptera		
Adia cinerella	0.868	0.898
Calliphora vicina	0.746	0.860
Fucellia tergina	0.925	0.993
Lucilia sericata	0.847	0.849
Megaselia rufipes	0.778	0.823
Paregle audacula	0.703	0.717
Rhinia apicalis	0.840	0.846
Scathophaga litorea	0.761	0.888
Scathophaga stercoraria	0.711	0.801
Sepsis biflexuosa	0.795	0.875
Sepsis lateralis	0.870	0.894
Sepsis neocynipsea	0.763	0.813
Sepsis thoracica	0.824	0.881
Stomorhina lunata	0.828	0.832

CONTRIBUTION OF EACH LAND-USE AND INP TO AREA PRIORITIZATION

Natural forests, naturalized vegetation areas, exotic forests and semi-natural pastures currently cover more than 50% of the cells corresponding to Terceira Island, with highest rank (last quartile: 0,75-1), for the beetles (Coleoptera), hoverflies (Syrphidae) and total set of species (Fig. 2 (a), (b), (e); Appendix II). These results are confirmed by the high probability mean incidence values and relatively high percentage of land-use area covered by these three groups of insects (Fig. 3; Fig. 5 All insects, Coleoptera, Syrphidae).

Hymenoptera (Fig. 2 (c)) and Lepidoptera (Fig. 2 (d)) species had above 40% of highly ranked areas (in the last quartile) covered by land use areas (Appendix II). With no corresponding high percentage area in naturalized vegetation areas, exotic forest and semi-natural pastures (Fig.3), and low values of probability mean incidence in natural forest and naturalized vegetation areas for Hymenoptera in comparison to Lepidoptera (Fig. 5 Hymenoptera, Lepidoptera).

Other Diptera species were the group with the lowest percentage of highly ranked areas (lower than 32.2% in the last quartile) covered by each different land-use (Fig. 2 (f); Appendix II), and corresponding low percentage of overall land-use areas covered. Within the low percentage of high ranked areas, intensive pastures, and agriculture and orchards areas had 27 and 32, respectively (Fig. 3; Appendix II). This latter result is opposed to the relatively high probability mean incidence values for natural forest, naturalized vegetation and orchards and agriculture areas (Fig. 5 Other Diptera).

