Respostes de l'ús del territori al paisatge en mamífers de mida gran i mitjana

Responses Of Territory Use To Landscape In Large And Medium-Sized Mammals

Guillem Molina Vacas

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RESPOSTES DE L'ÚS DEL TERRITORI AL PAISATGE EN MAMÍFERS DE MIDA GRAN I MITJANA

RESPONSES OF TERRITORY USE TO LANDSCAPE IN LARGE AND MEDIUM-SIZED MAMMALS

Memòria presentada per **Guillem Molina Vacas** per optar al grau de Doctor per la Universitat de Barcelona

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Índex

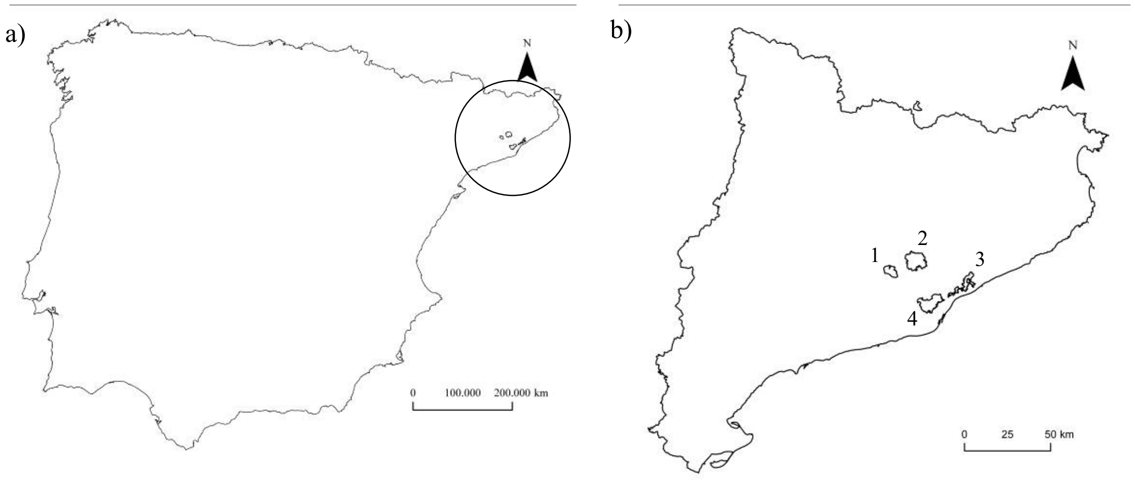
INTRODUCCIÓ GENERAL

El progressiu coneixement del funcionament dels sistemes naturals ha posat en evidència la necessitat de gestionar els espais, els recursos naturals i la biodiversitat de forma global per tal de mantenir els processos que s'estableixen dins i entre els ecosistemes. Per dur a terme aquesta tasca cal, però, un nou marc de treball que permeta la comprensió i l'anàlisi, a una escala espacial rellevant, d'aquests processos ecològics (Pino i Rodà 1999). L'ecologia del paisatge és una nova disciplina de l'ecologia, que des dels seus inicis ha crescut amb una clara voluntat d'aplicació a la conservació (Wiens 2009). Pel que fa al paisatge resulta difícil mesurar la distribució dels animals directament i no obstant això la conservació requereix sovint un coneixement del lloc on es troben els animals i en quin nombre, i també com les distribucions es podrien veure afectades per possibles intervencions humanes (Macdonald i Rushton 2003). La major part dels estudis sobre ecologia del paisatge se centren en l'estudi de la connectivitat (Schippers *et al.* 1996, Clergeau i Burel 1997, Bunn *et al.* 2000, Theobald 2001, Söndgerath i Schröder 2002, Stevens *et al.* 2004), o la fragmentació del paisatge, i de com afecta aquesta a l'estat de les poblacions que hi viuen, en base als efectes sobre la riquesa i/o abundància d'espècies (Bowne *et al.* 1999, Palomares *et al.* 1999, Debinski i Holt 2000, Graham 2001, Mac Nally i Horrocks 2002, Joly *et al.* 2003, Harper *et al.* 2005, Smith i Batzli 2006). Altrament, hi ha altres estudis de caire més aplicat, que aborden directament l'eficàcia dels corredors biològics per a la (re-)connexió d'espais naturals a diferents escales d'estudi (Bennett 1990, Rosenberg *et al.* 1997, Beier i Noss 1998, Bruinderik *et al.* 2003, Pukenis *et al.* 2004).

En general, els carnívors solen tindre abundàncies més elevades en paisatges en mosaic, on el bosc i els matolls s'intercalen amb els conreus la qual cosa fa pensar que els paisatges on es combinen clapes tancades amb altres d'obertes afavoreixen la diversitat de carnívors (Pita *et al.* 2009). Es considera que la pèrdua d'hàbitat és un dels factors més importants en la pèrdua de biodiversitat (Sala *et al.* 2000). Es calcula que la urbanització està implicada aproximadament en el 8 % de les espècies de vertebrats incloses al llistat roig de la UICN, i que cap a l'any 2030 bona part de les àrees protegides es trobaran a menys de mitja hora amb cotxe de la població urbana més propera. Així doncs, per tal de protegir la biodiversitat no n'hi ha prou d'incrementar la superfície de les àrees protegides, sinó que també resulta imprescindible suplementar-ho amb estratègies que protegesquen aquestes àrees de les pressions urbanístiques locals (Mcdonald *et al.* 2008). La conca Mediterrània és un dels quatre punts amb major alteració del medi del planeta (Myers *et al.* 2000), on l'increment de les activitats humanes com a conseqüència del ràpid desenvolupament econòmic de les darreres tres dècades amenaça l'estatus de conservació de moltes de les espècies de vertebrats i els seus hàbitats (de Juana 2004). A més, es tracta de la regió més intensament afectada per assentaments humans durant milers d'anys, especialment al llarg del litoral (Covas i Blondel 1998, Lavorel *et al.* 1998, Falcucci *et al.* 2007). La integració dels ecosistemes naturals i les activitats humanes tradicionals com l'agricultura, ramaderia, etc., és un dels motius que confereixen diversitat al medi característics de la regió Mediterrània. En àrees Mediterrànies s'ha vist que les zones muntanyenques han patit una forta reforestació, mentre que a les costaneres hi ha hagut un increment de població i pressió antròpica que ha produït una pèrdua d'ambients naturalitzats així com dels usos tradicionals del sòl (Falcucci *et al.* 2007).

ÀREA D'ESTUDI

El parc de Collserola, d'uns 85 km^2 de superfície, pertany a la Serralada Prelitoral Catalana, que s'estén uns 100 km de nord a sud paral·lelament al Mediterrania uns 10 km de la línia de costa, al NE de la Peninsula Ibèrica (Imatge 1). L'altitud varia dels 50 als 512 m sobre el nivell del mar i és el vessant barceloní (SE) la part més escarpada i elevada. Limita amb els rius Besòs i Llobregat al NO i SO respectivament, i amb la ciutat de Barcelona al SE. La resta del perímetre queda quasi totalment aïllada per un cinturó de nuclis urbans, infraestructures viàries i polígons industrials. El clima és típicament mediterràni, amb una temperatura i pluviositat mitjanes anuals de 14ºC i 672 mm respectivament, amb un ample rang de variació estacional. L'estiu és l'època més càlida i seca, mentre que la primavera i la tardor són més humides, i els hiverns, temperats. Tot i així, dins el parc es donen grans variacions micro-climàtiques a causa de l'asimetria del relleu. La part més interna del Parc (60 % de la superfície total) és coberta per una densa vegetació boscosa, formada principalment per pí blanc (*Pinus halepensis*) i alzina (*Quecus ilex*), esquitxada de roures solts o en petites clapes (*Quercus cerrioides*), i amb un dens sotabosc (*Rhamnus alaternus, Viburnum tinus*, *Arbutus unedo*, *Erica arborea, Hedera helix*). El parc és travessat per una xarxa de rieres i torrents, la major part dels quals només porta aigua desprès dels períodes de pluges intenses (excepte una riera permanent). La vegetació que envolta aquesta xarxa de torrents és constituïda principalment per vegetació de ribera degradada, és a dir bardisses (*Rubus ulmifolius, Smilax aspera*) i canyars (*Arundo donax, Phragmites australis, Coriaria mirtifolia*); malgrat que també hi ha àrees de vegetació de ribera madura composada per oms (*Ulmus campestres*) i pollancres (*Populus alba* i *P. nigra*). Exceptuant el vessant barceloní, la resta de la perifèria del Parc té una menor alçada i és principalment coberta per clapes d'arbusts (*Erica arborea*, *Arbutus unedo*, *Cistus* spp, *Pistacia lentiscus, Quercus coccifera* i *Spartium junceum*), prats sabanoides (*Hyparrhenia hirta*) i també per les poques clapes d'activitat agrícola que encara romanen actives a Collserola (6 % superfície del Parc).



Imatge 1. Situació a la Península Ibèrica (a) i al mapa de Catalunya (b) dels parcs de la Muntanya de Montserrat, Sant Llorenç del Munt, l'Obac i Serra de Marina i Collserola (1, 2, 3 i 4 respectivament).

El Parc està envoltat per més de quatre milions d'habitants i sotmès a una gran pressió antròpica. A més, existeix una extensa xarxa viària formada per 7.6 km d'autopista tancada, 70 km de carreteres convencionals i 42 de pistes forestals obertes al trànsit rodat, a més de la via del ferrocarril. La presència humana a l'interior del Parc és molt elevada, pel gran nombre d'àrees residencials, el gran nombre d'infraestructures viàries que el travessen i per l'ús com a espai d'oci dels habitants de la ciutat de Barcelona. Cal dir que, tot i la proximitat a la ciutat i el fet que algunes zones del parc tinguen característiques d'espai sub-urbà, bona part dels ambients que s'hi troben mantenen l'estructura, composició i aspecte d'espais naturals salvatges. Tot i així Collserola alberga una gran biodiversitat zoològica, amb 235 espècies de vertebrats, de les quals 24 són mamífers (Díaz-Diethelm et al. 2000). Hi habiten cinc espècies de carnívor, el teixó (*Meles meles*), la guineu (*Vulpes vulpes*), el gat mesquer (*Genetta genetta*), la fagina (*Martes foina*) i la mostela (*Mustela nivalis*). Gat mesquer i guineu presenten majors densitats i es distribueixen més àmpliament pel parc, mentre que els mustèlids tenen distribucions més relictes i menors densitats. D'altra banda, al parc també hi viuen poblacions tant de gats com de gossos esdevinguts feréstecs (*Felis catus* i *Canis familiaris* respectivament). A més, hi ha quatre espècies més de mamífers de mida mitjana, que són les dues espècies d'eriçò (*Erinaceus europaeus* i *Atelerix algirus*), l'esquirol (*Sciurus vulgaris*) i el conill (*Oryctolagus cunniculus*). El porc senglar (*Sus scrofa*) és l'animal de majors dimensions mida del Parc i assoleix grans densitats gràcies al canvi en els usos del sòl, l'abandonament de la major part dels conreus i l'increment de la superfície forestal (Raspall *et al.* 2004, Paül i Tonts 2005). Igualment, canvis comportamentals en l'espècie han permès que alguns d'aquests animals perden la por als humans i puguen alimentar-se de residus urbans la qual cosa n'incrementa la taxa de reproducció.

A començaments del segle XX una plaga de fil·loxera va acabar amb les vinyes, principal conreu al Parc i des de llavors s'ha desenvolupat com una zona d'habitatge residencial, amb només certa activitat agrícola relicta (Raspall *et al.* 2004). Entre els anys 1950 i 1975 l'Àrea Metropolitana de Barcelona va doblar la població, amb la conseqüent construcció massiva de vivendes, el que va propiciar que al 1987 s'establís un pla especial d'ordenament i protecció dels ambients naturals de Collserola (PMPC, 1990). Malgrat que aquest document va aconseguir paralitzar parcialment l'avanç de la construcció, sobretot a l'interior del Parc, no contemplava la connectivitat amb altres zones natural veïnes. En conseqüència, només van quedar dues petites franges al nord i nord-est sense construir, que a dia d'avui, després de la construcció del Centre Direccional de Cerdanyola, han quedat també tancades al pas de fauna. El Centre Direccional de Cerdanyola és un nus on confluiran les principals vies de transport per carretera de Barcelona, la construcció del qual implica també el desenvolupament d'habitatges i zones industrials. En conseqüència, podem dir que pel que fa als mamífers de mida gran i mitjana, Collserola és un espai tancat. Malgrat l'existència de plans directors que tracten de contenir el creixement urbanístic, l'àrea metropolitana de Barcelona ha continuat creixent a un ritme frenètic durant els darrers 40 anys (Serratosa 1999). Aquest creixement queda palès en el creixement global de sòl urbà, que es va duplicar (de 23.000 a 48.000 ha) entre 1972 i 1997. Durant aquest període la població va passar de 3,6 a 4,2 milions d'habitants (Solans 2002). D'altra banda, Muñoz (2003) assenyala que mentre a les àrees centrals de l'àrea metropolitana de Barcelona només el 40 % de les vivendes són de tipus residencial (xalet, adossat, etc.), als nuclis urbans més petits de les àrees perifèriques/rurals aquest valor arriba al 70 %. La millora en les infraestructures viàries ha permès que un major nombre de persones que treballen a Barcelona visquen en aquest tipus d'habitatges en zones més perifèriques on el preu del sòl és inferior (Nel·lo 2001; Durà-Guimerà 2003). Aquesta millora de les infraestructures de transport també va facilitar la relocalització de les activitats industrials de les àrees centrals de Barcelona a zones perifèriques de l'àrea metropolitana, la major part en terres planes que envolten els massissos muntanyencs (p. ex. Baix Llobregat i Vallès).

LES VÍES DE COMUNICACIÓ

Les col·lisions amb fauna salvatge són una important causa d'accidents en carretera. Les conseqüències d'aquestes incidències poden avaluar-se des de dos punts de vista. D'una banda tenim el vessant mediambiental, quant a la conservació de les poblacions salvatges; i d'altra banda hi ha el vessant de la seguretat vial, pel que fa a les conseqüències socials i econòmiques d'aquestes col·lisions (Serrano et al. 2002). Durant les darreres tres dècades, les col·lisions amb vehicles han superat, probablement, la cacera com a principal causa directa d'origen humà, de la mortalitat de vertebrats terrestres. Tot i que les vies de transport són una gran causa de mort per als vertebrats terrestres, els atropellaments tenen un efecte mínim en la mida poblacional excepte en un reduït nombre d'espècies rares (Forman i Alexander 1998). Però, potser no siga aquest efecte directe de les vies de transport sobre les poblacions el factor més perjudicial per a la seua conservació, sinó la fragmentació (o pèrdua de connectivitat) que la construcció i ús d'aquestes vies provoca. Les vies de comunicació provoquen un efecte d'evitació de la carretera que pot ser fins i tot més important que els mateixos atropellaments: el soroll, l'impacte visual, la contaminació i els predadors en moviment resseguint les carreteres són algunes de les causes d'aquest efecte d'evitació (Forman i Alexander 1998). L'accés dels humans a zones remotes i les conseqüents pertorbacions que açò comporta, tendeixen també a augmentar la densitats de carreteres. En definitiva, la fragmentació que una carretera causa depén de les característiques, tant com de les del paisatge on s'ubica (Serrano et al. 2002).

