

## Area prioritization for insect pollinator communities on an Oceanic Island

ANA PICANÇO, F. RIGAL & P.A.V. BORGES



Picanço, A., F. Rigal & P.A.V. Borges 2017. Area prioritization for insect pollinator communities on an Oceanic Island. *Arquipelago*. Life and Marine Sciences 34: 85-104.

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.

Ana Picanço (e-mail: email: analcp@gmail.com), François Rigal, P.A.V. Borges, cE3c – Centre for Ecology, Evolution and Environmental Changes/ Azorean Biodiversity Group and University of the Azores – Faculty of Agricultural and Environmental Sciences, Rua Capitão João d'Ávila, PT-9700-042 Angra do Heroísmo, Azores, Portugal. François Rigal, Environment and Microbiology Team, MELODY group, Université de Pau et des Pays de l'Adour, IPREM UMR CNRS 5254, BP 1155, 64013 Pau Cedex, France.

### 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](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 - 40° N latitude, 25 - 31° 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 et 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<sup>2</sup> 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 9° C in “Serra de Santa Bárbara”, to 17° C on the coast. Minimum temperature in winter varies between 4° and 12° C while the maximum summer temperature varies between 14° and 26° 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<sup>2</sup>) (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.

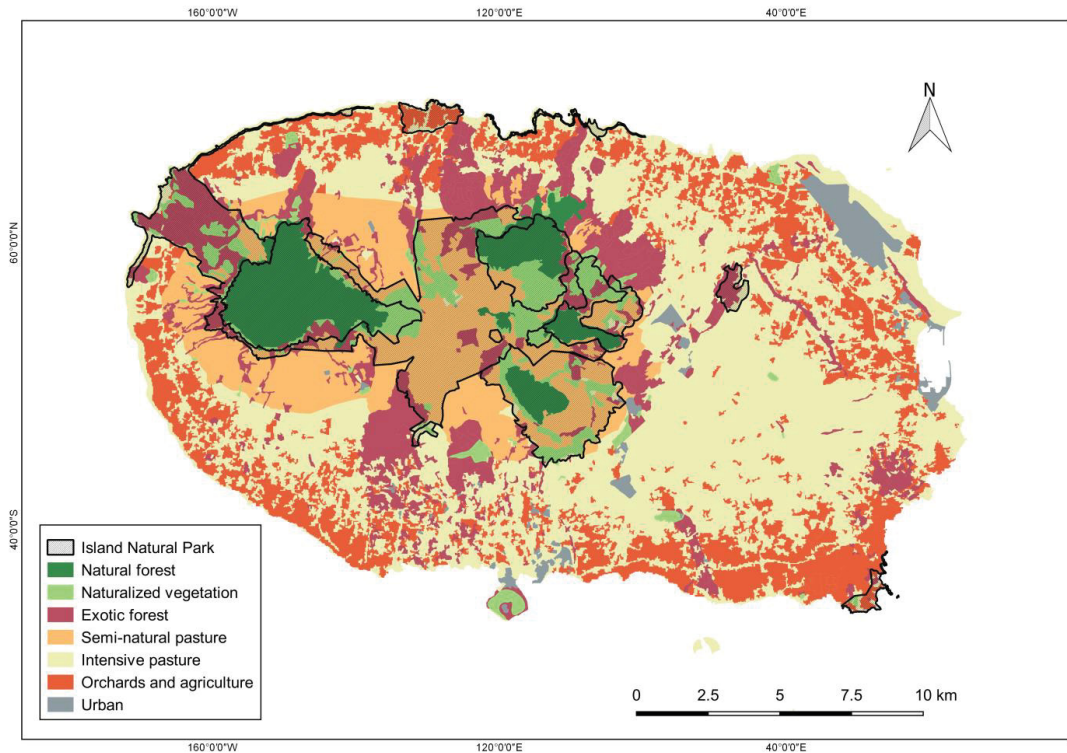


Fig. 1. Terceira Island with respective land-use distribution, including the island protected areas network – Terceira Island Natural Park.