The results of the Kruskal–Wallis test are significant (H = 38290, d.f.= 7, P < 0.001) and all pairwise differences between land uses are also significant (post-hoc Dunn tests P < 0.05) for all species groupings. The mean ranks of probability of incidence per insect species groups (Coleoptera, Hymenoptera, Lepidoptera, Syrphidae and other Diptera) and per all insects group are significantly different among the land uses. Terceira INP's current area covers about 39% of the cells, with the highest rank (in the last quartile: 0.75–1) for the total set of pollinating insects, beetles (Coleoptera) and hoverflies (Diptera, Syrphidae) (Fig. 2 (a), (b), (e); Appendix II). Lepidoptera was the taxonomic group with the largest number of highly ranked areas (about 69.2% in the last quartile; Fig. 2 (d); Appendix II) and high percentage (84%) covered by current overall INP area (Fig. 4).
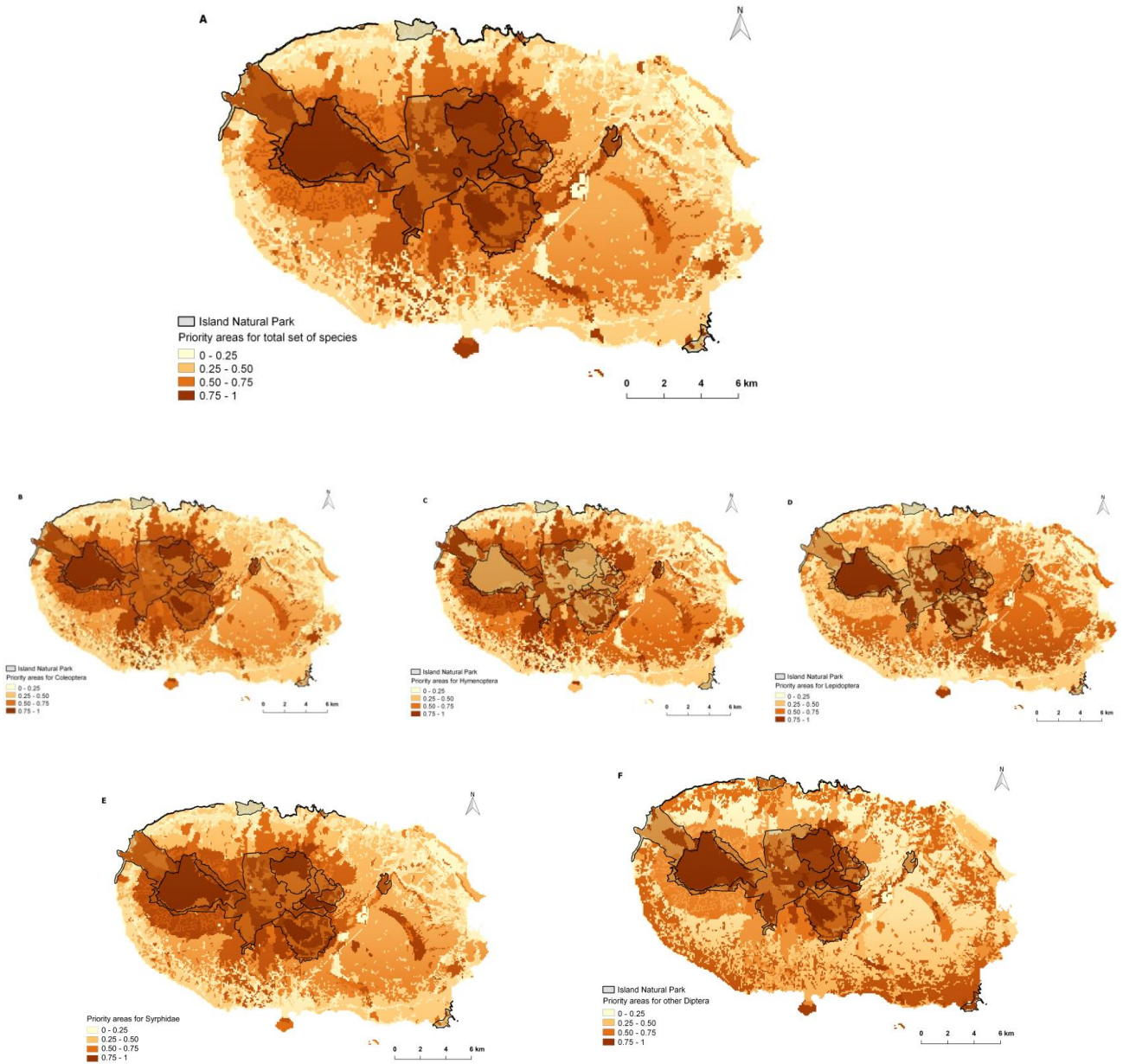
Figure 2. Ranking of priority areas for insect pollinators using zonation software: (A) all species, (B) Coleoptera, (C) Hymenoptera, (D) Lepidoptera, (E) Syrphidae, and (F) other Diptera.

Fig. 3. Percentage of land-use area - natural forest (Natfor), naturalized vegetation areas (Natveg), exotic forest (Exofor), semi-natural pasture (Semipast), intensively managed pasture (Intpast), agriculture/orchard areas (Orchards) and urban/industrial areas (Urban) - covered by each taxonomic group and all insect pollinators.

Fig. 4. Percentage of area inside and outside Terceira Island Natural Park (INP) covered by each taxonomic group and all insect pollinators.