Les investigacions sobre agregacions d'atropellaments de grans mamífers han demostrat que no succeeixen a l'atzar, sinó que estan espacialment agregades (Joyce i Mahoney 2001, Clevenger et al. 2003, Clevenger et al. 2005). La fauna salvatge tendeix a estar associada a hàbitats específics i als usos del sòl dels voltants; per tant s'espera que els patrons espacials del paisatge juguen un paper important en la determinació de les localitzacions i taxes d'atropellament. Els factors explicatius dels atropellaments de fauna salvatge varien considerablement entre espècies i taxa (Forman i Alexander 1998, Clevenger et al. 2003, Clevenger et al. 2005). L'agregació dels atropellaments de grans mamífers ha estat explicada prèviament per la distribució espacial de les seues poblacions, abundància, dispersió i factors relatius a les característiques de la carretera com topografia, vegetació, velocitat de circulació, localització de les tanques a banda i banda de la via o tipus de tanca (Forman i Alexander 1998, Clevenger et al. 2003).

Moltes de les carreteres existents van ser construïdes abans de l'explosió del coneixement ecològic i en conseqüència estan mal ubicades des d'aquest punt de vista. Les consideracions ecològiques són cada cop més importants en la política ambiental de transports. Açò s'ha vist en relació al gran nombre d'estudis desenvolupats a Austràlia, Holanda i EEUU; els dos primers països són capdavanters mundials en investigació sobre ecologia de carreteres (*road ecology*), una nova branca multidisciplinar de l'ecologia que va adquirint cada cop major rellevància pel que fa a conservació i gestió mediambiental (Forman i Alexander 1998).

ESPÈCIES D'ESTUDI

Els mamífers de mida gran i mitjana presenten una gran plasticitat en la selecció i ús de l'hàbitat al llarg de la seva distribució; d'igual manera, també hi ha una gran variació en els patrons d'organització social. Els carnívors es consideren animals particularment vulnerables a extincions locals en paisatges fragmentats a causa dels requeriments d'espai, les baixes densitats i la persecució per part dels humans (Noss *et al.* 1996, Woodroffe i Ginsberg 1998). Per aquest motiu poden resultar d'utilitat per a l'estudi de les pertorbacions ecològiques, els plans de conservació i el disseny de reserves, així com per a l'avaluació del grau de connectivitat funcional en relació al paisatge (Beier 1993, Noss *et al.* 1996). Molts dels mamífers de mida gran i mitjana són també espècies d'interès cinegètic (Palomo i Gisbert 2002), i a més, són els principals causants dels accidents de trànsit per col·lisions amb fauna, i responsables de la major part dels danys provocats a conreus, explotacions cinegètiques o explotacions piscícoles (Virgos i Travaini 2005, Huijser *et al.* 2009, McCown *et al.* 2009, Sales-Luis *et al.* 2009, Kamler *et al.* 2009). Per tot això, l'estudi de la seua ecologia espacial no només resulta interessant des del punt de vista purament teòric, sinó que també té una gran utilitat pràctica de cara a la conservació i gestió tant de la fauna com dels espais que ocupa, i també pel que fa a la millora de la seguretat vial.

Teixó

El teixó (*Meles meles* L. 1758) és un mustèlid d'hàbits nocturns que es distribueix per tota Europa i bona part d'Àsia (excepte al sub-continent Indi i la Península Aràbiga). A Europa té una àmplia distribució (Johnson *et al.* 2002) i un vast rang d'ambients i condicions ecològiques diferents (Kowalczyk *et al.* 2003). És capaç d'adaptar-se sota diverses condicions ambientals (meteorologia, cobertura vegetal, molèsties causades per l'ésser humà, etc.) i a explotar un ampli ventall de recursos tròfics. Aquesta diversitat ecològica es manifesta també en una gran variabilitat quant a densitat poblacional, al grau de sociabilitat i al patró d'explotació dels recursos tròfics (espectre del nínxol ecològic, comportament generalista *vs* especialista). El teixó mostra una gran variació intra-específica en la seua organització social, que és entesa com a reflex de la plasticitat ecològica, demogràfica i comportamental de l'espècie (Palphramand *et al.* 2007). Les poblacions europees de teixó presenten dos ordres de magnitud en la variació de la densitat poblacional, i paral·lelament, una considerable variació en l'organització espacial. La densitat poblacional varia des de menys d'un individus/km^2 a Polònia o al sud de la Península Ibèrica (Kowalczyk *et al.* 2000, Revilla i Palomares 2002), fins a més de 38 individus/km^2 en algunes àrees d'Anglaterra (Johnson *et al.* 2002). Resumint, les poblacions de baixa densitat poblacional es troben al nord (Broseth *et al.* 1997a) i al sud (Revilla i Palomares 2002) del rang de distribució de l'espècie, mentre que les poblacions d'elevades densitats es troben en latituds mitjanes i arriben a una densitat màxima a les illes Britàniques i Irlanda (Johnson *et al.* 2002). En termes generals, sembla que la densitat poblacional del teixó és més elevada en climes amb poques diferències climàtiques entre estacions (temperatura i precipitació), que no pas en aquells amb una marcada estacionalitat, com per exemple el clima Mediterrani. A més, associada a la densitat poblacional, també la distribució espacial dels individus de cada població és força variable. En poblacions de baixa densitat, els teixons solen ser solitaris (Pigozzi 1987) o formar grups composats per un màxim de tres individus (Revilla *et al.* 2001, Do Linh San *et al.* 2007a), i la mida del domini vital sol ser d'uns quants quilòmetres quadrats, fins a un màxim descrit de 25 km^2 (Kowalczyk *et al.* 2003). D'altra banda, a les poblacions d'elevada densitat, els grups poden arribar a incloure fins a 25 individus, incloent-hi adults d'ambdós sexes (Rogers *et al.* 1997), els corresponents territoris poden arribar a ser de només 0,14 km^2, i rarament arriben al quilòmetre quadrat (Cheeseman *et al.* 1981). Les grans densitats poblacionals enregistrades en els ambients plujosos de les illes Britàniques, caracteritzats per una relativa baixa estacionalitat (elevada humitat constant al llarg de l'any i un ventall tèrmic reduït), han estat típicament associades a l'abundància de cucs de terra en alguns dels ambients més modificats per l'acció humana: praderies i terres dedicades a la ramaderia extensiva (Kruuk i Parish 1981). Pel contrari, en els ambients mediterranis els teixons no s'han especialitzat en el consum de cucs de terra, segurament, a causa de l'escassa abundància (Virgós 2001), sinó que consumeixen preferentment fruits i una gran varietat d'invertebrats (insectes, caragols, cucs de terra) i també petits mamífers (Corral-Vistué 2003, Rosalino *et al.* 2005a). D'altra banda, els hàbits reservats i nocturns dels teixons els permet, en la mesura del possible, la coexistència amb l'ésser humà. Els caus de teixó, anomenats teixoneres, centre de la vida social del grup, suposen també un recurs limitant, clau per a l'espècie (Doncaster i Woodroffe 1993, Roper 1993). Els grups de teixons necessiten espai subterrani suficient per poder acomplir algunes funcions bàsiques: 1) higièniques: alternança en l'ocupació de les teixoneres per reduir la càrrega parasitària (Butler i Roper 1996, Broseth *et al.* 1997b); 2) reproductives: aïllament d'alguns individus del grup durant l'època de cria per augmentar l'èxit reproductiu (Cresswell *et al.* 1992); 3) energètiques: llocs on descansar durant les hores de llum o durant les èpoques d'hivernada en climes freds i de calor en climes càlids (Fowler i Racey 1988, Kruuk 1989); 4) de seguretat: refugis que redueixen el risc de predació i de molèsties causades per l'acció humana (Butler i Butler 1995, Jenkinson i Wheater 1998). La densitat, localització i característiques del paisatge de les teixoneres es troben entre les propietats més àmpliament estudiades de l'ecologia dels teixons (Roper 1992, Kowalczyk *et al.* 2000, Roper *et al.* 2001, Good *et al.* 2001, Moore i Roper 2003, Wilson *et al.* 2003, Bartmanska i Nadolska 2003, Roper i Moore 2003, Rogers *et al.* 2003, Fischer i Weber 2003, Macdonald *et al.* 2004, Pavlacik *et al.* 2004, Do Linh San *et al.* 2007b), incloent-hi també els ambients mediterranis (Revilla *et al.* 2001, Rosalino *et al.* 2005b, Remonti *et al.* 2006, Loureiro *et al.* 2007). El tipus d'hàbitat és el primer factor determinant en la localització de les teixoneres a Anglaterra (Huck *et al.* 2008). A més, les característiques dels llocs seleccionats per a l'establiment de les teixoneres varien amb el rang de distribució, seleccionant des de terres de pastura i tanques arbustives a Irlanda (Feore i Montgomery 1999, Hammond *et al.* 2001), àrees forestals a Itàlia, arbustos mediterranis al sud de la Península Ibèrica (Revilla *et al.* 2001), o ambients de riera a Barcelona (Bonet-Arbolí 2003).

El teixó ha esdevingut un model per a l'estudi de la socio-biologia dels mamífers ja que la seua plasticitat en l'organització social ha estat entesa com a un estadi primitiu previ a la sociabilitat que presenten alguns carnívors (Woodroffe i MacDonald 1993); això pot resultar clau per a identificar els avantatges ecològics i evolutius que han pogut fixar aquest patró de comportament. La sociabilitat en el teixó no sembla ser el resultat dels beneficis que comporten les activitats cooperatives, ja que aquestes han estat detectades en rares ocasions; sinó que sembla més aviat ser resultat de l'estratègia d'explotació dels recursos. La hipòtesi més àmpliament acceptada per explicar l'evolució dels grups espacials en el teixó és la Hipòtesi de la Dispersió dels Recursos (*Resource Dispersion Hipotesis*, RDH, Macdonald 1983). Segons aquesta hipòtesi, quan els recursos es distribueixen en clapes disperses en l'espai o en el temps, el mínim territori econòmicament defensable que puga suportar l'establiment dels primers colonitzadors, haurà de ser prou extens per a contenir una clapa amb aliment disponible i suficient per mantenir aquest(s) primer(s) colonitzador(s) en el moment de mínima abundància de recursos. Per tant, durant la major part del temps, aquest territori serà prou ric en recursos per albergar individus addicionals sense cap cost per als primers colonitzadors de manera que els desavantatges d'expulsar els nouvinguts són superiors als desavantatges de mantenir-los dins el territori. D'aquesta manera es donaria lloc a la formació de grups sense que fóra necessari cap benefici addicional perquè es formessen grups socials, o aquests serien negligibles. La territorialitat s'interpreta com una adaptació per a la defensa d'un recurs limitant (Woodroffe i MacDonald 1993). En conseqüència, diferents recursos han estat proposats com el factor limitant clau en la territorialitat dels teixons, i llur distribució pot determinar l'organització social de l'espècie. En la seua proposta inicial, la RDH es centrava en la dispersió del recursos tròfics com a factor principal (Macdonald 1983). D'altra banda, Doncaster i Woodroffe (1993) van proposar que, més que la distribució dels recursos tròfics, el factor que determina la mida i morfologia de les àrees dels territoris és la distribució dels caus de teixó (teixoneres), ja que aquests refugis són considerats un element clau per a l'espècie (Roper 1993). Com a resultat, els territoris serien majors que el mínimament necessari per a l'abastiment d'aliment i açò afavoriria el reclutament de més individus en el grup. Per últim, la hipòtesi Anti-Cleptogàmica, postulada per Roper *et al.* (*Anti-Kleptogamy Hypothesis, AKH*, Roper *et al.* 1986), proposa que les femelles tenen una menor territorialitat pel motiu que dediquen més recursos a la defensa dels caus i les cries, que no pas els mascles. De la qual cosa es dedueix que la territorialitat dels mascles tindria una funció de guarda de la còpula a més de la defensa del territori, com proposen Revilla i Palomares (2002). Tot i que aquestes hipòtesis sobre l'origen de l'organització social dels mamífers van ser plantejades originalment per al teixó, són perfectament aplicables a la resta de mamífers de mida gran i mitjana per tal d'identificar les possibles causes que expliquen els patrons d'organització espacial observats en les diferents espècies.

Guineu

La guineu (*Vulpes vulpes* L. 1758) és un cànid que, en ambients mediterranis, sol estar actiu principalment durant la nit (Servin *et al.* 1991, Lovari *et al.* 1994, Lucherini *et al.* 1995). La seua distribució natural quedava restringida a les regions Paleàrtica i Neàrtica, fins que va ser introduïda per l'acció humana a Austràlia als 1870s per al control biològic d'altres poblacions introduïdes de mamífers (Marks i Bloomfield 2006). Actualment, i a nivell mundial, és l'espècie de més amplia distribució entre els carnívors; per tant està adaptada a hàbitats molt diversos (Henry *et al.* 2005). En la Península Ibèrica, és també el carnívor més abundant atès que ocupa la pràctica totalitat del territori (Palomo i Gisbert 2002). Tant les poblacions naturals com les introduïdes, han estat objecte d'estudi en multitud de treballs. En termes generals, les guineus es consideren animals territorials i solitaris, que crien en parelles i amb una organització social estable (Doncaster i Macdonald 1992, Meia i Weber 1996, Goszczynski 2002). En alguns ambients suburbans amb elevades densitats poblacionals, però, poden arribar a conviure un major nombre d'individus per grup i assolir un major grau de sociabilitat (Doncaster i Macdonald 1992). Aquesta sociabilitat es limita a la cooperació en la cria dels cadells de la parella dominant per part dels individus subordinats emparentats amb ells (Cavallini 1996, Baker *et al.* 2004). Tot i així, al contrari del que succeeix amb els teixons, les guineus no solen presentar supressió de la reproducció de les parelles subordinades per les dominants (Mela i Weber 1996, Baker *et al.* 1998). La mida del domini vital mostra una gran variació al llarg de llur àrea de distribució, tot mostrant valors des de 30 ha en ambients urbans, fins a 2.730 ha en zones desèrtiques d'Aràbia Saudita (Jones i Theberge 1982, Marks i Bloomfield 2006). S'oberva un patró general en la mida del domini vital, en què les guineus que ocupen ambients urbans o suburbans tenen àrees menors que les que ocupen zones rurals o naturals. Aquest patró s'ha observat tant en poblacions australianes (Phillips i Catling 1991, Coman *et al.* 1991, White *et al.* 2006) i nord-americanes (Jones i Theberge 1982, Adkins i Stott 1998, Frey i Conover 2007, Silva *et al.* 2009), com europees (Doncaster i Macdonald 1991, Poulle *et al.* 1994, Meia i Weber 1995, Weber i Meia 1996, White *et al.* 1996, Dekker *et al.* 2001). En termes generals, en ambients mediterranis les guineus tenen una dieta omnívora (Fedriani *et al.* 1999) ja que mengen més d'un o altre recurs tròfic en funció de la disponibilitat relativa en cada hàbitat que ocupen. La dieta sol basar-se en fruits (Lovari *et al.* 1994, Rosalino i Santos-Reis 2009) i petits mamífers, principalment rosegadors (Serafini i Lovari 1993, Padial *et al.* 2002, Carvalho i

Gomes 2004). D'altra banda també s'ha observat que l'aliment d'origen humà pot arribar a representar fins la meitat de la ingesta en alguns ambients mediterranis (Cavallini i Volpi 1996).