#### 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).

#### SPECIES DISTRIBUTION MODELING

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

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

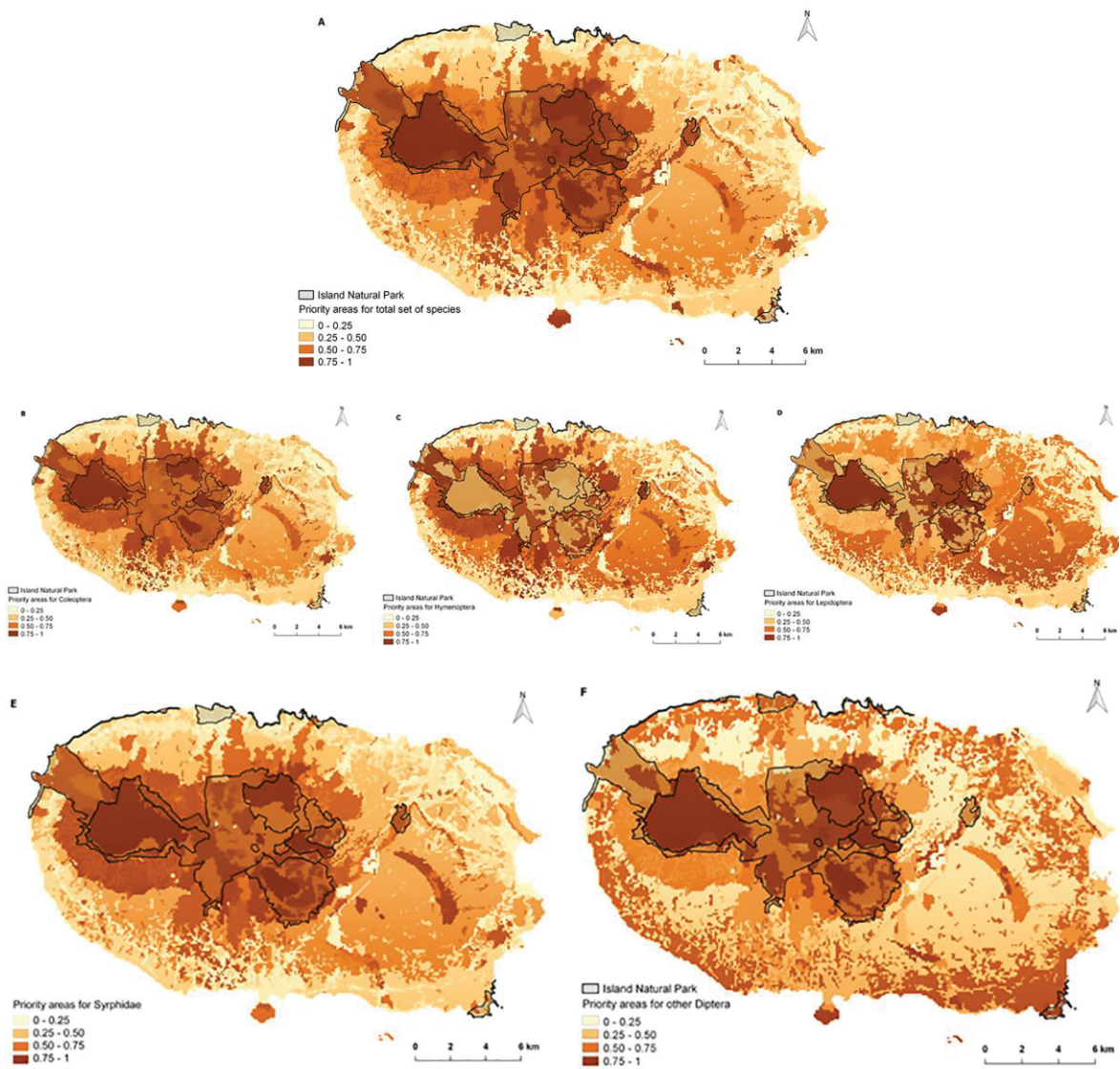


Fig. 2. Ranking of priority areas for insect pollinators using zonation software: (A) all species, (B) Coleoptera, (C) Hymenoptera, (D) Lepidoptera, (E) Syrphidae, and (F) other Diptera.

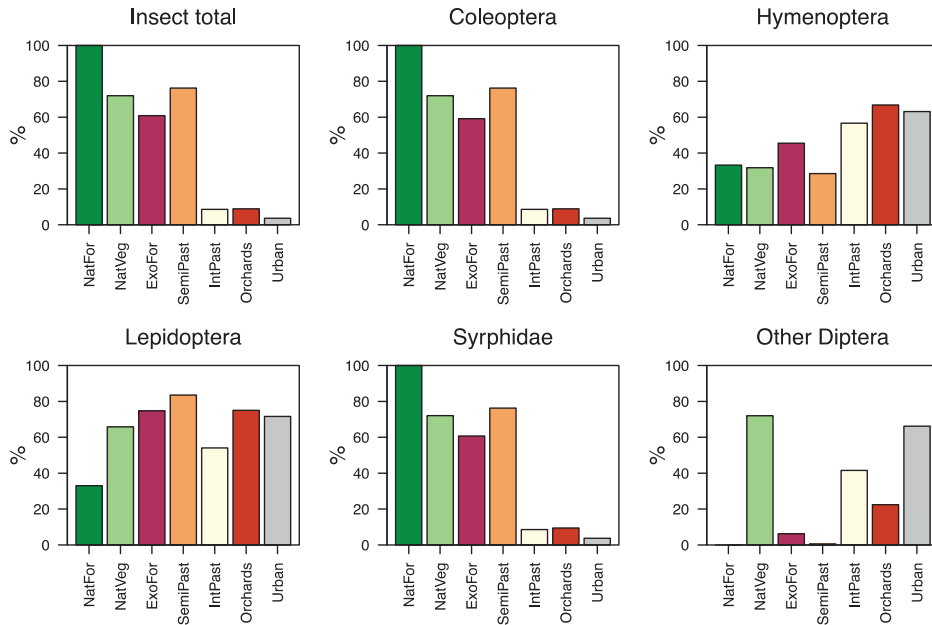


Fig. 3. Percentage of land-use area - natural forest (Natfor), naturalized vegetation areas (Natveg), exotic forest (ExoFor), semi-natural pasture (Semipast), intensively managed pasture (Intpast), agriculture/orchard areas (Orchards) and urban/industrial areas (Urban) - covered by each taxonomic group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