Fig. 5. Probability or predictive mean of species' occurrence (values range: 0, absent - 1, very high probability) from Zonation software and standard deviation of each taxonomic group and all insect pollinators: (a) all species, (b) Coleoptera, (c) Hymenoptera, (d) Lepidoptera, (e) Syrphidae, and (f) other Diptera, in dif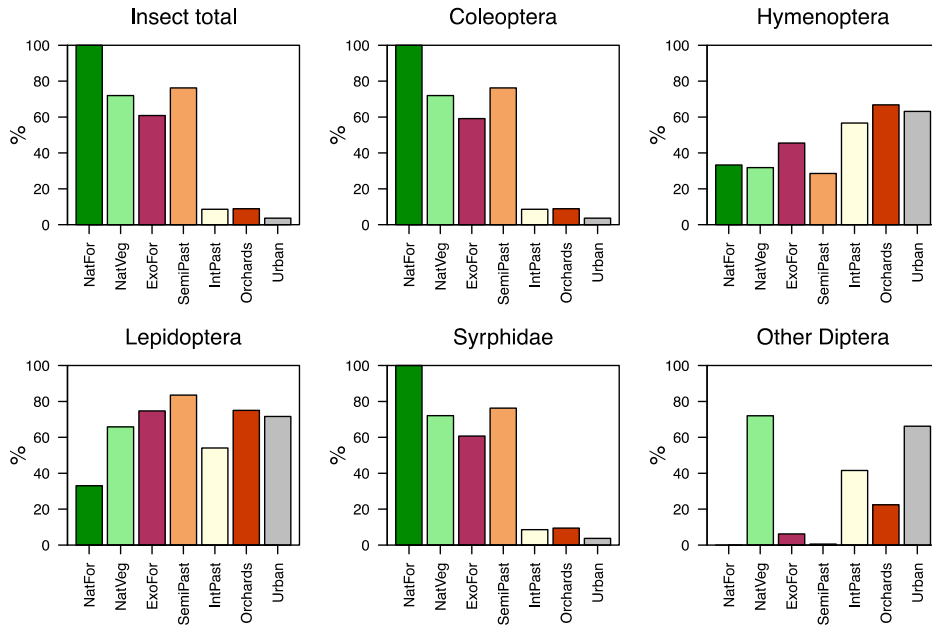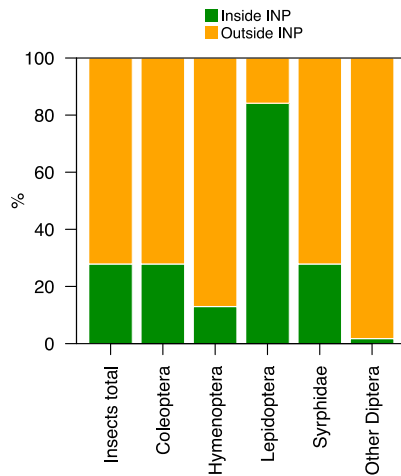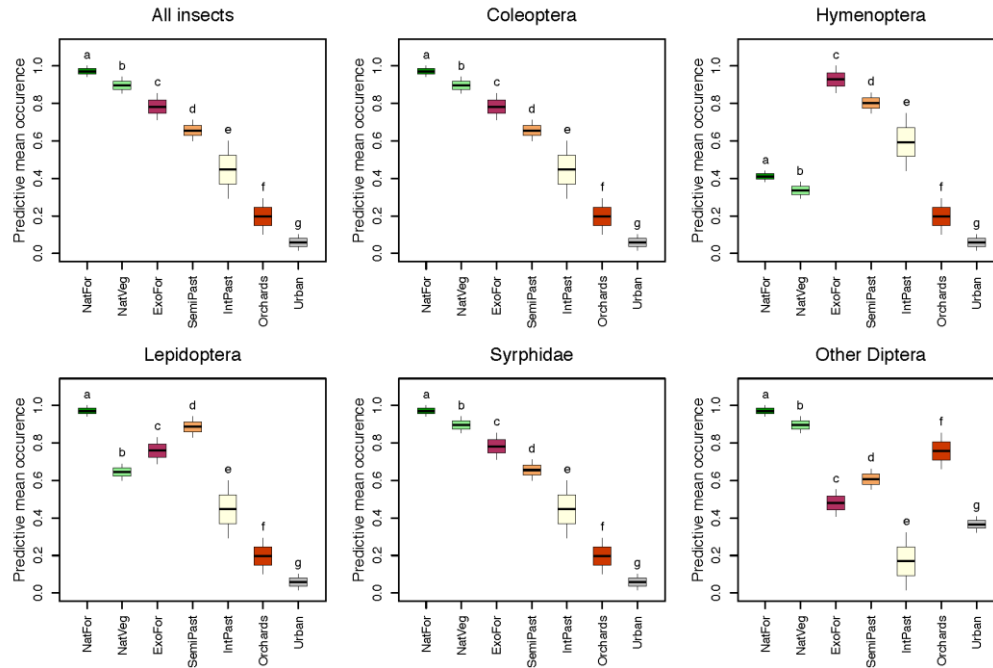ferent land uses: natural forest (Natfor), naturalized vegetation areas (Natveg), exotic forest (Exofor), semi-natural pasture (Semipast), intensively managed pasture (Intpast), agriculture/orchard areas (Orchards) and urban/industrial areas (Urban)

DISCUSSION

This study first combined standardized data covering a large fraction of the area of an oceanic island and species distribution modeling to overcome the Wallacean shortfall (i.e. distribution of described species is mostly unknown) and fulfil one of the two most important conservation planning objectives, which is species representation in protected areas i.e. the proportion of known species in a region that occur in protected areas. In this context, SDM approaches have proved to be particularity useful since obtaining reliable and fine-scale distribution data for arthropods species is costly (Cardoso et al. 2011). Our SDM analyses implemented with the MaxEnt program provided robust predictions of occurrences for nearly all selected species with an AUC value above 0.7. Second species persistence (Araújo & Williams 2000, Cabeza & Moilanen 2001, Cowling et al. 1999, Pressey et al. 2007) was estimated by using the information obtained from SDMs in the Zonation software as a decision support tool (Lehtomaki & Moilanen 2013). Note that in our study, we did not integrate any socio-economic scenarios, due to the lack of

information.