Porc senglar

El porc senglar (*Sus scrofa* L. 1758) es distribuïa originalment per la regió Paleàrtica, fins que al segle XIX van ser introduits porcs domèstics a Austràlia i EEUU, a partir de la qual es van formar poblacions de porcs salvatges (Barrett i Pine 1981, Dexter 1998). Actualment, els porcs salvatges ocupen 40 dels 50 estats nord-americans (Friebel i Jodice 2009). Tant les poblacions de porc senglars com les de porcs salvatges ocupen àrees relativament petites en relació a la mida corporal i presenten una elevada fidelitat al lloc, però també presenten una gran variació en relació al domini vital entre individus (Caley 1997, Keuling *et al.* 2008) i també al llarg de la seua distribució, amb valors que van des de 33 fins a 13.000 ha (Janeau i Spitz 1984, Russo *et al.* 1997). L'organització social és matrilineal, basada en els grups de femelles, que poden incloure diverses generacions d'adults i subadults més la descendència de l'any (Poteaux *et al.* 2009). Els individus juvenils solen cobrir àrees més grans que els grups familiars, i aquestes diferències es relacionen amb moviments exploratoris fora del territori natal (Cousse *et al.* 1994, Keuling *et al.* 2008). S'ha observat que l'ocupació d'espai dels porcs senglars pot respondre a diversos factors com la disponibilitat de recursos (p.ex. aliment, aigua o refugi), canvis demogràfics (p.ex. mida del grup, densitat, composició de sexes) i pertorbacions produïdes per l'activitat humana (p.ex. cacera, activitats recreatives, etc. Boitani *et al.* 1994, Keuling *et al.* 2008, Keuling *et al.* 2009). La densitat poblacional i l'abundància d'aliment han estat descrits com els principals factors que determinen la mesura del domini vital, però els seus efectes són difícilment distingibles l'un de l'altre (Baber i Coblentz 1986, Massei *et al.* 1997). A Catalunya, com a la resta d'Europa, llur àrea de distribució s'ha expandit durant els darrers 30-40 anys (Saez-Royuela i Telleria 1986, Rossell *et al.* 1998). En la dieta del porc senglar, la matèria vegetal pot arribar a representar fins a més del 90 % de la ingesta, la meitat de la qual es correspon amb plantes agrícoles (Gimenez-Anaya *et al.* 2008). Les espècies vegetals més consumides en ambients mediterranis són els aglans, les olives i els pinyons (Massei *et al.* 1996).

Gat mesquer

El gat mesquer (*Genetta genetta*) és un vivèrrid que fou introduït al sud-oest d'Europa en temps històrics, probablement com a predador domèstic de rates al nord del Marroc i a la Península Ibèrica (Morales 1994). Actualment ocupa les sabanes de l'Àfrica sub-sahariana, el Magreb, les penínsules Aràbiga i Ibèrica, alguna de les illes Balears i algunes regions de França i nord d'Itàlia (Gaubert *et al.* 2008). A Collserola, el mínim poblacional ha estat calculat en 0,98 individus/km^2 (Camps-Munuera i Llimona-Llobet 2004), mentre que al sud de la Península

Ibèrica aquest valor és de 0,33 (Palomares i Delibes 1994). El gat mesquer presenta el típic patró de distribució espacial de carnívor solitari (Vigo 2002). Els mascles solen tindre àrees vitals majors que les femelles, ja que d'una banda tenen més massa corporal i per tant majors requeriments tròfics, i de l'altra, ampliant l'àrea vital inclouen un major nombre de territoris de femelles diferents. Per la seua banda, les femelles, en tenir àrees menors, poden mantenir-se prop dels nius i així aportar-los aliment i defensar-los front a possibles predadors (Camps-Munuera i Llimona-Llobet 2004). El gat mesquer es troba en una situació intermèdia entre els típics carnívors generalistes, com la guineu, i els més especialistes, com la mostela (Virgós *et al.* 1999). A Collserola, la seua dieta es basa principalment en ocells i rosegadors (Pasquina i Cahill 2002), pel que podem dir que té una dieta més especialitzada que el teixó, la guineu o el porc senglar, al Parc. Els gats mesquers passen la major part del temps descansant als refugis (Palomares i Delibes 1988, 1994), per la qual cosa els caus desenvolupen un paper important en la seua biologia. Solen seleccionar els matollars densos i els forats als arbres com a refugi davant de predadors o gossos solts (Palomares i Delibes 1994, Camps-Munuera i Llimona-Llobet 2004).

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Objectius

OBJECTIUS

L'objectiu general d'aquesta tesi és avançar en el coneixement de l'ús que els mamífers de mida gran i mitjana fan del paisatge mediterràni amb diferents nivells d'urbanització i de quina manera les variacions en aquest s'associen a variacions en el comportament, l'ecologia i, per tant, en la conservació. Tenint en compte el creixement de la població humana en àrees mediterrànies i el desenvolupament de les infraestructures que acompanyen aquest creixement, l'estudi de les respostes de l'ús del territori en aquests ambients periurbans poden resultar de gran utilitat en un futur a mitjà i llarg termini, quan gran part dels espais naturals mediterranis es trobaran sota aquestes condicions "periurbanes". Les diferents característiques de cada espècie estudiada i el comportament esquiu i quasi pràcticament nocturn que presenten, implica la integració de diferents metodologies per al seu estudi. Per tal d'abordar aquesta proposta inicial, l'estudi es planteja a diferents nivells d'anàlisi i des de perspectives diferents. La primera part de la tesi, integrada pels capítols ú al tres, tracta sobre l'organització espacial dels individus, analitzada tant des del punt de vista de l'organització de l'espai, com de la selecció de l'hàbitat. La segona part de la tesi, formada pels capítols quatre i cinc, tracta d'una problemàtica més unida a les característiques periurbanes de Collserola: la incidència del trànsit viari sobre la supervivència de les espècies i la connectivitat de l'àrea amb altres zones perifèriques.

Objectius específics

Capítol 1 Analitzar de quina manera les diferències en el paisatge s'associen a diferències en el patró espacial en dos poblacions de teixó. Estudiar la mida dels grups, domini vital, àrees de màxima activitat, densitat poblacional i patró de comportament espacial dels teixons als parcs de Collserola i Montserrat mitjançant el marcatge d'individus amb collars radio-emissors.

Capítol 2 Analitzar la disponibilitat dels diferents tipus d'hàbitat en la mesura que afecta la situació dels dominis vitals, nuclis d'alimentació i la ubicació dels caus; per a la qual cosa s'ha estudiat la selecció de l'hàbitat dels teixons de Montserrat i Collserola en relació al nivell de domini vital, nuclis d'alimentació, i l'ambient circumdant a les teixoneres.

A partir dels resultats obtinguts amb la selecció de l'hàbitat dels teixons en el capítol anterior, al **Capítol 3** es va desenvolupar un altre treball sobre la selecció de l'hàbitat de tres espècies més de mamífers del parc de Collserola: guineus, gats mesquers i porcs senglars, per tal d'esbrinar els hàbitats importants per a cada espècie i observar si hi ha un patró general per al conjunt d'espècies.

En el **Capítol 4,** segona part d'aquesta tesi, s'analitzen algunes de les variables que poden afectar la localització, estacionalitat i distribució dels atropellaments de mamífers al parc de

Collserola, per tal de trobar algun patró general o específic de cada espècie que ajude a minvar parcialment les morts de fauna salvatge per atropellament, alhora que es redueix la sinistralitat vial en zones perifèriques a espais naturals.

En el **Capítol 5** es realitza una comparativa que té com a objectiu analitzar les diferències i similituds entre zones quant a composició d'espècies mitjançant una aplicació de la teoria de la informació per tal d'esbrinar si l'aïllament del Parc de Collserola i la manca de connectivitat ha tingut ja algun efecte sobre la distribució d'alguna de les espècies en les zones estudiades. Mitjançant la realització d'una campanya de transectes lineals en cerca de rastres d'algunes espècies de meso-mamífer, s'ha comparat la composició específica en tres zones perifèriques del parc, en tres dels parcs circumdants més propers (Montserrat, St.Llorenç del Munt i l'Obac, i Serra Marina), i finalment en les tres zones intermèdies entre Collserola i els tres parcs de destí ("corredors").

Informe dels directors

INFORME DELS DIRECTORS

El doctorand Guillem Molina Vacas presenta en la seva tesi doctoral titulada "**Respostes de l'ús del territori al paisatge en mamífers de mida gran i mitjana**". Els directors de tesi, el Dr. José Domingo Rodríguez Teijeiro i el Dr. Víctor Bonet i Arbolí, informen que aquesta tesi doctoral està composta de cinc treballs de gran qualitat científica en format article. Tres dels articles ha estat publicats recentment, i la resta estan actualment en revisió o seran sotmesos en breu en revistes científiques internacionals de gran prestigi incloses en el *Science Citation Index* (SCI). Passe a detallar a continuació la contribució científica que ha realitzat el doctorant en cada un dels articles, així com els seu factor d'impacte (*Thomson Institute for Scientific Information*):

1**. Spatial ecology of European badgers (*Meles meles*) in Mediterranean habitats of the North-Eastern Iberian Peninsula. I: home range, spatial distribution and social organization.**

Guillem Molina Vacas, Víctor Bonet i Arbolí, Elena Rafart Plaza & José Domingo Rodríguez Teijeiro

Vie et Milieu — Life & Environment (2009) 59 (2) : 227-236

Factor d'impacte (2008): 0.723

- El doctorant G.M.V. ha contribuït en el disseny de l'experiment, en la recollida i anàlisi de dades i en la redacció científica.

2. Spatial ecology of European badgers (*Meles meles*) in Mediterranean habitats of the North-Eastern Iberian Peninsula. II: habitat selection.

Guillem Molina Vacas, Víctor Bonet i Arbolí, Elena Rafart Plaza & José Domingo. Rodríguez Teijeiro

Vie et Milieu — Life & Environment (2009) 59 (2) : 237-246

Factor d'impacte (2008): 0.723

- El doctorant G.M.V. ha contribuït en el disseny de l'experiment, en la recollida i anàlisi de dades i en la redacció científica.

3. Habitat selection of three meso-mammal species in an isolated and highly antropogenic Mediterranean park: a multilevel approach.

Guillem Molina Vacas, Víctor Bonet i Arbolí, Seán Cahill, Elena Rafart Plaza, Francesc Llimona & José Domingo. Rodríguez Teijeiro

Italian Journal of Zoology (Sotmès a revisió)

Factor d'impacte (2009): 0.800

- El doctorant G.M.V. ha contribuït en el disseny de l'experiment, en la recollida i anàlisi de dades i en la redacció científica.

4. Atropellos de mamífero y tráfico en la red viaria de un espacio natural en el área metropolitana de Barcelona: quince años de seguimiento en el Parque de Collserola.

Anna Tenés, Seán Cahill, Francesc Llimona y Guillem Molina Vacas

Galemys (2007) N.E.: 169-188

Sense factor d'impacte

- El doctorant G.M.V. ha contribuït en el disseny de l'experiment, en la recollida i anàlisi de dades i en la redacció científica.

5. Assessing difference in the meso-mammal community composition between neighbouring natural areas by means of transect surveys: an information theory approach.

Guillem Molina Vacas, Eduardo Antonio García Galea, Víctor Bonet i Arbolí & José Domingo Rodríguez Teijeiro

Biodiversity and conservation (Pendent de sotmetre)

Factor d'impacte (2009): 2.066

- El doctorant G.M.V. ha contribuït en el disseny de l'experiment, en la recollida i anàlisi de dades i en la redacció científica.

SPATIAL ECOLOGY OF EUROPEAN BADGERS (*MELES MELES* L.) IN MEDITERRANEAN HABITATS OF THE NORTH-EASTERN IBERIAN PENINSULA I: HOME RANGE SIZE, SPATIAL DISTRIBUTION AND SOCIAL ORGANIZATION

G. Molina-Vacas, V. Bonet-Arbolí, E. Rafart-Plaza & J. D. Rodríguez-Teijeiro

Vie et Milieu - Life and Environment, 2009, 59 (2): 227-236

Capítol 1

CAPÍTOL 1

Spatial ecology of European badgers (*Meles meles* L.) in Mediterranean habitats of the North-Eastern Iberian Peninsula I: home range size, spatial distribution and social organization

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EUROPEAN BADGER,
IBERIAN PENINSULA
MEDITERRANEAN HABITATS
MELES MELES
SOCIAL ORGANIZATION
SPATIAL ECOLOGY
HOME RANGE SIZE

ABSTRACT. – Although there are some radio-telemetry studies on badger spatial organization in sub-humid Mediterranean lowlands, cork oak woods and Atlantic highland forest (in the South, West and North of the Iberian Peninsula respectively), the present study is the first carried out in the Mediterranean forests of the NE Iberian Peninsula in the parks of Collserola and Montserrat, close to Barcelona. The home range of 13 adult badgers (six males and seven females) was examined with the aim of providing results to compare with previous studies in order to advance in the understanding of badger social organization with special regard to low density populations in Mediterranean environments. Mean home range size was 307.6 ha ± 96.4 (± SE) and 72.8 ha ± 15.1 for males and females respectively for MCP95 and 287.4 ± 79.1 and 85.1 ± 26.6 for FK95 with differences between Parks. In addition, the home ranges of Collserola males were over four times larger than those of females, while for Montserrat this figure was 1.5. Moreover, badger groups were formed by one to three individuals in Collserola, and at least three individuals in Montserrat. This discrepancy points to a distinct social organization associated with differences in population densities (0.6 ind./km^2 in Collserola and 1.9 ind./km^2 in Montserrat) and landscape structure conditions. Our results suggest that the home range configuration of males is driven by female distribution in space

INTRODUCTION

The European badger (*Meles meles*) shows large intraspecific variation in social organization which is understood to reflect ecological, demographic and behavioural plasticity (Palphramand *et al.* 2007). Populations throughout Europe present a two-order of magnitude variation in density, which parallels considerable variation in social spacing. Population density varies from less than one ind./km^2 in Poland (Kowalczyk *et al.* 2000) and the South of Spain (Revilla & Palomares 2002), to over 38 ind./km^2 in some areas of Britain (Johnson *et al.* 2002). In brief, low density populations are found at the northern (e.g. Broseth *et al.* 1997) and southern (e.g. Revilla & Palomares 2002) edges of its distribution range while higher densities occur at medium latitudes, reaching a maximum in the British Isles and Ireland (see review in Johnson *et al.* 2002). In general terms, it seems that badger population density is higher in environments with minor differences between seasonal characteristics (i.e. temperature, rain, etc.) compared to more variable ones. Associated with this, the spatial distribution of individuals within populations is highly variable. In low density populations, groups are usually composed of one (Pigozzi 1987) to three individuals (Do Linh San *et al.* 2007a, Revilla *et al.* 2001) and territory size reaches several square kilometre, up to 25 km^2 (Kowalczyk *et al.* 2003). In contrast, in high density populations, groups can include over 25 individuals, including several adults of both sexes (e.g. Rogers *et al.* 1997) and territories rarely reach one square kilometre, being as small as 0.14 km^2 (Cheeseman *et al.* 1981).