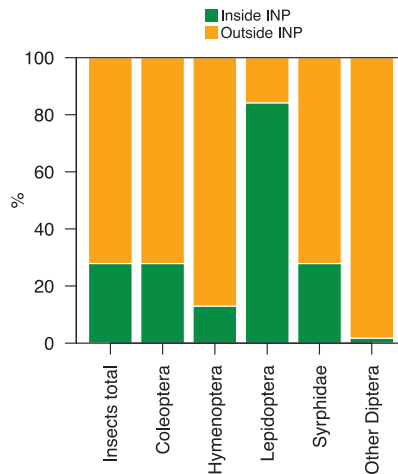


Fig. 4. Percentage of area inside and outside Terceira Island Natural Park (INP) covered by each taxonomic group and all insect pollinators.

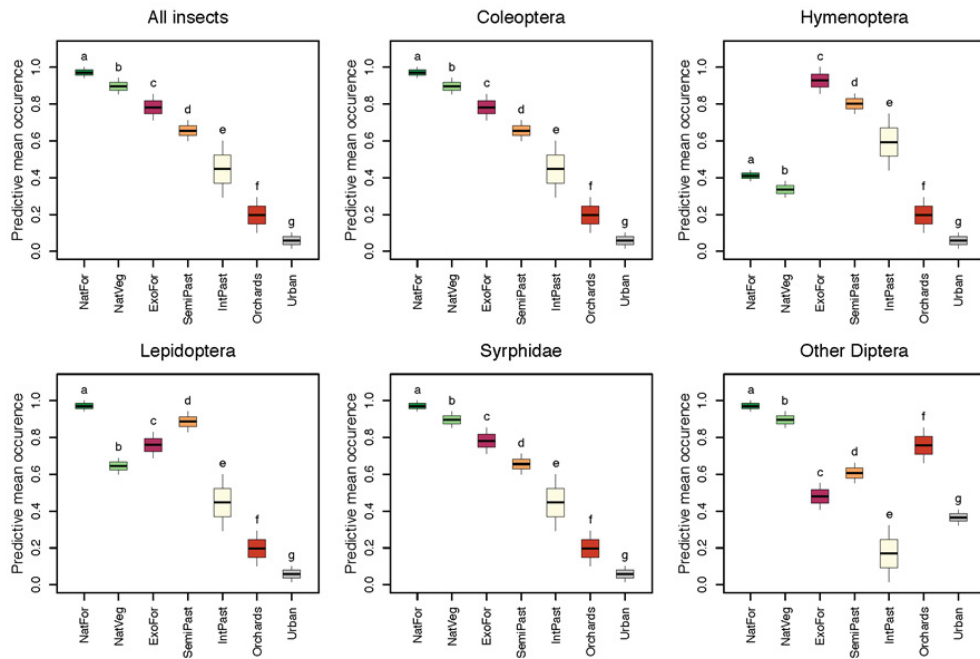


Fig. 5. Probability or predictive mean of species' occurrence (values range: 0, absent - 1, very high probability) from Zonation software and standard deviation of each taxonomic group and all insect pollinators: (a) all species, (b) Coleoptera, (c) Hymenoptera, (d) Lepidoptera, (e) Syrphidae, and (f) other Diptera, in different land uses: natural forest (Natfor), naturalized vegetation areas (Natveg), exotic forest (Exofofor), 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 particularly 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 (Winfrey 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 *Criptomera* sp. and *Eucalyptus* sp. plantations are being replaced by endemic/native plant species *Juniperus brevifolia*, *Ilex azorica*, *Prunus 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.

## ACKNOWLEDGEMENTS

AP was supported by a Ph.D. grant from Direcção Regional da Ciência e Tecnologia dos Açores (M3.1.2/F/031/2011). FR was supported by the Post-Doc Grant FCT - PTDC/BIA-BIC/119255/2010.