Our results show similar patterns for beetles, hoverflies and total insect species groups for the different land uses (natural forest, naturalized vegetation, exotic forest and semi-natural pasture) and INP area covered (Fig. 2 (a), (b), (e); Fig. 3; Fig. 4), and values of mean probability of occurrence (Fig. 5). The beetles and hoverflies seem to act as key groups in area prioritization patterns, which were obtained by the Core-area Zonation function and subsequently reflected in total set of insects group. Interestingly, for beetles the probability mean of occurrence decreases with land-use intensification (Fig. 5b), which is in accordance with previous results for other taxa on Azores (Cardoso et al. 2009). On the contrary, for Hymenoptera and Lepidoptera species, the high ranked areas with high percentage were identified in overall land uses, for some of which it is difficult to apply conservation efforts, like intensive pasture, agricultural and urban areas (Fig. 2 (c), (d)). The high widespread distribution of bees, butterflies and moths relative to other insect pollinators can be due to a larger range of food resources, habitat availability, beekeeping activity, and also large foraging area (Valido & Olesen 2010) or to moderate human land–use intensification, where pollinator responses can be variable and sometimes positive (Winfree 2013).

For a high representation of species or high ranking areas, all native fragments of natural forests are included in the PA optimal solutions for all groups, except other Diptera. Borges et al. (2005b) and Gaspar et al. (2011) found similar results, where all fragments are included in the optimal solutions for 80% of abundance target representation of species.

For other Diptera species, the high ranked areas had a relatively low percentage (above 32%), which reflects the low importance for conservation of the overall land-use areas for this group (Fig. 2 (f)), probably due to its high adaptability and dispersal ability. Nevertheless, other Diptera had its highest representativeness in naturalized vegetation areas (Fig. 3). Hence, the group had a low percentage of area covered in native forests and inside INP (Fig. 4). This can be the case reported by Gaspar et al. (2011) for some arthropod species with high dispersal ability, but with minimum solution sets of PA, possibly due to unsuccessful establishment of possible populations in these forests.

The central zone of the island, where PAs identified by Zonation are located, generally corresponded to natural forest areas, and overlapped most PAs classified in INP (see Fig. 1 and Fig. 2). The high ranked areas identified outside INP, located in the north and south of the island are naturalized vegetation areas, exotic forest and semi-natural pastures that are partially included in INP and extend to the urban areas in the island coastal zones. These areas include Monte Brasil peninsula which corresponds to a naturalized vegetation area intertwined with exotic forest (see Fig. 1 and Fig. 2) that was also identified by Fattorini et al. (2012) as an important area. Although this high representation of pollinating insect species may be difficult to implement, these areas can potentially harbor numerous species, increasing the value of those areas for conservation and as a target for the restoration of the Azorean native forest (Kaiser-Bunbury et al. 2017). Even without legal protection, these areas can have a positive impact to the PA (Wilson et al. 2010). With this purpose, projects are under way, managed by Direcção Regional dos Recursos Florestais (DRRF) in some exotic forest areas, where *Criptomeria* sp. and *Eucalyptus* sp. plantations are being replaced by endemic/native plant species *Juniperus brevifolia*, *Ilex azorica*, *Prunnus azorica*, *Laurus azorica*, *Viburnum treleasei* (Engineer C. Meneses, pers. comm., June 6, 2016). This active measure is advantageous to promote conservation of native species, and possibly retain and/or decrease invasive species development, which endangers the INP PA purpose. Therefore, we cannot consider only PAs, but also the areas that might contribute to vast conservation goals, for example, application of environmental-friendly techniques into agricultural and orchard areas for pollinator species conservation.

The implementation of priority areas (PAs) are usually constrained to the existing reserve systems (Pressey 2004), because the addition of other land-uses is too financially constrained to take them into consideration for conservation (Ferrier et al. 2000). However, additionally to the well-preserved and protected native forest of Terceira, other habitats, such as naturalized vegetation areas, exotic forests, and semi-natural pastures, could serve as a continuum for the protected areas, with the possibility of creating some corridors between native forest areas. Therefore, our results suggest that protecting marginal non-natural areas may also be important, especially in

reserve systems when areas with well-preserved natural habitats are scarce.