The badger has become a model in mammal socio-biology because its plasticity in social organization has been understood as a primitive level of sociality in carnivores (Woodroffe & Macdonald 1993). Sociality in badgers does not seem to be a result of the benefits of cooperative activities, as these have rarely been detected, but rather a result of a resource exploitation strategy. The most persistent ecological theory for the evolution of spatial groups is the *Resource Dispersion Hypothesis* (RDH; Macdonald 1983). In brief, it asserts that, when resources are patchily distributed in space and/or time, the smallest, economically defensible territory able to support its primary holders would usually be rich enough to support additional individuals with little or no cost to the primary holders. Therefore, a benefit is not necessary for spatial groups to develop, or benefits are considered almost negligible. Territoriality is supposed to be an adaptation for the defence of a limiting resource (Woodroffe & Macdonald 1993). Accordingly, different resources have been proposed as the key factors driving badger territoriality, and their distribution would determine badger spatial organization. In the original form, RDH focuses on food dispersion as the main factor (Macdonald 1983). Doncaster & Woodroffe (1993) argued that the distribution of setts, which are considered a key resource for the species (Roper 1993), rather than food, determines territory size and shape, resulting in territories that are larger than needed in relation to food abundance and, thus, allow more individuals to stay (*Sett Dispersion Hypothesis,* SDH). Finally, the *Anti-kleptogamy Hypothesis* (AKH; Roper *et al.* 1986) proposes that the availability of breeding opportunities is the most important factor in male spatial distribution. Accordingly, territoriality in males would have a mate-guarding function, as also proposed by Revilla & Palomares (2002).

In order to improve our understanding on badger socio-spatial organization in low-density Mediterranean populations, and also in a global context, we studied the home range size, group size and population density of two badger populations of the North-Eastern Iberian Peninsula by means of radio-tracking, den-watching, and camera trapping between 1997 and 2007. The specific objectives of the present investigation were 1) to describe badger socio-spatial organization in our study areas to assess which of the above-mentioned explanatory hypotheses fits best with the obtained results, and 2) to compare our data with other European studies.

MATERIALS AND METHODS

Study areas

The Park of Collserola (41º27'N, 2º6'E) is an 85 km^2 natural space belonging to the Catalan Coastal Cordillera, which spreads over about 100 km in a North-South direction, parallel to the Mediterranean Sea, roughly 10 km away from the coastline. This space is naturally separated from the rest of the cordillera by the rivers Besòs to the NE and Llobregat to the SW. Its south-eastern limit is formed by the city of Barcelona and the rest of its perimeter is almost closed by a belt of cities and highways except for two narrow corridors to the north. It is basically composed of slates with some granite outcrops on the northern side and calcareous outcrops to the south. Altitude ranges from 50 to 512 m above sea level. Mean annual temperature and rainfall are 14ºC and 672 mm respectively, with wide seasonal variations in both factors. Summer is usually the hottest and driest season, whereas spring and autumn are the wettest ones and winters are mild. The inner 80 % of the park surface is covered by dense woodland, largely dominated by the Aleppian pine (*Pinus halepensis*) and the holm oak (*Quercus ilex*), with very dense undergrowth. At the periphery, vegetation mostly consists of Mediterranean scrub patches, basically composed of tree heath (*Erica arborea*) and rock rose (*Cistus* sp.). These peripheral areas hold most of the small amount of agricultural activity remaining inside Collserola (8 % of its area). Even though some areas of Collserola can be classified as sub-urban habitats, most of it retains the features of a wild natural space.

The second study area is located on the southern side of Montserrat Mountain Natural Park and in its agricultural surroundings (41º36'N, 1º48'E), 40 km NW of the city of Barcelona (16 km apart from Collserola Park) with an area of over 50 km^2. The Montserrat massif shows a particular relief with a columnar appearance. It is formed basically by conglomerates created by alluvial sedimentation. Large alluvial cones were raised by Alpine tectonics which originated the Catalan Precoastal Cordillera. Altitude ranges from 250 m to 1224 m. Climate is typically Mediterranean, similar to Collserola, but is drier and hotter on the southern side. Wood and scrub are the dominating vegetation types with the same species as in Collserola Park. This vegetation alternates with croplands: olive crops (*Olea europaea*), vineyards (*Vitis* sp.) and cereal crops. The two populations live in similar habitats, however with the following differences. Montserrat is less woody and more patchy and has a higher proportion of fruit crops relative to cereal crops. In addition, these Parks have notable differences in connectivity levels and human pressure. The badgers in Collserola and Montserrat are considered as separated populations owing to the high level of infrastructures that isolate Collserola from the rest of the surrounding natural habitats.

Badger capture and radio-telemetry

Trapping took place between 1997 and 2006. Badgers were captured with padded leg hold traps (Victor Soft Catch 1.5, Woodstream Corp Lititz, PA) placed on well-used badger paths near setts or latrines, which is the most effective method for capturing badgers in Mediterranean landscapes (Bonet-Arbolí 2003, Loureiro *et al.* 2007, Muñoz-Igualada *et al.* 2008, Rafart-Plaza 2005). Traps were checked and defused every day at dawn to avoid trapping domestic animals, and were activated again at dusk. All the Recommendations of the Animal Welfare Protocol of the European Union were followed and no badger was injured during handling. Badgers were anesthetized by intramuscular injections of combinations of ketamine and xylazine hydrochloride (Kreeger 1997), diazepam or medetomidine (Palphramand *et al.* 2007). Sex, body mass to the nearest 0.1 kg and morphometric measurements were taken. We estimated the age of animals on the basis of tooth wear, body mass and date of capture (da Silva & Macdonald 1989). Only adults were equipped with a radio-transmitter (TW-5, Biotrack Ltd.). We used a portable VHF receiver (R1000, Communications Specialists Inc.) and a handheld three element Yagi antenna (Biotrack Ltd.) for radio-tracking data collection. Locations were taken with the triangulation method (White & Garrot 1990), as direct observation was impossible in most badger ranges because of the dense undergrowth of the wood.

The radio-tracking protocol was established as follows. The night (19h00-07h00, in solar time) was divided into four periods of three hours each. Each radio-tracking session consisted of one or two periods, during which we recorded as many locations as possible. We recorded all bearings for each radiolocation within a 10-minute interval to reduce error associated with badger movement and within 45-135º intervals for cross bearings. Exceptions to this were the first night after the release of the animal and when a particular animal was difficult to find. In these cases, radio-tracking took place for the whole night. Each individual was followed for at least one session every ten days when possible.

Space use analyses

Radio-tracking data and spatial estimators were calculated with Range VII software (South *et al.* 2005). Thirteen out of the 15 monitored badgers had reached home range stabilization according to the Incremental Area Plot method (hereafter IAP; Harris *et al.* 1990), which represents the accumulated area used with the increasing number of fixes. Only active locations outside the sett (n = 640) of these 13 badgers were used for the analyses. No major changes in the environment were noted during the 10-year study period, so we analyzed all territories irrespective of the year during which data were collected. To avoid problems in home range estimators caused by unequal time intervals between locations we first randomly deleted locations until they were at least one hour apart in the same night-period (de Solla *et al.* 1999). When individual home ranges overlapped with others simultaneously, a Multi-Response Permutation Procedures test (MRPP, Biondini *et al.* 1988) was performed in order to test for significant differences in space use. If significance was not reached, badgers were considered as members of the same group, the home range of which was obtained by merging all fixes. In spite of criticism (Borger *et al.* 2006), the Minimum Convex Polygon (hereafter MCP) is the method employed most frequently in home range studies. However, MCP requires a subjacent uniform distribution of data, and it is therefore not necessarily optimal for comparing data across studies. Otherwise, the Kernel method seems to be a better index for home range description, but it also has the problem that the bandwidth selection method has a great influence on the results, which prevents robust comparisons between studies (Laver & Kelly 2008). Thus, home ranges were estimated using both methods in order to provide better comparability with other studies: Minimum Convex Polygon with 95% of locations (MCP95) and fixed kernel estimator (Worton 1989) with 95% of the utilization distribution (FK95) as recommended by Laver & Kelly (2008). For fixed kernel estimates an optimal smoothing parameter was created for each home range (Kenward *et al.* 2001) by multiplying the smoothing parameter found by the minimum square method (hcv) by a correcting factor (Worton 1995, Seaman & Powell 1996, de Solla *et al.* 1999). This factor was searched, by trial and error, at 0.01 intervals starting from one hcv and was accepted when FK95 was the smallest range that allowed a single shape as a home range (avoiding unconnected patches) as expected for territorial species like the badger (Blundell *et al.* 2001, Borger *et al.* 2006, Hodder *et al.* 1998). Comparisons between sexes and areas concerning mean values of home range estimators (MCP and FK, Table I) were conducted with the Mann-Whitney test using SPSS 15 for Windows (SPSS, Chicago, IL). We obtained similar results for both estimators, so in the text we only show the results of FK to avoid redundant data.

Group size and population density

Group size was estimated in a systematic way for a wooded area of Collserola only, whereas a coarser estimation was obtained for Montserrat. The procedure for the calculation of group size was based on the simultaneous monitoring of all known setts in each home range on a given night. Badgers were very suspicious and shy, and our previous experience showed that, in most cases, they would not come out of a sett if humans were around. In addition, each individual used between at least three and ten setts during their tracking period (Bonet-Arbolí 2003), so a lot of people would be required to simultaneously watch all setts at night. Therefore sett monitoring was performed by sign surveys during two consecutive mornings in order to ascertain which setts had been used by badgers on a given night and in a given range. The sett watching procedure usually extends for three consecutive nights in order to deal with the possibility of badgers occasionally sleeping away from their usual setts. In our case, we decided to perform the censuses over several non-consecutive nights in the course of one year (07/1998-07/1999) in each territory because, although a clear seasonal pattern of sett use exists in Collserola (Bonet-Arbolí *et al.* 2005), badgers frequently, and unpredictably, move away from their favorite setts for several consecutive days within seasons. This monitoring schedule was also useful to dilute the effect that transients visiting a given range for a few days (particularly males, see results) would have on the overestimation of group size in such a low density population. Therefore, results are given as the mean number of individual ± standard error across monitoring sessions, in each home range. Censuses started when the limits of each monitored range had been established by means of radio-tracking, and sometimes extended beyond the death of the tracked individual.

The estimation of the number of badgers based on the number of active setts requires knowledge of all setts in a range. Besides the discovery of new setts thanks to the radio-tracking of badgers, a systematic survey (1992-1995) conducted in an area (*A*) of approximately 400 ha before the beginning of the trapping period allowed us to find several setts of interest for that purpose, because *A* was later partially included in three adjacent badger ranges. The area of *A* represented 65 % of the home range of F5 + F 6, 20 % of the home range of M7 and 96 % of the home range of F9 (Fig. 1). Sett surveys are highly time-consuming in Collserola owing to the roughness of the landscape and the thickness of the vegetation such that it would have been impossible to complete the survey of each territory within the study period. Therefore we used the number of setts (S) found inside A during that previous survey to extrapolate the total number of setts (S_{tot}) in each range. All setts were visited several times during the study period and those that were clearly abandoned by badgers were discarded for the subsequent calculations. In order to take into account those setts that would have gone unnoticed during the survey, together with those built since then, we calculated the survey efficiency from the number of setts that the tracked individuals used within A and which were already known from the previous survey. This figure was 75 % (i.e. in 1992-1995 we found three out of every four setts present in the surveyed area of Collserola at the time of radio-tracking). Therefore, $S_{tot} = [(S/0.75)/A(\text{ha})] * \text{K95(ha)} + \text{outliers}$.

Fig. 1. – a, Location of study areas in the Iberian Peninsula (Montserrat Mountain Park in the upper left corner and Collserola in the bottom right corner). b, c, and d, represent the home ranges of all radio-tagged badgers based on MCP95 contours in the UTM reference system. b, Montserrat study area at a scale of 1:20,000; c, Southern side of Collserola study area (7 individuals) at a scale of 1:33,000; and d, Northern side of Collserola study area (2 individuals) at a scale of 1:21,000. Solid and broken lines represent males and females respectively. Stippled areas represent wooded patches. Only individuals with Incremental Area Plot (the increase in the accumulated used area when adding more fixes) stabilization are represented.

Outliers were setts used by the tracked individuals that were located outside home ranges and setts not used by the tracked individuals and located outside home ranges at a similar distance (mean distance of outlier setts used by the tracked individuals to the border of the home range in question).

Thus, the total number of active setts on a given night (ΔS_{tot}) as extrapolated from the number of setts actually found active (ΔS) is: $\Delta S_{tot} = (\Delta S/S)*S_{tot}$.

Finally, two additional factors are needed to estimate the number of badgers based on the number of active setts: the sett changing rate (i.e. the frequency with which badgers change from one sett to another between two consecutive days) and sett sharing frequency.

Concerning the sett changing rate, the use of the same sett on two consecutive days by an individual results in one active sett/badger whereas sett shifting would result in two active setts/badger. With radio-tracking data and using 23 series of two consecutive days spread over the four seasons (of all individuals in these three territories), the probability of returning to the same sett was 0.48 and the probability of moving to another sett was 0.52. Therefore, we assumed 0.5 frequencies for each situation and we thus obtained ¾ badgers/active sett, if $\Delta S_{tot} > 1$.

Sett sharing frequency was estimated by opportunistically setting camera-traps at setts that seemed to be in use all around the ranges of Collserola where the censuses took place. We detected two badgers on only one occasion out of the nine sampled nights (12.5 %). Given this low figure we assumed that each active sett was occupied by a single badger on a given day.

In Montserrat, a camera trapping survey was carried out over two periods: the first one during the trapping sessions in order to confirm badger activity in setts, and the second one, one year later, to detect and identify the maximum number of individuals per group. 373 camera/night were placed near sett entrances, badger paths and latrines, in the three territories (two of them holding one radio-tagged badger and one holding two) as well as in an adjacent control area without tagged animals but with known badger activity (Area *O*). Each camera was in place for an average of only 3.73 days at a given site, so results were considered together with those obtained by live-trapping and must be considered with caution. The minimum number of recorded individuals in each home range was used as an estimator of group size.

Population density was calculated on the basis of total recorded individuals across groups, per study area, and two figures are presented, one considering only the area occupied by ranges on the one hand and a wider area encompassing all ranges on the other.