## REFERENCES

- Alcover, J.A., H. Pieper, F. Pereira & J.C. Rando 2015. Five new extinct species of rails (Aves: Gruiformes: Rallidae) from the Macaronesian Islands (North Atlantic Ocean). *Zootaxa* 4057: 151–190.
- Araújo, M.B. & P.H. Williams 2000. Selecting areas for species persistence using occurrence data. *Biological Conservation* 96: 331-345.
- Azevedo, E.B., L.S. Pereira & B. Itier 1999. Modelling the local climate in islands environments: water balance applications. *Agricultural Water Management* 40: 393e403.
- Azevedo, E.B., M.C. Rodrigues & J.F. Fernandes 2004. O clima dos Açores. Pp. 25 - 48 in: V.H. Forjaz, J. M. Tavares, E. M. V. B. Azevedo & J.C. Nunes (Eds). *Atlas Básico dos Açores*. Observatório Vulcanológico e Geotérmico dos Açores. Ponta Delgada. 112 pp.
- BEST – Environment Directorate General of the European Commission ('DG Environment') 2016. Voluntary scheme for biodiversity and ecosystem services in European outermost regions and overseas countries and territories [Internet]. Available from: [http://ec.europa.eu/environment/nature/biodiversity/best/index\\_en.htm](http://ec.europa.eu/environment/nature/biodiversity/best/index_en.htm) (visited Nov 2 2016).
- Bonn, A. & K.J. Gaston 2005. Capturing biodiversity: selecting priority areas for conservation using different criteria. *Biodiversity & Conservation* 14: 1083-1100.
- Borges, P.A.V. 2005a. Introduction. Pp. 11 – 20 in P.A.V. Borges, R. Cunha, R. Gabriel, A.M.F. Martins, L. Silva & V. Vieira (Eds). *A list of the terrestrial fauna (Mollusca and Protected Areas in the Azores Arthropoda) and flora (Bryophyta, Pteridophyta and Spermatophyta) from the Azores*. Direcção Regional de Ambiente & Universidade dos Açores, Horta, Angra do Heroísmo & Ponta Delgada, Portugal. 318 pp.
- Borges, P.A.V., C. Aguiar, J. Amaral, I.R. Amorim, G. André, A. Arraiol, A. Baz, et al. 2005b. Ranking protected areas in the Azores using standardized sampling of soil epigeal arthropods. *Biodiversity & Conservation* 14: 2029–2060.
- Borges, P.A.V., A. Costa, R. Cunha, R. Gabriel, V. Gonçalves, A.F. Martins, I. Melo, M. Parente, P. Raposeiro, P. Rodrigues, R.S. Santos, L. Silva, P. Vieira & V. Vieira 2010. *A List of the Terrestrial and Marine Biota from the Azores*. Princípiã, Oeiras, Portugal, 432 pp.
- Borges, P.A.V., M. Reut, N.B. Ponte, J.A. Quartau, M. Fletcher, A.B. Sousa, M. Pollet, A.O. Soares, J. Marcelino, C. Rego & P. Cardoso 2013. New records of exotic spiders and insects to the Azores, and new data on recently introduced species. *Arquipelago. Life and Marine Sciences* 30: 57-70.
- Borges, P.A.V., A.R.M. Serrano & J.A. Quartau 2000. Ranking the Azorean Natural Forest Reserves for conservation using their endemic arthropods. *Journal of Insect Conservation* 4: 129–147.
- Borges, P.A., K.I. Uglund, F. Dinis & C. Gaspar 2008.