In conclusion our study shows that (i) similar patterns of core-area zones are defined by Zonation for beetles (Coleoptera) and Syrphidae (Diptera), and that patterns for these two insect pollinator groups are again projected in the total set of insect species, which can imply that these can act as key groups for selection of areas for prioritization; and (ii) highly ranked areas for prioritization adjacent to already official priority areas are identified in naturalized vegetation areas, exotic forests and semi-natural pastures, making these potential areas ideal to create a buffer zone or corridors to maintain and preserve pollinating insect species. These outcomes indicate that the conservation of insect pollinating species will imply the combination of the management of existing PAs and the additional sustainable use of the surrounding matrix, taking into account pollinators ecological interactions established in the different Azorean land uses. Based on our study and other similar research performed in the Azores (e.g. Borges et al. 2000, 2005b, Gaspar et al. 2011; Fattorini et al. 2012; Cardoso et al. 2013), we call for the implementation of a more integrative approach in future conservation planning on Terceira Island. Finally, we also believe that the approach introduced in the present study can be easily applied to other islands in the archipelago and any similar island systems, to improve conservation planning (such as habitat restoration) and to design specific buffer zones around protected area networks.

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APPENDICES

Appendix I. Geographical coordinates of insect species records on Terceira Island with respective taxonomic information and colonization status.

Order	Family	Species	Status	Longitude, Latitude
Coleoptera	Nitidulidae	*Meligethes aeneus*	exotic	492915, 4284493; 475715, 4289193; 474515, 4291693; 472615, 4289593; 474615, 4288393; 475015, 4289093; 490615, 4282693
	Phalacridae	*Stilbus testaceus*	native	492915, 4284493; 470315, 4287093; 471515, 4288993; 474615, 4288393
	Scraptiidae	*Anaspis proteus*	native	478815, 4280793; 480915, 4284393; 472615, 4289593; 482015, 4289793; 471515, 4288993; 473915, 4287893; 481715, 4291093; 482015, 4287593; 474615, 4288393; 475415, 4287693; 485415, 4286193; 494115, 4288395; 475015, 4289093; 470115, 4288693
Diptera	Anthomyiidae	*Adia cinerella*	native	469715, 4290793; 470315, 4285993
		Fucellia tergina	native	478815, 4280793; 475415, 4293193
		Paregle audacula	native	477115, 4283293; 470315, 4287093; 490215, 4280293; 474515, 4291693; 486215, 4289493; 485815, 4282693; 472615, 4289593; 482015, 4289793; 479015, 4285993; 485415, 4286193; 483015, 4283593
	Calliphoridae	*Calliphora vicina*	exotic	483915, 4290293; 478815, 4280793; 478915, 4290093; 471515, 4288993; 481715, 4291093; 494115, 4288395; 483415, 4293493; 470915, 4289693; 487415, 4277793; 470315, 4285993
		Lucilia sericata	exotic	492915, 4284493; 477115, 4283293; 475415, 4293193; 483415, 4293493; 476415, 4289493
		Rhinia apicalis	native	485815, 4282693; 472215, 4287993; 469715, 4290793; 482815, 4285893; 483415, 4293493; 487415, 4277793; 490615, 4282693; 470115, 4288693; 479115, 4285493; 476415, 4289493
		Stomorhina lunata	native	475715, 4289193; 478815, 4280793; 478915, 4290093; 485515, 4289493; 490215, 4280293; 474515, 4291693; 475415, 4293193; 485815, 4282693; 482015, 4289793; 471515, 4288993; 481715, 4291093; 474615, 4288393; 475415, 4287693; 469715, 4290793; 479015, 4285993; 48541, 4286193; 483415, 4293493; 470915, 4289693; 487415, 4277793; 470115, 4288693; 473015, 4284293; 470315, 4285993; 479115, 4285493
	Phoridae	*Megaselia rufipes*	exotic	487415, 4291893; 485815, 4282693; 482015, 4289793; 470115, 4288693; 470315, 4285993; 483015, 4283593
	Scathophagidae	*Scathophaga litorea*	native	484315, 4288993; 480915, 4284393; 472615, 4289593; 472215, 4287993; 474615, 4288393; 479015, 4285993; 494115, 4288395; 470315, 4285993; 479115, 4285493
		Scathophaga stercoraria	native	478915, 4290093; 477115, 4283293; 470315, 4287093; 485515, 4289493; 475415, 4281293; 488115, 4287193; 487415, 4291893; 490215, 4280293; 475415, 4293193; 486215, 4289493; 480915, 4284393; 472215, 4287993; 481715, 4291093; 474615, 4288393; 487415, 4277793; 475015, 4289093; 489915, 4285393; 473015, 4284293; 476415, 4289493; 483015, 4283593
	Sepsidae	*Sepsis biflexuosa*	native	478815, 4280793; 484315, 4288993; 485515, 4289493; 472615, 4289593; 479015, 4285993
		Sepsis lateralis	native	478815, 4280793; 472615, 4289593; 472215, 4287993; 479015, 4285993; 494115, 4288395