RESULTS

We obtained sufficient data for 13 radio-tracked badgers that had reached home range stabilization as judged from the IAP (six males and seven females, Table I, 578 fixes, mean = 44.46 ± 30.17, range 20-127). These were all of the Montserrat individuals (two males and two females) and nine badgers from Collserola (four males and five females). In terms of home range size, in Collserola we found differences between the sexes (FK95: ♂ = 388.1 ± 72.8 ha, ♀ = 95.2 ±37.3 ha; $U = 1$, $P = 0.027$). Two females (F5 and F6) had overlapping home ranges (MRPP test, $\delta = 0.809$, $P = 0.42$, F5 + F6 FK95 67.0 % for F5 and 79.4 % for F6, Fig. 1) and were therefore considered as belonging to the same group. The magnitude of the difference between the sexes did not seem as high in Montserrat Mountain Park (FK95: ♂ = 85.9 ± 32.8 ha, ♀ = 59.7 ± 2.3 ha), but the small sample size precludes statistical analysis. In Montserrat, the home ranges of M2 and F4 overlapped almost completely (MRPP test, $\delta = 0.809$, $P = 0.79$, M2 + F4 FK95 overlap = 81.7 % for M2 and 75.7 % for F4, Fig. 1). However, in spite of a small overlap between the ranges of M1 and F3, the locations of these two individuals were significantly separated in space ($\delta = 48.287$, $P < 0.001$, M1 + F3 FK95 overlap = 8.8 % for M1 and 5.2 % for F3, Fig. 1). Therefore, M2 and F4 were considered members of the same group, whereas M1 and F3 belonged to separate groups. According to home range size tests, we distinguished three badger groups for further analysis: Montserrat badgers, Collserola males and Collserola females. There was a significant difference between

Badger ID	Tracking period DD.MM.YY	Cause	Fixes	Home Range MCP95	FK95
M1*	18.12.99−02.01.01	Battery ran out	44	117.7	118.7
M2*	07.02.00−17.10.00	Broken collar	29	63.8	53.1
F3*	23.02.00−08.09.00	Battery ran out	22	57.5	62.0
F4*	08.02.00−12.10.00	Battery ran out	24	53.9	57.3
F5†	17.02.97−22.07.97	Death (unknown)	45	77.4	58.1
F6†	17.02.97−03.03.99	Death (unknown)	85	57.8	49.0
M7†	24.01.98−09.07.98	Death (poaching)	34	284.6	314.4
F8†	05.02.99-03.05.99	Death (road-kill)	9	-	-
F9†	03.03.99−19.08.99	Broken collar	28	88.2	135.9
F10†	23.03.00−14.01.01	Death (Poaching)	29	23.7	12.1
M11†	11.11.03-04.12.03	Signal loss	4	-	-
M12†	16.06.04−13.06.05	Broken collar	52	450.3	501.4
M13†	31.07.05−17.11.06	Battery ran out	39	227.0	219.0
F14#	16.02.06−10.03.06	Broken collar	20	151.0	221.0
M15#	02.12.06−23.07.07	End of field work	127	702.2	517.7
Mean Montserrat males ± SE (*n*=2)			37 ± 8	90.8 ± 27.0	85.9 ± 32.8
Mean Montserrat females ± SE (*n*=2)			23 ± 1	55.7 ± 1.8	59.7 ± 2.3
Mean Collserola males ± SE (*n*=4)			63 ± 22	416 ± 106.5	388.1 ± 72.8
Mean Collserola females ± SE (*n*=5)			41 ± 12	79.6 ± 20.9	95.2 ± 37.3
Mean males ± SE (*n*=6)			54 ± 15	307.6 ± 96.4	287.4 ± 79.1
Mean females ± SE (*n*=7)			36 ± 9	72.8 ± 15.1	85.1 ± 26.6

Table I. – Location, radio-tracking period, cause of the end of tracking, number of radio locations, and home range size (ha). *M* male, *F* female. * Montserrat Mountain Natural Park, † Southern side of Collserola Park, and # Northern side of Collserola Park.

these groups (Kruskal-Wallis test, FK95: H = 6.89, *df* = 2, *P* = 0.032): Collserola males have larger home ranges than Collserola females (FK: *U* = 1, *P* = 0.032) and Montserrat badgers (FK: *U* = 0, *P* = 0.028), whereas Collserola females and Montserrat badgers have similar home range sizes (FK: *U* = 10, *P* = 1). According to IAP functions, we found two different patterns of home range exploitation. All females and males M1, M2 (Montserrat) and M13 (Collserola) gradually reached the maximum size of their ranges by regularly moving across their home ranges, whereas the remaining males (all of them belonging to Collserola) and female F3 (Montserrat) increased their home range by exploiting different areas at different times, which entails a sharp rise in the IAP curve (Fig. 2).

Census and group size in the wooded area of Collserola

During the census period, one to three badgers were detected in home range F5 + F6 (mean: 1.5 ± 0.3, n = 7 monitoring sessions); zero to two individuals were detected in home range M7 (1.8 ± 0.5, n = 4, M7 was not found during one of the censuses) and one individual was detected in home range F9 in the two monitoring sessions carried out. In home range F5 + F6, the monitoring sessions were carried out after the death of F5. Therefore, while this home range was used by at least two females in 1997, the number of animals during the following two years was normally one (F6), although we detected two individuals on one occasion and three individuals on another. In home range M7, the most frequent number of badgers detected was two, while it is clear that F9 ranged alone during its tracking period. Taking into account the size of the home ranges, badger density in the wooded part of Collserola during the study period was 1.6 individuals/km^2 (considering only the area occupied by the three territories). Given that these territories were adjacent, the density within the MCP100 drawn around all locations of all individuals (720 ha) was 0.6 individuals/km^2.

In Montserrat at least three badgers were detected in home range M1: M1 and two other non-tagged adults, which could be distinguished by the different tonality of their hair. In home range F3 we found a minimum of three badgers as well: F3 and two subadults, which were probably her previous year's offspring. Home range M2 + F4 also contained three animals: M2, F4 and one non-tagged adult. Finally, in Area *O* we again identified a minimum of three individuals (one adult, one sub-adult and one cub) by camera trapping. So we obtained a minimum group size of three individuals (adults and sub-adults) per home range and a population density of 1.9 individuals/km^2

Ranging patterns

Males seem to range over larger areas than females in Collserola. For example, M7 was caught in January 1998 and was consistently detected within the eastern half of its home range (Fig. 1) and slept in dens within that part of the home range. In April, it started to exploit the neighboring female home range (F5 + F6) and slept in a den in the overlap zone, while occasionally returning to its former range to forage and rest. In July it disappeared from the study area, returning in October to the F5 + F6 home range, when it was shot by a poacher. Similarly, individual M12 was caught near a sett in June 2004, in the western part of its home range and its signal was lost after release. In August, it was found foraging and sleeping in the opposite (Eastern) corner of its home range, and in February 2005 it returned to the original home range inhabited by at least one female (as judged from the presence of signs made by cubs). Finally its collar was broken when it moved to a new area in June 2006.

Although one-night excursions far away from the normal range were performed by several individuals in both study areas, no such movements lasting for several weeks were observed for the Montserrat individuals or Collserola females. The high mobility of males is further illustrated by the fact that two males disappeared from the area in which they were caught, shortly after release. One of them was caught the same day at the same sett that F10 was caught, the signal of its transmitter having been lost the night of its release. Another one was caught inside the home range of M12, eight months before M12, and after a few days of tracking, it disappeared. Although a failure in the radio system cannot be ruled out, this never happened to Montserrat individuals or Collserola females. Indeed, the sole Collserola female for which we could not gather enough data to calculate its home range was followed for two months before it was killed by a car. This female was consistently using the western third of the F5 + F6 home range (when F6 was already dead) but it slept outside the limits of this home range.

In Montserrat the three studied territories contained at least three members, with at least one of them containing individuals of both sexes (M2 + F4). In contrast, in Collserola, F9 was solitary in its home range, as revealed by the systematic census carried out. Several one-day visits at all known setts in the small range of F10 suggested that this female was living solitarily as well. On the other hand, F6 sometimes shared its home range with one or, occasionally, two additional individuals (one of them was F5 in 1997), but the census revealed that it was sometimes ranging alone.

DISCUSSION

For both study areas we found population density values close to those obtained for the South and West Iberian Peninsula (Revilla & Palomares 2002, and Rosalino *et al.* 2004 respectively). These results are also comparable to those obtained by Kowalczyk *et al.* (2000) in Bialowieza Primeval Forest, and place our populations at the corresponding low population density level of the sclerophyllous Mediterranean dry forests (Virgós & Casanovas 1999) in contrast to badger populations inhabiting the British Isles (Johnson *et al.* 2002). Along with the low population densities, territories were large, particularly in the case of Collserola males. Only badgers from Poland and the south of the Iberian Peninsula have larger home ranges than Collserola males at a lower population density (Kowalczyk *et al.* 2003, Revilla *et al.* 2001).

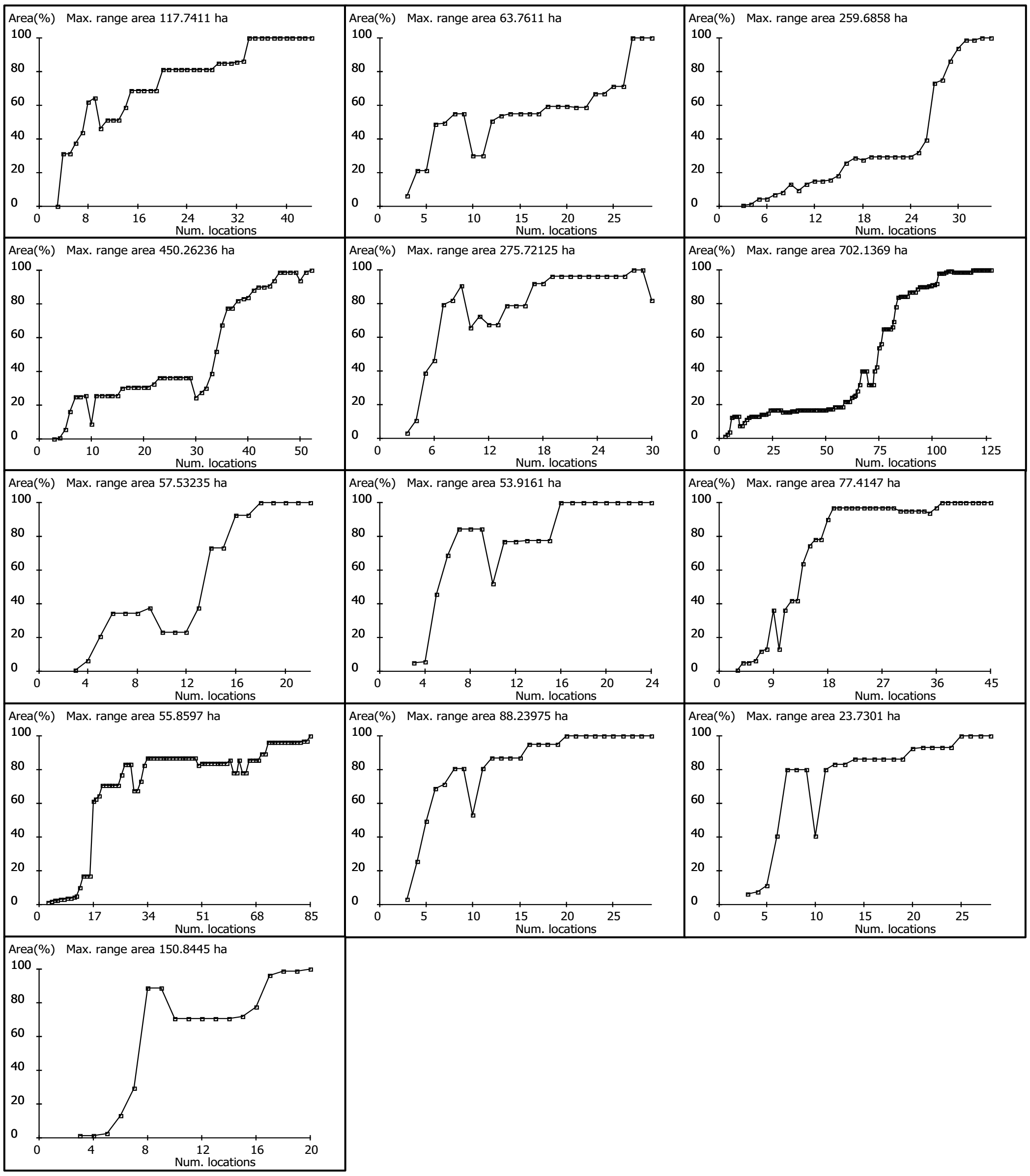

Fig. 2. – Incremental Area Plot for MCP95 for individuals which reached the home range stabilization (M1 to M15). Same plotting was conducted for FK95 with similar results (MRA= Maximum Range Area).

Even though the small sample size in Montserrat precludes statistical analysis, it is clear that the magnitude of the difference between male and female home range sizes is much greater in Collserola than in Montserrat (Table I): Collserola males had a mean home range size over five times that of females for MCP95 and over four times for FK95, whereas for Montserrat this figure was less than two for both estimators (Table I). In addition, for MCP95 the smallest male home range in Collserola (M13) was 1.5 times larger than the largest female home range (F9) while in Montserrat the smallest male home range (M2) had a size comparable to that of females.

Similar, but less marked, tendencies for male home ranges to be larger than those of females have been reported for some other low density populations (Do Linh San *et al.* 2007b, Kowalczyk *et al.* 2003). No such striking differences in home range size between sexes have been reported for any other European population (e.g. Bodin *et al.* 2006, Palphramand *et al.* 2007, Kowalczyk *et al.* 2003, Remonti *et al.* 2006). Nevertheless, the situation in Collserola is similar to that of Hinode in the suburbs of Tokyo where male badgers have territories three times larger than females (Kaneko *et al.* 2006). This difference in home range size is attained by males by exploiting different areas of their territories at different times of the year (as judged from IAP patterns). Therefore, all evidence strongly suggests that males are more mobile than females and exploit or occasionally visit different areas at different times. In Montserrat, even though the sample size was small, all evidence points to the fact that badgers form classical mixed-sex groups of small size like other European low density populations. In Collserola, the basic territorial unit seems to be a solitary female, which would be the first animal to settle in an empty area based on the richness in trophic resources (Tuyttens *et al.* 2000b, Tuyttens *et al.* 2000a). It may subsequently associate with other individuals under unknown conditions, probably females, as suggested by the fact that the only two individuals tracked at the same time that completely overlapped their ranges were two females (F5 and F6). Assuming that both sexes have similar overall metabolic requirements, and therefore the difference in home range size can not be explained by differences in energetic needs, the large difference in home range size in Collserola suggests that females are the key resource in male spatial organization, as predicted by the AKH (Neal & Cheeseman 1996, Roper *et al.* 1986).