- Insect and spider rarity in an oceanic island (Terceira, Azores): true rare and pseudo-rare species. Pp. 47–70 in: Fattorini, S. (Ed.). *Insect Ecology and Conservation*. Research Signpost, Kerala, India. ISBN: 978-81-308-0297-8, 317 pp.
- Cabeza, M. & A. Moilanen 2001. Design of reserve networks and the persistence of biodiversity. *Trends in Ecology & Evolution* 16: 242-248.
- Cardoso, P., S.C. Aranda, J.M. Lobo, F. Dinis, C. Gaspar & P.A.V. Borges 2009. A spatial scale assessment of habitat effects on arthropod communities of an oceanic island. *Acta Oecologica* 35: 590-597.
- Cardoso, P., P.A.V. Borges, A.C. Costa, R.T. Cunha, R. Gabriel, A.M.F. Martins, L. Silva, et al. 2008. A perspectiva arquipelágica - Açores. Pp. 421–449 in: Martín, J.L., M. Arechavaleta, P.A.V. Borges & B. Faria (Eds). *TOP 100 - As cem espécies ameaçadas prioritárias em termos de gestão na região europeia biogeográfica da Macaronésia*. Consejería de Medio Ambiente y Ordenación Territorial, Gobierno de Canarias, 500 pp. [One hundred threatened species in Macaronesia european management region].
- Cardoso, P., T.L. Erwin, P.A.V. Borges & T.R. New 2011. The seven impediments in invertebrate conservation and how to overcome them. *Biological Conservation* 144: 2647-2655.
- Cardoso, P., F. Rigal, S. Fattorini, S. Terzopoulou & P.A.V. Borges 2013. Integrating landscape disturbance and indicator species in conservation studies. *PLoS ONE* 8: e63294.
- Carvalho, S.B., J.C. Brito, R.L. Pressey, E. Crespo & H.P. Possingham 2010. Simulating the effects of using different types of species distribution data in reserve selection. *Biological Conservation* 143: 426–438.
- Cowling, R.M. & R.L. Pressey 2001. Rapid plant diversification: planning for an evolutionary future. *Proceedings of the National Academy of Sciences* 98: 5452-5457.
- Cowling, R.M., R.L. Pressey, A.T. Lombard, P.G. Desmet & A.G. Ellis 1999. From representation to persistence: requirements for a sustainable system of conservation areas in the species-rich mediterranean-climate desert of southern Africa. *Diversity & Distributions* 5: 51 - 71.
- DROTRH 2008. *Carta de ocupação do solo da região Autónoma dos Açores* - Projecto SUEMAC. Secretaria Regional do Ambiente, Direcção Regional do Ordenamento do território e dos Recursos Hídricos, Ponta Delgada. [Land use map for Azores region].
- Elias, R.B., A. Gil, L. Silva, J.M. Fernández-Palacios, E.B. Azevedo & F. Reis 2016. Natural zonal vegetation of the Azores Islands: characterization and potential distribution. *Phytocoenologia* 46: 107-123.
- Elith, J., C.H. Graham, R.P. Anderson, M. Dudík, S. Ferrier, A. Guisan, R.J. Hijmans, et al. 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography* 29: 129–151.
- Fattorini, S., P. Cardoso, F. Rigal & P.A.V. Borges 2012. Use of arthropod rarity for area prioritisation: insights from the Azorean Islands. *PLoS ONE* 7: e33995.
- Ferrier, S., R.L. Pressey & T.W. Barrett 2000. A new predictor of the irreplaceability of areas for achieving a conservation goal, its application to real-world planning, and a research agenda for further refinement. *Biological Conservation* 93: 303-325.
- França, Z., J.V. Cruz, J.C. Nunes & V.H. Forjaz 2005. Geologia dos Açores: uma perspectiva actual. *Açoreana* 10: 1-141.
- Franklin, J.F. & D.B. Lindenmayer 2009. Importance of matrix habitats in maintaining biological diversity. *Proceedings of the National Academy of Sciences* 106: 349-350.
- Gaspar, C., P.A.V. Borges & K.J. Gaston 2008. Diversity and distribution of arthropods in native forests of the Azores archipelago. *Arquipelago - Life and Marine Sciences* 25: 1-30.
- Gaspar, C., K.J. Gaston, P.A.V. Borges & P. Cardoso 2011. Selection of priority areas for arthropod conservation in the Azores archipelago. *Journal of Insect Conservation* 15: 671-684.
- Secretariat of the Convention on Biological Diversity (SCBD) and Global Island Partnership Organization 2016. *Global Island Partnership (GLISPA)* [Internet]. Available from: <https://www.cbd.int/island/glispa.shtml> (visited Nov 2 2016).
- Jackson, S.F., K. Walker & K.J. Gaston 2009. Relationship between distributions of threatened plants and protected areas in Britain. *Biological Conservation* 142: 1515-1522.
- Jauker, F. & V. Wolters 2008. Hover flies are efficient pollinators of oilseed rape. *Oecologia* 156: 819-823.
- Kaiser-Bunbury, C.N., J. Mougil, A.E. Whittington, T. Valentin, R. Gabriel, J.M. Olesen & N. Blüthgen 2017. Ecosystem restoration strengthens pollination network resilience and function. *Nature* 542: 223-227.
- Kaiser-Bunbury, C.N. & N. Blüthgen 2015. Integrating network ecology with applied conservation: a synthesis and guide to implementation. *AoB Plants* 7: plv076.
- Klein, A.M., Vaissiere, B.E., Cane, J.H., I. Steffan-Dewenter, S.A. Cunningham, C. Kremen, & T. Tschamtkke 2007. Importance of pollinators in changing landscapes for world crops. *Proceedings*