		Sepsis neocynipsea	native	492915, 4284493; 475715, 4289193; 472415, 4292593; 478915, 4290093; 470315, 4287093; 485515, 4289493; 487415, 4291893; 490215, 4280293; 474515, 4291693; 492115, 4286893; 475415; 4293193; 485815, 4282693; 480915, 4284393; 472615, 4289593; 472215, 4287993; 482015, 4289793; 471515, 4288993; 473915, 4287893; 481715, 4291093; 482015, 4287593; 474615, 4288393; 475415, 4287693; 469715, 4290793; 479015, 4285993; 482815, 4285893; 485415, 4286193; 494115, 4288395; 470915, 4289693; 475015, 4289093; 481815, 4285993; 490615, 4282693; 489915, 4285393; 470115, 4288693; 473015, 4284293; 470315, 4285993; 479115, 4285493; 476415, 4289493
		Sepsis thoracica	native	490215, 4280293; 492115, 4286893; 472215, 4287993; 475415, 4287693
	Syrphidea	*Episyrphus balteatus*	native	492915, 4284493; 475715, 4289193; 478815, 4280793; 484315, 4288993; 478915, 4290093; 477115, 4283293; 470315, 4287093; 485515, 4289493; 487415, 4291893; 490215, 4280293; 475415, 4293193; 472615, 4289593; 472215, 4287993; 482015, 4289793; 471515, 4288993; 473915, 4287893; 481715, 4291093; 482015, 4287593; 474615, 4288393; 475415, 4287693; 469715, 4290793; 479015, 4285993; 482815, 4285893; 494115, 4288395; 470915, 4289693; 481215, 4287293; 475015, 4289093; 470115, 4288693; 473015, 4284293; 479115, 4285493
		Eristalis arbustorum	native	492915, 4284493; 486215, 4289493; 474615, 4288393; 494115, 4288395; 476415, 4289493
		Eristalis tenax	native	492915, 4284493; 483915, 4290293; 490215, 4280293; 475415, 4293193; 482015, 4287593; 474615, 4288393; 475415, 4287693; 494115, 4288395; 473015, 4284293
		Eupeodes corollae	native	492915, 4284493; 483915, 4290293; 475715, 4289193; 472415, 4292593; 475415, 4281293; 473515, 4283393; 475415, 4293193; 486215, 4289493; 485815, 4282693; 480915, 4284393; 472215, 4287993; 482015, 4289793; 471515, 4288993; 481715, 4291093; 482015, 4287593; 474615, 4288393; 475415, 4287693; 482815, 4285893; 494115, 4288395; 483415, 4293493; 470915, 4289693; 481215, 4287293; 487415, 4277793; 475015, 4289093; 481815, 4285993; 490615, 4282693; 470315, 4285993
		Meliscaeva auricollis	native	492115, 4286893; 475415, 4293193; 472215, 4287993; 475415, 4287693; 469715, 4290793
		Myathropa florea	native	492915, 4284493; 475415, 4293193; 480915, 4284393; 482015, 4287593; 474615, 4288393; 469715, 4290793; 487415, 4277793; 470115, 4288693
		Sphaerophoria nigra	endemic	485515, 4289493; 482015, 4287593; 474615, 4288393; 481215, 4287293
		Sphaerophoria scripta	native	478815, 4280793; 484315, 4288993; 477115, 4283293; 487415, 4291893; 490215, 4280293; 475415, 4293193; 469715, 4290793; 481215, 4287293
		Syritta pipiens	native	492915, 4284493; 483915, 4290293; 472415, 4292593; 478915, 4290093; 470315, 4287093; 485515, 4289493; 490215, 4280293; 474515, 4291693; 492115, 4286893; 475415, 4293193; 480915, 4284393; 472615, 4289593; 482815, 4285893; 494115, 4288395; 490615, 4282693; 470315, 4285993; 476415, 4289493
		Xanthandrus azorensis	endemic	492915, 4284493; 472415, 4292593; 475415, 4293193; 472615, 4289593; 472215, 4287993; 471515, 4288993; 473915, 4287893; 482015, 4287593; 474615, 4288393
		Xanthandrus comtus	native	472415, 4292593; 472215, 4287993; 473915, 4287893; 482015, 4287593
		Xylota segnis	native	473515, 4283393; 469715, 4290793; 490615, 4282693; 479115, 4285493
	Tephritidae	*Euaresta bullans*	exotic	478815, 4280793; 477115, 4283293; 485515, 4289493; 490215, 4280293; 472615, 4289593; 472215, 4287993; 471515, 4288993; 482015, 4287593; 474615, 4288393; 481215, 4287293