We found a notable difference in population density between the two Parks (Collserola 0.6 individuals/km^2, Montserrat 1.9 individuals/km^2), in spite of them having similar habitat, weather and soil conditions. This may reflect the fact that, even though there are few habitat differences between Collserola and Montserrat when grouping habitats into main categories, Montserrat Park has a higher proportion of fruit crops than cereals, which could provide higher food availability. In addition, the Collserola badger population is physically isolated from other surrounding natural reserves and suffers a higher influx of people than Montserrat, which means higher levels of badger sett disturbance, poaching and road-kill risk. Nevertheless, it has to be borne in mind that the systematic census was carried out in a wooded part of Collserola and, even though this is representative of 80 % of the Park's area, several indications suggest that density may be higher in the agricultural periphery. For example, visual observations on one night revealed at least three badgers wandering around a sett used by M12 in the agricultural periphery of Collserola (G Molina-Vacas pers. obs.). This suggests that group size in agricultural areas may be higher than in wooded areas. Given that territories were similar in size, density may be higher as well. In contrast, we found a strikingly small home range in that agricultural part of Collserola (the range of F10 was less than half the size of the range of the other females) and its female inhabitant was apparently living solitarily. Therefore, a higher density could also be reached by the juxtaposition of very small territories in the richest parts of the Park (i.e. the agricultural ones, see Molina-Vacas *et al.*, this issue) inhabited by one, or a few females. More research in the agricultural periphery of Collserola is needed in order to ascertain which the prevailing mode is.

Although it was not the aim of the present paper to discuss territoriality in our populations, all indications suggest that badgers of Montserrat and Collserola are indeed territorial, as is the case for all the studied populations of any density to date, with the possible exception of the Bristol population (Harris 1984). First, the intra-sexual home range overlap is almost a case of all or nothing (c.f. Fig. 1). Second, F9 and F6 were tracked simultaneously for two months without trespassing over their common range borders. Shortly after F6 died, after which its range remained empty for some months, F9 made a two-night excursion deep into the F5 + F6 range. Finally, a fight between two unknown individuals was observed on the border of the F5 + F6 range, which was marked with a combination of visual (i.e. paths) and chemical (i.e. latrines) signs (Bonet-Arbolí 2003).

At first glance, the spatial organization of badgers in Collserola is similar to the typical mustelid spacing pattern (Powell 1979), with the likelihood of females forming groups, probably due to the greater tolerance between females of this species compared to other mustelid species (Woodroffe & Macdonald 1995). The pattern observed in Collserola was first observed by Kruuk (1978) in Wytham Woods. Kruuk observed that 45% of the studied individuals belonged to a specific kind of social group, which he named joint ranges, in which the males' ranges overlapped with those of females from different main setts. We suggest that, at low densities, where females range alone or in very small groups, males need to encompass several female territories in order to increase their mating opportunities, and this could be achieved at low risk for males of encountering other aggressive males. This spatial strategy in males is only achievable if female territories are not too large, which is the case in both study areas, probably due to the existence of sufficient food resources. Where home range richness is very low and females need to have large territories to satisfy their nutritional needs (Broseth *et al.*1997, Rodriguez *et al.* 1996, Revilla & Palomares 2002) males would be unable to encompass more than one female home range, thus giving rise to pairs as a basic unit of social organization. In contrast, at high densities, where several females cohabit, one home range is enough to ensure a high number of mating opportunities, and the probability of encountering aggressive neighboring males is high, so that it would be advantageous for a male to be a permanent member of a multi-female group.

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SPATIAL ECOLOGY OF EUROPEAN BADGERS (*MELES MELES* L.) IN MEDITERRANEAN HABITATS OF THE NORTH-EASTERN IBERIAN PENINSULA II: HABITAT SELECTION

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Capítol 2

CAPÍTOL 2

Spatial ecology of European badgers (*Meles meles* L.) in Mediterranean habitats of the North-Eastern Iberian Peninsula II: habitat selection

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EUROPEAN BADGER
HABITAT SELECTION
IBERIAN PENINSULA
MEDITERRANEAN HABITATS
MELES MELES

ABSTRACT. – The adaptability of badgers to diverse environments under conditions of variable food availability (amount and variety) together with their social organization patterns have allowed them to inhabit a vast geographical range across Europe. Consequently, badger habitat selection has been addressed throughout most of its distribution range in terms of both individual ranges and sett locations. Several versions of the Resource Dispersion Hypothesis have been proposed to explain habitat selection by badgers. Here we performed a compositional analysis to evaluate the habitat preferences of badgers in the NE Iberian Peninsula. For this purpose, we used data from the radio-tracking of 13 adult individuals in two Natural Parks near Barcelona (at home range and core foraging area scale), and also the location data of 39 setts in one of these parks. At the home range level, badgers selected mainly riparian vegetation habitats and avoided residential areas. Similar results were also obtained from the sett environment analysis. However, badgers chose crop fields for core foraging areas. In accordance with previous findings, our results show that badgers in Mediterranean environments choose habitats on the basis of the capacity of these to provide protective shelter rather than on food availability where food is not a critical, limiting resource in the badger environment. We conclude that the same habitat characteristics are chosen for both sett sites and home ranges while agricultural patches define core foraging areas. These results are in accordance with the Sett Dispersion Hypothesis.

INTRODUCTION

The European badger has a wide distribution across Europe (Johnson *et al.* 2002), encompassing a broad range of environments and ecological conditions (e.g. Kowalczyk *et al.* 2003, Kauhala *et al.* 2006, Revilla *et al.* 2000). As a result, badgers are highly adapted to exploiting resources and to living under diverse conditions (weather, vegetation coverage, human disturbance, etc.). Consequently, these animals show high variability in population densities and in their pattern of trophic resource exploitation (niche width, food specialist *vs* food generalist). In addition, they show a variable social organization across their distribution range (Palphramand *et al.* 2007), from groups of up to 25 individuals in England (Rogers *et al.* 1997) to solitary individuals in a Mediterranean habitat in Italy (Pigozzi 1987). Moreover, the nocturnal and secretive habits of the badgers allow them to coexist with man to a limited extent. Badger burrows, called setts, which are central to the group's social life, are also a key resource for the species (Doncaster & Woodroffe 1993, Roper 1993). Like most species, the requirements for food, shelter and other resources are expected to shape badger habitat selection in such a way that the use of habitat types deviates from their proportional availability. Some habitats are selected because they provide these resources while others are avoided because they offer no advantage or adversely affect badger settlement.

Habitat selection by the badger in its European distribution range has been studied in a variety of environments. These include habitats as diverse as grasslands or meadows (northeast England, Palphramand *et al.* 2007; Italian Alps, Prigioni *et al.* 2008) arable lands (southeast England, Delahay *et al.* 2006) and woodlands (northern Italy, Balestrieri *et al.* 2006; Swiss Jura Mountains, Do Linh San *et al.* 2007a, Do Linh San *et al.* 2007b suburban; Tokyo, Kaneko *et al.* 2006). In Mediterranean environments, which have a more sclerophyllous xeric vegetation, badgers select habitats comprising Mediterranean shrubs (Revilla *et al.* 2000, Mangas *et al.* 2008), riparian woods (Virgós 2001a), ash tree forests (Virgós & Casanovas 1999) or cork oak woods (Rosalino *et al.* 2004, Rosalino *et al.* 2008). The high badger population densities found in the rainy habitats of the British Isles characterized by a relatively low seasonal differences in the precipitation regime, have been typically associated with the abundance of earthworms in meadows and pastures (Kruuk & Parish 1981). In contrast, in Mediterranean habitats, badgers are not earthworm specialists because of their low availability (Virgós 2001b), but mainly ingest fruits and also prey on a variety of items (insects, snails, earthworms and small vertebrates, Rosalino *et al.* 2005b). In our study areas, crop fields occur in a patchy agricultural mosaic included in the forest matrix. These habitats allow badgers to feed on a variety of cultivated plants (fruits and vegetables) and also on the invertebrate fauna associated with these environments. Therefore, a priori, these habitats are ideal foraging grounds because they provide food all year round.

There is consensus that badger groups need enough underground space in order to fulfil several basic functions: 1) Hygienic: sett alternation to reduce ecto-parasite load (Broseth *et al.* 1997a, Butler & Roper 1996); 2) Reproductive: isolation of some individuals from others during the breeding season for reproductive success (Cresswell *et al.* 1992); 3) Energetic: daytime resting sites (Kruuk 1989) or overwintering shelters (Fowler & Racey 1988); and 4) Security: shelter to reduce the risk of predation (Butler & Roper 1995) and human disturbance (Jenkinson & Wheater 1998). The density, location and habitat features of badger setts are among the most widely studied characteristics of badger ecology across its European distribution range (Bartmanska & Nadolska 2003, Do Linh San *et al.* 2007a, Fischer & Weber 2003, Good *et al.* 2001, Kowalczyk *et al.* 2000, Macdonald *et al.* 2004, Moore & Roper 2003, Pavlacik *et al.* 2004, Rogers *et al.* 2003, Roper 1992, Roper *et al.* 2001, Roper & Moore 2003, Wilson *et al.* 2003) including Mediterranean habitats (Loureiro *et al.* 2007, Remonti *et al.* 2006, Revilla *et al.* 2001, Rosalino *et al.* 2005a). Habitat type is the main factor that determines sett location in the English badger (Huck *et al.* 2008). Moreover, the characteristics of the sites selected for sett establishment also vary across its distribution range, from pasturelands and hedgerows in Ireland (Hammond *et al.* 2001, Feore & Montgomery 1999) to under tree-cover areas in Italy (Remonti *et al.* 2006), or Mediterranean scrubland in the south of the Iberian Peninsula (Revilla *et al.* 2001).

The Resource Dispersion Hypothesis (RDH) proposes that group-living may be a consequence of resource exploitation patterns (see a recent revision in Macdonald *et al.* 2004). Therefore, the social organization of badgers will be determined by the heterogeneous distribution of patchy resources and by the richness of the patches. The proposed limiting resources on which territory configuration hinges have typically been two: food resources (Food Dispersion Hypothesis, FDH), and suitable sites at which badgers can build a sett (Sett Dispersion Hypothesis, SDH). The relative importance of food patch distribution and availability of sett sites varies between populations and it is therefore difficult to compare their respective effects since the two factors are expected to act together (da Silva *et al.* 1993). Under some circumstances, the optimality of badger foraging regimes (energy budgets) could be compromised in order to take advantage of suitable sett sites, so far as ultimate energetic constraints permit. When outside the sett, they are expected to spend most of their time foraging in areas that include the habitat patches where they preferentially feed. If food patch dispersion determines the home range configuration, as predicted by the FDH, one would expect badgers to select the same habitat types for home ranges as for core foraging grounds. However, if suitable sites for sett location determine home range configuration (Johnson *et al.* 2002), as predicted by the SDH, one would expect a high proportion of sett habitat types within the home range and a positive selection for these habitats.

The present study describes the key habitat types used by badgers for territory settlement (home range), foraging (core foraging areas), and sett sites in two Mediterranean study areas. We aim to: 1) assess which of the proposed hypotheses best fits the situation of the badger populations in two environments that are subjected to high levels of human pressure and habitat fragmentation; and 2) identify the most important habitats for badgers in the study areas in order to improve species management and habitat preservation programmes.

MATERIALS AND METHODS

Study areas

The Collserola Park (41º27'N, 2º6'E) comprises 85 km^2 and belongs to the Catalan Coastal Cordillera, which spreads over about 100 km in a North-South direction, parallel to the Mediterranean Sea, roughly 10 km away from the coastline. Altitudes range from 50 to 512 m above sea level and the mean yearly rainfall during the study period was 672 mm, with wide seasonal variations. Summer is usually the hottest and driest season (13.2ºC-30.9ºC), whereas spring (3.8ºC-23.3ºC) and autumn (6.5ºC-24.2ºC) are the wettest ones and winters are mild (0.3ºC-17.6ºC). The inner 80 % of the Park are covered by dense woodland, largely dominated by the Aleppo pine (*Pinus halepensis*) and the holm oak (*Quercus ilex*). The Park contains a dense network of temporary streams, most of which are dry year round, except for brief periods after intense rain. The riparian woods are made up of elms (*Ulmus campestris*) and poplars (*Populus alba* and *P. nigra*), but most of them are in a poor state of conservation and the river beds and their surroundings slopes are populated by dense blackberry (*Rubus ulmifolius*), sarsaparilla (*Smilax aspera*) and patchy reed (*Arundo donax*) communities. The periphery of the Park is formed by more gently slopes, except the one facing Barcelona, and the vegetation is mostly scrub patches of tree heath (*Erica arborea*), strawberry tree (*Arbutus unedo*), rock rose (*Cistus* ssp), mastic tree (*Pistacia lentiscus*), holly oak (*Quercus coccifera*) and Spanish broom (*Spartium junceum*), depending on the orientation of the slope. These peripheral areas hold most of the little agricultural activity remaining in Collserola, mainly allotments, orchards and cereal fields (8 % of its surface). For a complete description of the Park, see Cañas (1995). It is important to note that although the Collserola Park is almost completely isolated from other natural surroundings by the city-belt, and accordingly some areas of Collserola can be classified as sub-urban habitats, most of the Park remains a wild natural environment.

The second study area is located on the southern side of the Montserrat Mountain Natural Park and its agricultural surroundings (41º36'N, 1º48'E), 16 km apart from Collserola Park. The altitudes of the Montserrat massif range from 250 to 1224 m. The climate is typically Mediterranean, similar to that of Collserola, but dryer and hotter on the southern side. The most common tree species is the Aleppo Pine (*Pinus halepensis*) and herbaceous vegetation is abundant. This cover alternates with olive crops (*Olea europaea*) near the mountains on the north-eastern side and vineyards (*Vitis* sp.) and cereal crops on the south-western side. The typical coastal holm oak wood is abundant at low altitudes. Contrary to the Collserola Park, Montserrat is an open and less fragmented area. Indeed, in general terms, Montserrat is patchier and has more agricultural and herbaceous areas and fewer forest areas and shrubs than the Collserola Park (Fig. 1).

Trapping and radio-tracking

Collserola is a long-term study site while Montserrat was added as a short-term comparison. Trapping took place between 1997 and 2006 in Collserola and in 1999-2000 in Montserrat. Badgers were captured with padded leg-hold traps (Victor Soft Catch 1.5, Woodstream Corp. Lititz, PA) following the Recommendations of the Animal Welfare Protocol of the European Union. No badger was injured during handling. Badgers were anesthetized by intramuscular injections of combinations of ketamine and xylazine hydrochloride (Kreeger 1997) or diazepam and medetomidine (Palphramand *et al.* 2007). Only adults (six males and five females in Collserola, and two males and two females in Montserrat, Table I) were equipped with a radio-transmitter (TW-5, Biotrack Ltd). The radio-signal of two males from Collserola was lost just after release or after a short period of time and was never found again.