- of the Royal Society of London B: Biological Sciences 274: 303–313.
- Kremen, C., A. Cameron, A. Moilanen, S.J. Phillips, C.D. Thomas, H. Beentje & G.J. Harper 2008. Aligning conservation priorities across taxa in Madagascar with high-resolution planning tools. *Science* 320: 222–226.
- Kukkala, A.S. & A. Moilanen 2013. Core concepts of spatial prioritisation in systematic conservation planning. *Biological Reviews* 88: 443–464.
- Lehtomäki, J. & A. Moilanen 2013. Methods and workflow for spatial conservation prioritization using Zonation. *Environmental Modelling & Software* 47: 128–137.
- MacArthur, R. & E. Wilson 1967. *The Theory of Biogeography*. Princeton University Press, Princeton, New Jersey. 203 pp.
- Margules, C.R. & R.L. Pressey 2000. Systematic conservation planning. *Nature* 405: 243–253.
- Martín, J.L., M. Arechavala, P.A.V. Borges & B. Faria 2008. *TOP 100. Las 100 especies amenazadas prioritarias de gestión en la región europea biogeográfica de la Macaronesia*. Consejería de Medio Ambiente Y Ordenación Territorial, Gobierno de Canarias, 500pp. [*One hundred threatened species in Macaronesia european management region*].
- Moilanen, A. 2007. Landscape Zonation, benefit functions and target-based planning: Unifying reserve selection strategies. *Biological Conservation* 134: 571–579.
- Moilanen, A., B.J. Anderson, F. Eigenbrod, A. Heinemeyer, D.B. Roy, S. Gillings & C.D. Thomas 2011. Balancing alternative land uses in conservation prioritization. *Ecological Applications* 21: 1419–1426.
- Moilanen, A., A.M. Franco, R.I. Early, R. Fox, B. Wintle & C.D. Thomas 2005. Prioritizing multiple-use landscapes for conservation: methods for large multi-species planning problems. *Proceedings of the Royal Society B: Biological Sciences* 272: 1885–1891.
- Moilanen, A., F.M. Pouzols, L. Meller, V. Veitch, A. Arponen, J. Leppänen, & H. Kujala 2014. *Zonation Version 4 User Manual*. C-BIG Conservation Biology Informatics Group, Department of Biosciences, University of Helsinki, Helsinki.
- Moilanen, A., K.A. Wilson & H. Possingham 2009. *Spatial Conservation Prioritization – Quantitative Methods and Computational Tools*. Oxford University Press, Oxford, UK, 304 pp.
- Newbold, T., L.N. Hudson, S.L. Hill, S. Contu, I. Lysenko, R.A. Senior & J. Day 2015. Global effects of land use on local terrestrial biodiversity. *Nature* 520: 45–50.
- Ollerton, J., R. Winfree & S. Tarrant, 2011. How many flowering plants are pollinated by animals? *Oikos* 120: 321–326.
- Pereira, H.M. & G.C. Daily 2006. Modeling Biodiversity dynamics in countryside landscapes. *Ecology* 87: 1877–1885.
- Phillips, S.J., R.P. Anderson & R.E. Schapire 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling* 190: 231–259.
- Phillips, S.J., M. Dudík & R.E. Schapire 2004. *A maximum entropy approach to species distribution modeling*. Proceedings of the 21st International Conference on Machine Learning, pp. 655–662. Banff, Canada. [www document]. URL [www.cs.princeton.edu/schapire/papers/maxent\\_icml.pdf](http://www.cs.princeton.edu/schapire/papers/maxent_icml.pdf)
- Picanço, A., F. Rigal, T.J. Matthews, P. Cardoso & P.A.V. Borges 2017. Impact of land-use change on flower-visiting insect communities on an oceanic island. *Insect Conservation & Diversity* 10: 211–223. DOI: 10.1111/icad.12216.
- Pierce, S.M., R.M. Cowling, A.T. Knight, A.T. Lombard, M. Rouget & T. Wolf 2005. Systematic conservation planning products for land-use planning: interpretation for implementation. *Biological Conservation* 125: 441–458.
- Pollard, E. & T.J. Yates 1993. *Monitoring butterflies for ecology and conservation*. Chapman and Hall, London, UK. 274 pp.
- Pressey, R.L. 2004. Conservation planning and biodiversity: assembling the best data for the job. *Conservation Biology* 18: 1677–1681.
- Pressey, R.L., M., M.E. Watts, R.M. Cowling, K.A. Wilson 2007. Conservation planning in a changing world. *Trends in Ecology & Evolution* 22: 583–92.
- Primack, R.B. 2006. *Essentials of conservation biology*. Fourth. ed. Sinauer Associates, Sunderland, Massachusetts. 603 pp.
- Rader, R., I. Bartomeus, L.A. Garibaldi, M.P. Garratt, B.G. Howlett, R. Winfree & R. Bommarco 2015. Non-bee insects are important contributors to global crop pollination. *Proceedings of the National Academy of Sciences* 113: 146–151.
- Regional Legislative Decree No. 11/2011/A of 20th April. Establishes the Legal Regime of Terceira Island Natural Park. [www document]. URL [www.azores.gov.pt/NR/rdonlyres/45B97553-5DFC-4856.../DLR\\_11\\_2011\\_A.pdf](http://www.azores.gov.pt/NR/rdonlyres/45B97553-5DFC-4856.../DLR_11_2011_A.pdf)
- Small Island Developing States Global Business Network 2016. *Samoa Pathway-Sustainable Development knowledge Platform*. [Internet]. Available from: <http://www.sids2014.org/samoapathway> (visited Nov 2 2016).
- Sarkar, S. & P. Illoldi-Rangel 2010. Systematic conservation planning: an updated protocol. *Natureza & Conservação* 8: 19–26.
- Silva, L., E.L. Ojeda & J.L. Rodriguez-Luengo 2008. *Invasive Terrestrial Flora & Fauna of*