Hymenoptera	Apidae	*Apis mellifera*	exotic	483915, 4290293; 484315, 4288993; 478915, 4290093; 485515, 4289493; 475415, 4281293; 488115, 4287193; 487415, 4291893; 474515, 4291693; 492115, 4286893; 473515, 4283393; 475415, 4293193; 486215, 4289493; 485815, 4282693; 482015, 4287593; 474615, 4288393; 469715, 4290793; 485415, 4286193; 494115, 4288395; 480415, 4277293; 487415, 4277793; 489915, 4285393; 473015, 4284293; 476415, 4289493
		Bombus ruderatus	native	492915, 4284493; 483915, 4290293; 475715, 4289193; 472415, 4292593; 478815, 4280793; 484315, 4288993; 478915, 4290093; 477115, 4283293; 470315, 4287093; 485515, 4289493; 475415, 4281293; 474515, 4291693; 492115, 4286893; 473515, 4283393; 475415, 4293193; 486215, 4289493; 485815, 4282693; 480915, 4284393; 472215, 4287993; 471515, 4288993; 481715, 4291093; 482015, 4287593; 474615, 4288393; 469715, 4290793; 485415; 4286193; 494115, 4288395; 481215, 4287293; 487415, 4277793; 481815, 4285993; 489915, 4285393; 473015, 4284293; 470315, 4285993; 476415, 4289493
		Lasioglossum morio	native	472415, 4292593; 478815, 4280793; 484315, 4288993; 477115, 4283293; 490215, 4280293; 474515, 4291693; 475415, 4293193; 482015, 4289793; 481715, 4291093; 469715, 4290793; 479015, 4285993; 485415, 4286193; 470915, 4289693; 480415, 4277293; 481815, 4285993; 470115, 4288693; 473015, 4284293; 470315, 4285993; 479115, 4285493; 476415, 4289493
		Lasioglossum smeathmanellum	native	474515, 4291693; 473515, 4283393; 485815, 4282693
		Lasioglossum villosulum	native	492915, 4284493; 478815, 4280793; 477115, 4283293; 470315, 4287093; 485515, 4289493; 490215, 4280293; 474515, 4291693; 473515, 4283393; 475415, 4293193; 486215, 4289493; 485815, 4282693; 480915, 4284393; 472615, 4289593; 472215, 4287993; 482015, 4289793; 471515, 4288993; 482015, 4287593; 469715, 4290793; 485415, 4286193; 470915, 4289693; 480415, 4277293; 470115, 4288693; 473015, 4284293; 470315, 4285993; 476415, 4289493
		Megachile centuncularis	native	472415, 4292593
	Chrysididae	*Chrysis ignita ignita*	native	478815, 4280793
	Formicidae	*Lasius grandis*	native	478815, 4280793; 478915, 4290093; 485515, 4289493; 475415, 4281293; 490215, 4280293; 474515, 4291693; 475415, 4293193; 485815, 4282693; 474615, 4288393; 475415, 4287693; 479015, 4285993; 482815, 4285893; 483415, 4293493; 480415, 4277293; 481815, 4285993; 490615, 4282693; 476415, 4289493
	Vespidae	*Ancistrocerus parietum*	native	492915, 4284493; 472415, 4292593; 470315, 4287093; 475415, 4293193; 486215, 4289493; 490615, 4282693
		Vespula germanica	native	492915, 4284493; 483915, 4290293; 472415, 4292593; 470315, 4287093; 487415, 4291893; 486215, 4289493; 474615, 4288393
Lepidoptera	Choreutidae	*Tebenna micalis*	exotic	492915, 4284493; 485415, 4286193
	Nymphalidae	*Hipparchia azorina azorina*	endemic	472615, 4289593; 472215, 4287993; 473915, 4287893; 482015, 4287593
	Pieridae	*Colias croceus*	native	492915, 4284493; 484315, 4288993; 475415, 4281293; 490215, 4280293; 492115, 4286893; 486215, 4289493; 471515, 4288993; 487415, 4277793; 481815, 4285993; 476415, 4289493
		Pieris brassicae azorensis	endemic	492915, 4284493; 472415, 4292593; 484315, 4288993; 475415, 4281293; 492115, 4286893; 486215, 4289493; 485415, 4286193; 494115, 4288395; 480415, 4277293; 487415, 4277793; 481815, 4285993; 489915, 4285393
	Sphingidae	*Agrius convolvuli*	native	475415, 4281293

Appendix II. Priority areas ranked in Zonation for each taxonomic group and total set of species, according to land-use on Terceira Island (natural forest, naturalized vegetation, exotic forest, semi-natural pasture, intensively managed pasture, agriculture and orchard, urban and industrial) and INP areas (ncells: number of cells; INP: Island Natural Park).