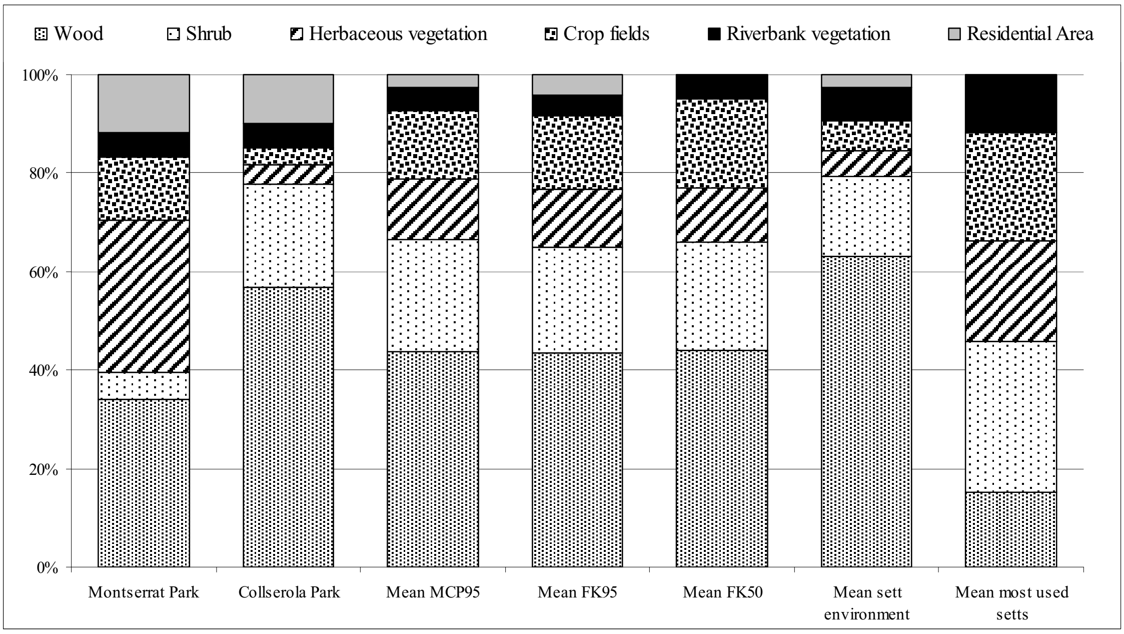

Fig. 1. – Habitat percentages of the 3 radio-telemetry study areas, home range average for MCP95 and FK95, average of core areas (FK50), for the habitats available in the Collserola Park, the average for the 39 sett environments and the average of the 9 most used setts.

We used a portable VHF receiver (R1000, Communications Specialists Inc) and a hand-held three element Yagi antenna (Biotrack Ltd) to collect radio-tracking data. We recorded all bearings for each radiolocation within a 10-minute interval to reduce the error associated with badger movement and within 45-135º intervals for crossing bearings. Radio-tracking data and spatial estimators were calculated with Ranges VII software (South *et al.* 2005).

Habitat classification

On the basis of Catalonian type of cover digital cartography (CREAF), six habitat types were distinguished in our study areas: riverbank vegetation (RV); pine woods and oak tree woods (W); shrub (S); crop field (C); herbaceous vegetation (HV); and residential areas (RA; Table I). Pine and oak tree habitats were merged into a woodland habitat association because oak wood rarely occurs alone but mixed with pine. Urban nuclei, transport networks (railways, roads and highways) and industrial estates were excluded from the analyses because they were considered unsuitable habitats for badgers. We conducted ground surveys and comparisons with digitized aerial photographs to ensure that we correctly classified polygons into each habitat class. Special attention was given to small orchards, which are sometimes omitted from standard cartography.

Data analysis

From 1997 to 2007, the spatial behavior of 13 badgers was studied by means of radio-tracking: two males and two females in Montserrat (M1, M2, F3 and F4), and four males and five females in Collserola (F5, F6, M7, F8, F9, M10, M11, F14 and M15). Home range and core foraging areas were used to define the habitat polygons in each study area using ArcView GIS 3.2 (ESRI, 1992) and to produce the data for calculating the proportional area of habitat classes (Brunjes *et al.* 2006). For home range estimators, we used the Minimum Convex Polygon with 95 % of fixes (MCP95) and Fixed Kernel with 95 % of fixes (FK95, Worton 1989).

For fixed kernel estimates, an optimal smoothing parameter (*h*) was created for each home range (Kenward *et al.* 2001) by multiplying the smoothing parameter found by minimum squares method (*hcv*) by a correcting factor by trial and error. This correcting factor was found by intervals of 0.01 starting in one *hcv*. We accepted the smoothing parameter resulting in the smallest FK95 that allowed a single shape as a home range, avoiding unconnected patches (Bonet-Arbolí 2003). For core foraging areas, we used only Fixed Kernel with 50 % fixes (FK50) because MCP distinguishes only one concentric core area patch per home range, which is incongruous with the movements of each individual observed. In order to avoid pseudo-replication, overlapping home ranges were merged to make the compositional analyses (M2+F4 in Montserrat and F5+F6 in Collserola).

Habitat association	Vegetation units	Main species included
Riverbank vegetation (RV)	5 m buffer around water streams 10 m buffer around 1st class rivers 15 m buffer around 2nd class rivers	*Rubus fructicosus, Smilax aspera, Arundo donax, Phragmites australis*
Woodland (W)	Pine-dominating wood	*Pinus halepensis, Pinus pinea*
	Esclerophite-dominating wood	*Quercus ilex, Quercus coccifera*
	Deciduous-dominating wood	*Quercus pyrenaica, Quecus suber*
Crop field (C)	Fruit trees	*Prunus dulcis, Ceratonia siliqua, Olea europaea*
	Irrigated fruit trees	*Ficus carica, Prunus avium*
	Vineyards	*Vitis ssp.*
	Dry grass crops	*Hordeum vulgare*
	Irrigated grass crops	*Medicago sativa*
	Small orchards	A variety of fruit and vegetable species
Shrub (S)	Bush-dominating wood	*Bupleurum fruticosum, Calicotome spinosa, Cistus monspeliensis, Cistus salviifolius, Rosmarinus officinali, Erica multiflora, Genista scorpius*
	Makis-dominating wood	*Quercus coccifera, Chamaerop humilis, Ceratonia siliqua, Rhamus alicoides*
	Wood with poor vegetation coverage	*Erica arborea, Lavandula stoechas, Pistacia lentiscus, Smilax aspera, Quecus coccifera*
Herbaceous vegetation (HV)	Meadow-dominating vegetation	*Hyparrhenietum hirto-pubescens*
Residential areas (RA)	Neighbourhoods of variable extension inside the Park	Same as woodland and shrub habitats
Not included (NI)	Urban	Urban nucleus
	Transport infrastructures	Areas occupied by motorways and roads
	Industry	Areas occupied by factories and industrial areas

Table I. – Correspondence between habitat associations, areas included and plant communities.

Compositional analysis (Aebischer *et al.* 1993) was used to study badger preferences of habitat use by replacing all non used habitat types by a value of 0.03 (Brennan 2004). We assessed habitat selection at two hierarchical orders based on badger behavior, which we adapted from Johnson (1980). To evaluate second order habitat selection, the composition of habitats within home ranges (MCP95 and

FK95) was compared with that of habitats within the corresponding study area. As a third order habitat selection, we compared the composition of habitats within core foraging areas (FK50) with that of habitats within the corresponding home range (Beasley *et al.* 2007), but avoiding the less preferred habitat resulting from the second order analysis (Aebischer *et al.* 1993). However, for third order analysis, we used the individual core foraging areas because, only in one case, did the core areas of two individuals partially overlap. For sex and Park comparisons, we used simple MANOVA with log ratios (Aebischer *et al.* 1993). To set the limits of a study area, a Fixed Kernel with 99 % of the distribution of all fixes merged for all badgers in each study area was drawn with a 500 m buffer around it (Lamberti *et al.* 2006). Habitat attributes were exported to DBASE IV files and used to obtain the proportions of each habitat class in each of the three study areas by means of ArcView GIS 3.2 (ESRI, 1992). To carry out compositional analyses, an Excel (Microsoft, Redmond, WA) macro was used (Smith 2005).

The badger population

We obtained a mean home range of about 300 ha for males and 80 ha for females, varying slightly depending on the estimator used (MCP95 or FK95). In Collserola, males had ranges over four times larger than those of females, while male badgers captured in Montserrat exhibited a 1.5 fold range over females. Estimated population densities were 0.6 individuals/km^2 for Collserola and 1.9 ind./km^2 for Montserrat, and badger groups were formed by one to two individuals and by one to three individuals respectively (Molina-Vacas *et al.* 2009). According to our calculations, based on sett and camera-trapping surveys we estimated that 40-50 % of the resident badgers in the study areas of both parks were tracked. Indeed, this represents 15 % of the population of the whole Collserola Park. However, as Montserrat is an open environment, we cannot precisely ascertain the percentage of the population tracked. The highly populated urban nuclei which surround Collserola Park come to over four million people, this high human pressure involves a high influx of people in the Park which means higher levels of badger sett disturbance by humans and domestic animals (loose and abandoned dogs), and an increase of poaching and road-kill risk.

Sett environment selection in the Collserola Park

From 1992 to 1995, we carried out several surveys with the help of volunteers and Park keepers to find the largest possible number of badger setts in Collserola Park. A total of 151 badger burrows were found, 52 of which were subsequently monitored weekly during several three-month periods in 1995 and 1996 by means of field-sign surveys, so that an activity status (i.e. active/non active) could be ascribed to each sett for each week. Six setts were monitored during the eight periods, while the remainders were monitored for one to seven periods (85 % being monitored for five or more periods). Burrows that were found to be in use for at least one week (n = 26, Bonet-Arbolí 2003) were then selected for compositional analyses together with 8 setts used by the radio-tracked individuals during the 1997-2007 period, and five additional setts, which were not monitored or used by the radio-tracked badgers but which showed signs of recent use when found. Thus the total sample included 39 setts. The median number of sett entrances was three (range 1-15). The habitat of a sett was defined by creating a 50 m-radius circle around each sett barycentre (Kaneko *et al.* 2006), and establishing habitat coverage categories on the basis of the same classification used for individual home range analysis (Table I).

The habitat percentages derived were then compared with the composition of the Collserola Park (as available habitat) using compositional analyses (Aebischer *et al.* 1993).

For sett habitat selection analysis, a third order compositional analysis was performed using the habitat composition of the 39 badger setts as available habitat and that of the most used setts as the habitat selected. Log-survivor curves separated those setts monitored with high activity levels (> 30 % weeks) from those of low activity on the one hand, and those with low changing rate (< 15 % of weeks with a different status from the preceding week) from those with a high changing rate. Setts with high activity and a low changing rate (n = 4) were then considered the "most used setts". For more details on these analyses see Bonet-Arbolí (2003). In Collserola, each badger uses several setts during a given year (2-9, Bonet-Arbolí 2003) and shows a clear preference for one ("preferred sett"), which is used for more than 40 % of the days. Five out of the eight radio-tracking setts included in the second order analysis were preferred setts and were thus included in the 'most used setts' category. Thus the total sample was nine. For this analysis, we avoided the least used habitat type resulting from the first order analysis, as recommended by Aebischer *et al.* (1993).

RESULTS

Individual foraging habitat selection

Considering all the home ranges (n = 11) and comparing their habitat composition with the percentages of the available habitat (second order analysis), we detected a habitat selection different from availability (non random) from both methods with the same selection sequence (MCP95: $\lambda = 0.096$, $P < 0.001$, $df = 5$, n = 11, FK95: $\lambda = 0.24$, $P = 0.007$, $df = 5$, n = 11), the preferred habitat being riverbank vegetation, followed by woodland, shrub, crop field and herbaceous vegetation. Residential areas were the least used habitat. Significant differences in the preference order were found between residential areas and all other habitats, except for herbaceous vegetation (Table II). No significant difference in habitat selection was found between parks (MCP95: $F = 1.719$, $P = 0.283$; FK95: $F = 2.824$, $P = 0.140$). When comparing individual core foraging areas with the corresponding home ranges (third order analysis), and after removing residential areas from the analysis, we found a significant habitat selection for all badgers (FK50: $\lambda = 0.287$, $P = 0.003$, $df = 4$, n = 13). Crop fields were the preferred core foraging habitat, followed by woodland, shrub, and riverbank vegetation. Herbaceous vegetation was the least used habitat, with significant differences between crop field and all other habitats, except for shrubs (Table II). In contrast to the second order analysis, at the third level, badgers showed a preference for crop fields (mainly small orchards, vineyards and fruit tree plantations) over woodlands or riverbank vegetation. This observation indicates that crop fields contribute to determining foraging patterns. No differences in habitat selection were found between the parks ($F = 1.294$, $P = 0.350$) or between sexes ($F = 3.236$, $P = 0.074$).

Sett habitat selection in Collserola Park

We also found a significant selection concerning sett environments ($\lambda = 0.394$, $P = 0.001$, $df = 5$, n = 39), the preferred habitat being riverbank vegetation again, followed by woodlands, crop fields, herbaceous vegetation and shrubs. Residential areas were the least used habitat. Significant differences between woodlands and the four habitats ranking lowest as well as between riverbank vegetation and the same four habitat types were found; badgers also showed a significant preference for crop fields and herbaceous vegetation over residential areas (Table II).

In addition, a significant difference in habitat selection between the complete data-set of the 39 surveyed setts and the nine most frequently used setts was detected ($F = 4.111$, $P = 0.005$). Thus we conducted a further analysis for these nine setts and obtained evidence of a marginally significant habitat selection ($\lambda = 0.151$, $P = 0.053$, $df = 4$, n = 9). Riverbank vegetation was again the preferred habitat type, but with shrub habitat ranking second and woodland habitat as the least used. Significant differences were also found between riverbank vegetation as compared to woodland and herbaceous vegetation (Table II).

a) MCP95 *vs.* Study Area	RV	W	S	C	HV	RA	Rank
Riverbank vegetation (RV)		+	+	+	+	+++	5
Woodland (W)	-		+	+	+	+++	4
Shrub (S)		-	-	+	+	+++	3
Crop field (C)	-	-	-		+	+++	2
Herbaceous vegetation (HV)	-	-	-	-		+	1
Residential area (RA)	---	---	---	---	-		0

b) FK95 *vs.* Study Area	RV	W	S	C	HV	RA	Rank
Riverbank vegetation (RV)		+	+	+	+	+++	5
Woodland (W)	-	+	+		+	+++	4
Shrub (S)	-		+	-	+	+++	3
Crop field (C)	-	-	+	-		+	2
Herbaceous vegetation (HV)	-	-		-	-	+	1
Residential area (RA)	---	---	-	---	-		0

c) FK50 *vs.* FK95	C	W	S	RV	HV		Rank
Crop field (C)		+++	+	+++	+++		4
Woodland (W)	---		+	+	+		3
Shrub (S)	-	-		+	+		2
Riverbank vegetation (RV)	---	-	-		+		1
Herbaceous vegetation (HV)	---	-	-	-			0

d) 39 setts *vs.* Collserola Park	RV	W	C	HV	S	RA	Rank
Riverbank vegetation (RV)		+	+++	+++	+++	+++	5
Woodland (W)	-		+++	+++	+++	+++	4
Crop field (C)	---	---		+	+	+++	3
Herbaceous vegetation (HV)	---	---	-		+	+++	2
Shrub (S)	---	---	-	-		+	1
Residential area (RA)	---	---	---	---	-		0

e) 9 setts *vs.* 39 setts	RV	S	HV	C	W		Rank
Riverbank vegetation (RV)		+	+++	+	+++		4
Shrub (S)	-		+	+	+		3
Herbaceous vegetation (HV)	---	-		+	+		2
Crop field (C)	-	-	-		+		1
Woodland (W)	---	-	-	-			0

Table II. – Simplified ranking matrices obtained with compositional analysis by a) comparing proportional habitat use within MCP95 with the proportion in the corresponding study area; b) *idem* with FK95; c) comparing proportional habitat use within core foraging area (FK50) with the proportion in the corresponding home range (FK95) d) comparing used habitat around Collserola setts with the proportion in the Collserola Park; and e) comparing used habitat around 9 more used setts with used habitat around Collserola setts. +++ and --- show positive and negative significant difference respectively between habitat types ($P < 0.05$), and + and - no significant.