- Macaronesia. TOP 100 in Azores, Madeira and Canaries*. ARENA, Ponta Delgada, 546pp.
- Steffan-Dewenter, I. & C. Westphal 2008. The interplay of pollinator diversity, pollination services and landscape change. *Journal of Applied Ecology* 45: 737–741.
- Terzopoulou, S., F. Rigal, R. Whittaker, P.A.V. Borges & K.A. Triantis 2015. Drivers of extinction: the case of Azorean beetles. *Biology Letters* 11: 1-4.
- Triantis, K.A. & S.A. Bhagwat 2011. Applied island biogeography. Pp.190-223 in: Ladle, R & R.J. Whittaker (Eds). *Conservation Biogeography*. Wiley-Blackwell, Oxford, UK. 256 pp.
- Triantis, K.A., P.A.V. Borges, R.J. Ladle, J. Hortal, P. Cardoso, C. Gaspar, F. Dinis et al. 2010. Extinction debt on oceanic islands. *Ecography* 33: 285-294.
- Vergilio, M., C. Fonseca, H. Calado, P.A.V. Borges, R.B. Elias, R. Gabriel, A. Martins et al. 2016. Assessing the efficiency of protected areas to represent biodiversity: a small island case study. *Environmental Conservation* 43: 337-349.
- Vitousek, P.M., H.A. Mooney, J. Lubchenco & J.M. Melillo 1997. Human domination of Earth's ecosystems. *Science* 277: 494-499.
- Walker, L.R. & P. Bellingham 2011. *Island environments in a changing world*. Cambridge University Press, New York, USA, 312 pp.
- Whittaker, R. J., & J. M. Fernández-Palacios 2007. *Island biogeography: ecology, evolution and conservation*. Oxford University Press, Oxford, UK., 383 pp.
- Wilson, K.A., E. Meijaard, S. Drummond, H.S. Grantham, L. Boitani, G. Catullo, L. Christie, et al. 2010. Conserving biodiversity in production landscapes. *Ecological Applications* 20: 1721-1732.
- Winfree, R. 2013. Global change, biodiversity, and ecosystem services: What can we learn from studies of pollination?. *Basic and Applied Ecology* 14: 453-460.
- Winfree, R., I. Bartomeus & D.P. Cariveau 2011. Native pollinators in anthropogenic habitats. *Annual Review of Ecology, Evolution, and Systematics* 42: 1-22.

Received 26 Apr 2017. Accepted 21 Jul 2017.

Published online 7 Sep 2017.

## 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	<i>Meligethes aeneus</i>	exotic	492915, 4284493; 475715, 4289193; 474515, 4291693; 472615, 4289593; 474615, 4288393; 475015, 4289093; 490615, 4282693
	Phalacridae	<i>Stilbus testaceus</i>	native	492915, 4284493; 470315, 4287093; 471515, 4288993; 474615, 4288393
	Scaphitidae	<i>Anaspis proteus</i>	native	478815, 4280793; 480915, 4284393; 472615, 4289593; 482015, 4289793; 471515, 4288993; 473915, 4287893; 481715, 4291093; 482015, 4287593; 474615, 4288393; 475415, 4287693; 485415, 4286193; 494115, 4288393; 475015, 4289093; 470115, 4288693
Diptera	Anthomyiidae	<i>Adia cinerella</i>	native	469715, 4290793; 470315, 4285993
		<i>Fucellia tergina</i>	native	478815, 4280793; 475415, 4293193
	Calliphoridae	<i>Paregle audaccula</i>	native	477115, 4283293; 474515, 4291693; 486215, 4289493; 485815, 4282693; 472615, 4289593; 482015, 4289793; 479015, 4285993; 485415, 4286193; 483015, 4283593
		<i>Calliphora vicina</i>	exotic	483915, 4290293; 478815, 4280793; 478915, 4290093; 471515, 4288993; 481715, 4291093; 494115, 4288393; 483415, 4293493; 470915, 4289693; 487415, 4277793; 470315, 4285993
		<i>Lucilia sericata</i>	exotic	492915, 4284493; 477115, 4283293; 475415, 4293193; 483415, 4293493; 476415, 4289493
		<i>Rhinia apicalis</i>	native	485815, 4282693; 472215, 4287993; 469715, 4290793; 482815, 4285893; 483415, 4293493; 487415, 4277793; 490615, 4282693; 470115, 4288693; 479115, 4285493; 476415, 4289493
	Phoridae	<i>Stomorphina lunata</i>	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
		<i>Megaselia rufipes</i>	exotic	487415, 4291893; 485815, 4282693; 482015, 4289793; 470115, 4288693; 470315, 4285993; 483015, 4283593
		<i>Scathophaga litorea</i>	native	484315, 4288993; 480915, 4284393; 472615, 4289593; 472215, 4287993; 474615, 4288393; 479015, 4285993; 494115, 4288393; 470315, 4285993; 479115, 4285493
	Sepsidae	Sepsidae	<i>Scathophaga stercoraria</i>	native
<i>Sepsis biflexuosa</i>			native	478815, 4280793; 484315, 4288993; 485515, 4289493; 472615, 4289593; 479015, 4285993
		<i>Sepsis lateralis</i>	native	478815, 4280793; 472615, 4289593; 472215, 4287993; 479015, 4285993; 494115, 4288393