Group	Quartile	Natural forest Total (ncells)	ncells	%	Naturalized vegetation Total (ncells)	ncells	%	Exotic forest Total (ncells)	ncells	%	Semi-natural pasture Total (ncells)	ncells	%	Intensive pasture Total (ncells)	ncells	%	Agriculture/Orchards Total (ncells)	ncells	%	Urban/Industrial Total (ncells)	ncells	%	INP Total (ncells)	ncells	%
Coleoptera	0-0.25	5	1	20	70	18	25,7	586	254	43,3	117	21	17,9	419	345	82,3	521	422	81	52	42	80,8	13	8	61,5
	0.25-0.50	5	0	0	70	0	0	586	0	0	117	0	0	419	0	0	521	0	0	52	0	0	13	0	0
	0.50-0.75	5	0	0	70	0	0	586	0	0	117	0	0	419	0	0	521	0	0	52	0	0	13	0	0
	0.75-1	5	4	80	70	52	74,3	586	332	56,6	117	96	82,1	419	74	17,7	521	99	19	52	10	19,2	13	5	38,5
Hymenoptera	0-0.25	5	3	60	70	38	54,3	586	276	47	117	62	53	419	207	49,4	521	276	53	52	34	65,4	13	10	76,9
	0.25-0.50	5	0	0	70	0	0	586	0	0	117	0	0	419	0	0	521	0	0	52	0	0	13	0	0
	0.50-0.75	5	0	0	70	0	0	586	0	0	117	0	0	419	0	0	521	0	0	52	0	0	13	0	0
	0.75-1	5	2	40	70	32	45,7	586	310	52,9	117	55	47	419	212	50,6	521	245	47	52	18	34,6	13	3	23,1
Lepidoptera	0-0.25	5	3	60	70	20	28,6	586	251	42,8	117	42	36	419	193	88,1	521	246	47,2	52	26	50	13	4	30,8
	0.25-0.50	5	0	0	70	0	0	586	0	0	117	0	0	419	0	0	521	0	0	52	0	0	13	0	0
	0.50-0.75	5	0	0	70	0	0	586	0	0	117	0	0	419	0	0	521	0	0	52	0	0	13	0	0
	0.75-1	5	2	40	70	50	71,4	586	335	57,2	117	75	64	419	226	53,9	521	275	52,8	52	26	50	13	9	69,2
Syrphid	0-0.25	5	1	20	70	18	25,7	586	254	43,3	117	21	17,9	419	345	82,3	521	422	81	52	42	80,8	13	8	61,5
	0.25-0.50	5	0	0	70	0	0	586	0	0	117	0	0	419	0	0	521	0	0	52	0	0	13	0	0
	0.50-0.75	5	0	0	70	0	0	586	0	0	117	0	0	419	0	0	521	0	0	52	0	0	13	0	0
	0.75-1	5	4	80	70	52	74,3	586	332	56,6	117	96	82,1	419	74	17,7	521	99	19	52	10	19,2	13	5	38,5
Other diptera	0-0.25	5	4	80	70	4	5,7	586	50	8,5	117	9	7,7	419	51	23,3	521	73	14	52	12	23,1	13	3	23,1
	0.25-0.50	5	0	0	70	0	0	586	0	0	117	0	0	419	0	0	521	0	0	52	0	0	13	0	0
	0.50-0.75	5	0	0	70	0	0	586	0	0	117	0	0	419	0	0	521	0	0	52	0	0	13	0	0
	0.75-1	5	1	20	70	7	10	586	64	10,9	117	2	1,7	419	112	26,7	521	168	32,2	52	0	0	13	2	15,4
Total insects	0-0.25	5	1	20	70	18	25,7	586	254	43,3	117	21	17,9	419	345	82,3	521	422	81	52	42	80,8	13	8	61,5
	0.25-0.50	5	0	0	70	0	0	586	0	0	117	0	0	419	0	0	521	0	0	52	0	0	13	0	0
	0.50-0.75	5	0	0	70	0	0	586	0	0	117	0	0	419	0	0	521	0	0	52	0	0	13	0	0
	0.75-1	5	4	80	70	52	74,3	586	332	56,6	117	96	82,1	419	74	17,7	521	99	19	52	10	19,2	13	5	38,5

Area priorization for insect pollinator communities on an Oceanic Island