	<i>Sepsis neocynipsea</i>	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, 4289993; 473915, 4288993; 471515, 4287893; 481715, 4291093; 482015, 4287593; 475415, 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
	<i>Sepsis thoracica</i>	native	490215, 4280293; 492115, 4286893; 472215, 4287993; 475415, 4287693
	<i>Episyphus balteatus</i>	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, 4289993; 473915, 4288993; 481715, 4291093; 482015, 4287593; 475415, 4288393; 475415, 4287693; 469715, 4290793; 479015, 4285993; 482815, 4285893; 494115, 4288395; 470915, 4289693; 475015, 4289093; 481815, 4285993; 490615, 4282693; 489915, 4285393; 470115, 4288693; 473015, 4284293; 470315, 4285993; 479115, 4285493
	<i>Eristalis arbustorum</i>	native	492915, 4284493; 486215, 4289493; 474615, 4288393; 494115, 4288395; 476415, 4289493
	<i>Eristalis tenax</i>	native	492915, 4284493; 483915, 4290293; 490215, 4280293; 475415, 4293193; 482015, 4287593; 474615, 4288393; 475415, 4287693; 494115, 4288395; 473015, 4284293
	<i>Eupeodes corollae</i>	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
Syrphidea	<i>Meliscaeva auricollis</i>	native	492115, 4286893; 475415, 4293193; 472215, 4287993; 475415, 4287693; 469715, 4290793
	<i>Myathropa florea</i>	native	492915, 4284493; 475415, 4293193; 480915, 4284393; 482015, 4287593; 474615, 4288393; 469715, 4290793; 487415, 4277793; 470115, 4288693
	<i>Sphaerophoria nigra</i>	endemic	485515, 4289493; 482015, 4287593; 474615, 4288393; 481215, 4287293
	<i>Sphaerophoria scripta</i>	native	478815, 4280793; 484315, 4288993; 477115, 4283293; 487415, 4291893; 490215, 4280293; 475415, 4293193; 469715, 4290793; 481215, 4287293
	<i>Syrpitta pipiens</i>	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
	<i>Xanthandrus azorensis</i>	endemic	492915, 4284493; 472415, 4292593; 475415, 4293193; 472615, 4289593; 472215, 4287993; 471515, 4288993; 473915, 4287893; 482015, 4287593; 474615, 4288393
	<i>Xanthandrus comtus</i>	native	472415, 4292593; 472215, 4287993; 473915, 4287893; 482015, 4287593
	<i>Xylota segrisi</i>	native	473515, 4283393; 469715, 4290793; 490615, 4282693; 479115, 4285493
Tephritidae	<i>Euaresta bullans</i>	exotic	478815, 4280793; 477115, 4283293; 485515, 4289493; 490215, 4280293; 472615, 4289593; 472215, 4287993; 471515, 4288993; 482015, 4287593; 474615, 4288393; 481215, 4287293

Hymenoptera	Apidae	<i>Apis mellifera</i>	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	
		<i>Bombus rudraterus</i>	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, 4282693; 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	<i>Lasioglossum morio</i>	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	
		<i>Lasioglossum smeathmanellum</i>	native	474515, 4291693; 473515, 4283393; 475415, 4281293; 485515, 4282693	
		<i>Lasioglossum villosulum</i>	native	492915, 4284493; 478815, 4280793; 477115, 4283293; 470315, 4287093; 485515, 4289493; 490215, 4280293; 474515, 4291693; 475415, 4293193; 485815, 4282693; 474615, 4288393; 475415, 4287693; 482015, 4287593; 469715, 4290793; 483415, 4293493; 480415, 4277293; 481815, 4285993; 490615, 4282693; 476415, 4289493	
		<i>Megachile centuncularis</i>	native	472415, 4292593	
		<i>Chrysis ignita ignita</i>	native	478815, 4280793	
		Formicidae	<i>Lasius grandis</i>	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
			<i>Ancistrocenus parietum</i>	native	492915, 4284493; 472415, 4292593; 470315, 4287093; 475415, 4293193; 486215, 4289493; 490615, 4282693
		Vespidae	<i>Vespula germanica</i>	native	492915, 4284493; 483915, 4290293; 472415, 4292593; 470315, 4287093; 487415, 4291893; 486215, 4289493; 474615, 4288393
<i>Tebenna micalis</i>	exotic		492915, 4284493; 485415, 4286193		
Nymphalidae	<i>Hipparchia azorina azorina</i>	endemic	472615, 4289593; 472215, 4287993; 473915, 4287893; 482015, 4287593		
	<i>Colias croceus</i>	native	492915, 4284493; 484315, 4288993; 475415, 4281293; 490215, 4280293; 492115, 4286893; 486215, 4289493; 471515, 4288993; 487415, 4277793; 481815, 4285993; 476415, 4289493		
Pieridae	<i>Pieris brassicae azorensis</i>	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		
	<i>Agrius convolvuli</i>	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, agriculture and orchard, urban and industrial) and INP areas (ncells):

number of cells; INP: Island Natural Park).

Group	Quartile	Natural forest		Naturalized vegetation		Exotic forest		Semi-natural pasture		Intensive pasture		Agriculture/Orchards		Urban/Industrial		INP	
		Total (ncells)	%	Total (ncells)	%	Total (ncells)	%	Total (ncells)	%	Total (ncells)	%	Total (ncells)	%	Total (ncells)	%	Total (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