DISCUSSION

Habitat selection

Badgers show a preference for woodland habitats in many regions of Europe (Broseth *et al.* 1997b, Do Linh San *et al.* 2007a, Kowalczyk *et al.* 2003, Palphramand *et al.* 2007), Japan (Kaneko *et al.* 2006), and also in some Mediterranean areas (Balestrieri *et al.* 2006, Rosalino *et al.* 2004). Similarly, in central Iberian Peninsula, badger abundance is positively correlated with deciduous woods and mountain pastures (Virgós & Casanovas 1999). In Mediterranean habitats, the woodland matrix contributes to food resources because of the abundance of insects (Rosalino *et al.* 2005c) and the presence of carob beans (*Ceratonia siliqua*) or wild fruit trees and shrubs (e.g. *Arbutus unedo*) scattered in the matrix. However, in our study areas, badgers selected riverbank vegetation in the second order analysis, while woodland ranked second in the second and third order analyses. In addition, given that the woodland habitat in the Collserola and Montserrat Parks includes coniferous and deciduous trees, usually mixed in an intricate matrix, we could not easily differentiate between preferences for each wood type.

However, as predicted *a priori* for our study areas, core foraging areas comprised more crop fields than expected from their abundance in home ranges. This observation implies that badgers spend most of their active time and effort foraging in or near crop fields. Our finding confirms the relevance of mosaic environments comprising crop fields interspersed with small woods, shrubby banks or small streams and fallow lands for badger foraging activity in Mediterranean environments (Rosalino *et al.* 2004). Moreover, in our study areas, most crop fields are artificially irrigated year round, thereby allowing badgers to feed on the invertebrate fauna associated with damp environments, in addition to cultivated fruits and vegetables. Although a systematic study of badger diet has not been performed in our study areas, an analysis of stomach contents of badgers killed on roads collected across Catalonia (32,000 km^2), a region in which our study areas are located, showed a dominance of fruits and insects (Corral-Bistué 2002), as it is the rule for most of the Iberian Peninsula (Melis *et al.* 2002, Rosalino *et al.* 2005c). Superficial examination of many badger faeces in the field indicated a similar diet in our study areas (authors' observation), although a rigorous diet study is required to ascertain the link between diet and foraging habitats.

At the second order of analysis, a significant avoidance of residential areas was detected for both home range and sett environments, as reported in other studies (Balestrieri *et al.* 2006, Do Linh San *et al.* 2007a, Kaneko *et al.* 2006). This observation indicates that despite the badger's wellknown tolerance of human proximity (Davidson *et al.* 2008, Remonti *et al.* 2006), it does not select residential areas as suitable habitats. This strategy could be explained by the poor food or shelter resources that these habitats offer and by the presence of loose dogs, which increases the risk of predation and sett disturbance. Moreover, road traffic accidents would be more probable near residential areas due to a higher vehicle transit. Similarly, the herbaceous vegetation habitat plays a minor role for home range and core foraging areas. Pastures are important foraging areas for badgers at higher latitude/altitude with wetter environments because of the abundance of earthworms (Kruuk & Parish 1981).

However, in our study areas, at low-altitude, herbaceous vegetation is the driest habitat and holds few trophic resources for badgers.

Sett environment selection

In the British Isles and Ireland, where pastureland is the dominant land-use type, and which is food productive for badgers (in terms of earthworm abundance), setts are more abundant in pastures (Hammond *et al.* 2001) or in hedgerows, woodlands and shrubs, but also near pasturelands (Feore & Montgomery 1999). In contrast, in NW Italy, badgers preferentially select woods and shrubs to build their setts (Remonti *et al.* 2006), as reported in Mediterranean habitats of the South Iberian Peninsula, where scrub zones are the sites for sett location (Revilla *et al.* 2001). However, in our study areas, badgers selected riverbank vegetation for sett location (second order analysis). Moreover, this habitat type was also the environment in which the most frequented setts, which had three times more active entrances that the remaining 30 setts, were preferentially located (third order analysis), while the woodland habitat was avoided. The profile of river banks, which present more of a cross-section, afford badgers an easier digging opportunity than the flatter conditions in woodland areas. Moreover, riverbanks are the most concealed and least accessible sites of Collserola Park, with heights ranging from two to three metres up to about 30 m and widths of about 2-3 m up to 10-20 m steep slopes (with a mean slope angle between 45-80 degrees), and they hold higher and thornier vegetation cover, thereby hindering incursions by humans. Indeed, after the last five decades of increasing human population growth, particularly around Collserola, our results indicate that the most suitable habitats for sett location are the roughest ones while the most open habitats (residential, crop and herbaceous) rank third or lower in second and third order analyses.

Explanatory hypothesis

In the study areas, riverbank vegetation was selected for sett location in both first and second order analyses as well as for home range habitat (second order analysis) but not for core foraging areas, where it ranked fourth (out of five habitats considered). This observation implies that the same habitat features are taken into account by badgers when establishing a territory as when deciding where to dig a sett. Moreover, the finding that a distinct (agricultural) environment was selected for foraging suggests that the selection of riverbank vegetation at the home range level is not related to feeding strategies. Thus food may not be the sole factor that determines home range configuration and sett site availability may be a limiting resource for badgers (Rosalino 2005b), thereby supporting the SDH (Doncaster & Woodroffe 1993), at least in low density populations subjected to high human pressure (habitat degradation in quality, quantity and connectivity, and also direct persecution) in the Mediterranean area.

Nevertheless, the possibility that riverbank vegetation is chosen for distinct reasons for home range establishment and sett digging cannot be disregarded. For example, the need for shelter and steep slopes is the strongest factor explaining the importance of riverbank vegetation for building setts. However, shelter could also be a critical factor in the habitat composition of home ranges. The branching nature of these riverbank habitats allows badgers to move unnoticed across their home ranges, as occurs in scrub habitat in Brighton, UK (Davidson *et al.* 2009). Therefore, the shelter provided by riverbanks could explain their first rank in the habitat preference order in home ranges, independently of the need for shelter around sett sites.

Finally, the observation that factors other than food availability explain habitat selection at the home range level does not imply that food distribution is not important during home range establishment but rather that the effect of the availability of refuges on the configuration of the home range depends on shelter availability in each environment. To occupy a given territory, badgers need rich food patches (crop fields and adjoining environments in our case) with nearby refuges for protection (riverbank vegetation). In high density badger populations, like those found in the UK, food resources are the main limiting factor for home ranges (Macdonald *et al.* 2004). In contrast, in our low density populations, badgers showed strong shelter requirements because of human disturbance (hunting, poaching, road-kills, loose dogs).

Conservation of badgers in Mediterranean habitats

In our study areas, badgers live at low densities, in social groups of by one to three individuals (Do Linh San *et al.* 2007a, Revilla *et al.* 2001), as expected for a region with dry and markedly seasonal weather conditions (Johnson *et al.* 2002). Furthermore, due to the dense human population around the study areas (especially in Collserola), badgers live under great human pressure. Given the marked habitat preference of badgers for riverbank vegetation and traditional agricultural environments, the promotion and maintenance of these areas should be a priority in the design of management plans for these mustelids. Furthermore, riparian habitats are also used by other mammals inhabiting the two Parks, such as the red fox and wild boar (authors' unpublished data). This observation highlights the importance of this habitat type for wild mammal preservation. Managers and Park authorities should therefore pay particular attention to the preservation of these degraded riparian habitats, rather to restore them to their primeval state when promoting suitable habitats for these species.

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HABITAT SELECTION OF THREE MESO-MAMMAL SPECIES IN AN ISOLATED AND HIGHLY ANTHROPOGENIC MEDITERRANEAN PARK: A MULTILEVEL APPROACH

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Capítol3

CAPÍTOL 3

Habitat selection of three meso-mammal species in an isolated and highly anthropogenic Mediterranean park: a multilevel approach

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HABITAT SELECTION,
MESO-MAMMAL,
MEDITERRANEAN,
SUS SCROFA,
VULPES VULPES,
GENETTA GENETTA

ABSTRACT. – Since habitat selection is a key aspect of animal activity, its study in anthropogenic environments could show some cues about how meso-mammals deal with the fact of living in suburban Mediterranean habitats. Compositional analysis was performed to evaluate the habitat selection of foxes, wild boars and genets in a highly humanized metropolitan park of the NE Iberian Peninsula at three orders of analysis: population, home range and core foraging area. For this purpose radio-tracking data of eight, nine and 16 individuals of each species respectively was used, and also the data obtained by a camera-trapping survey. At the 1st-level significant selection was found for the three species. Foxes and genets selected for riverbank vegetation, while wild boars did so for woodland. Foxes did not show habitat selection at 2nd and 3rd-order selection, while wild boars showed habitat selection only for 2nd-order, selecting again for riverbank vegetation. Genets showed significant selection at both 2nd and 3rd-orders, being woodland the preferred habitat in both cases. In general terms, riverbank vegetation and woodlands were positively selected. On the contrary, the residential areas, and to some extent also herbaceous vegetation and shrubs were avoided. Species results are discussed considering their respective ecological particularities.

INTRODUCTION

The factors driving species distribution are among the most important tools in conservation biology, since distributional patterns reflect fundamental ecological processes (Gehring & Swihart 2003, Sarmento *et al.* 2010). Habitat selection is considered to be a key aspect of animal activity, affecting subsequent behavioural decisions and, ultimately, fitness (Orians & Wittenberger 1991). The choices an individual makes about which habitats to use in a given environment must reflect a balance between the maximization of energy intakes when foraging and the corresponding constraints. Many ecological factors would positively and negatively affect habitat choice: e.g. food availability, predation risk, vegetation coverage, as well as behavioural constraints or hunting preserves configuration. For most species, requirements for food and shelter are expected to shape habitat selection in such a way that the use of habitat types deviates from their proportional availability. Some habitats are selected because they provide these resources while others are avoided because they offer no advantage or adversely affect animal settlement. Different available habitats represent different levels of food and shelter readiness for each species in each environment. The criteria for a species habitat selection could be different depending on the considered scale of the study so that it is preferable to study it as a hierarchy with multiple scales (Orians & Wittenberger 1991, Schaefer & Messier 1995, Rettie & Messier 2000, Meriggi & Sacchi 2001). Consideration of multi-scale responses enhances the effectiveness of conservation strategies (Gehring & Swihart 2003). The present study is a multilevel approach to habitat selection by three meso-mammals, wild boar, genet and red fox, and it was carried out in Collserola Park (Catalonia, Spain), which offers an interesting environmental diversity. In addition, the high human pressure which it is subjected to can be considered as a particular type of predation risk. Therefore, the environmental diversity and the high human pressure offer an interesting opportunity to study the possible responses adopted by different meso-mammal species in order to deal with these conditions. Radio-telemetry and camera-trapping methods have been previously shown to be useful techniques for the study of meso-mammals in the Park (Pla *et al.* 2000, Camps-Munuera & Llimona-Llobet 2004, Molina-Vacas *et al.* 2009*a*, Molina-Vacas *et al.* 2009*b*). In the present study, radio-telemetry data was used for 2nd and 3rd -order selection analysis, while camera-trapping survey data was used for 1st-order analysis.

Collserola Park is subjected to strong pressure by human activities, implying human presence in almost all habitats to some extent: farming, harvesting, hunting, asparagus and mushroom picking, sightseeing, cycling, jogging, etc. We proposed a habitat selection study of red fox, wild boar and genet to better understand how the current landscape composition influences habitat selection and which habitats are the key factors for each species. Since urban areas are predicted to grow significantly at the periphery of the Park in the foreseeable future because of increasing human population growth, rational management programs must be based on a good understanding of the key habitats of these species in Collserola (Cahill *et al.* 2003*a*). This is of considerable interest due to possible effects on biodiversity and human-wildlife conflicts (Baker & Harris 2007).

None of the three study species is threatened, being considered as common in Iberian ecosystems. Their behavioural plasticity allows them to cohabitate with humans (Morales 1994, Marks & Bloomfield 2006, Baker & Harris 2007, Kotulski &

Koenig 2008), even benefitting to some extent from habitat transformations (e.g. agricultural fields, livestock pastures, gardening, game preserves, etc.) or human waste. The three species occupy a diverse range of habitat types; as a result they must be adapted to exploiting different resources, to living under diverse conditions, and to changing the trophic resource exploitation pattern when needed. These characteristics make them useful as indicators of the quality of the habitat (Virgos *et al.* 2001, Galantinho & Mira 2009, Sarmento *et al.* 2010) as well as for identifying the habitats with higher ecological value for meso-mammals in anthropogenic environments. How can these species maintain good healthy populations in such a highly anthropogenic habitat? Foxes and wild boars have learnt to feed on harvests and scraps, and have got used to tolerating human presence by changing their behavioural patterns: e.g. by concentrating the activity during the nocturnal period (Cavallini & Lovari 1994, Cahill *et al.* 2003*b*) or learning how to access to rubbish bins (author's personal observation). But to what extent do they depend on these artificial resources? Do foxes, wild boars or even genets positively select those human-modified habitats (e.g. residential areas, crop fields) for feeding or resting? Or on the contrary, do they avoid these altered habitats and select more naturalized habitats as would be expected for wild species? In a recent study carried out in the same study area and time period, Molina-Vacas *et al.* (2009a, 2009b), showed that European badgers (*Meles meles*) selected mainly the dense riverbank vegetation at the home range level as well as for den settlement. On the other hand, badgers avoided residential areas, while at core foraging area level they showed a preference for crop fields. Similarly, Matos *et al.* (2009) showed that in Mediterranean ecosystems of southern Portugal, in spite of the extensive state of degradation, riparian habitats played an important role as carnivore habitat. This habitat recorded higher carnivore species richness and abundances than the adjacent matrix.

The red fox is a cosmopolitan species and has the widest distribution among carnivores (Henry *et al.* 2005). The species range was restricted to America and Eurasia until it was introduced to Australia for biological control purposes (Marks & Bloomfield 2006). In spite of the apparent abundance of foxes, no data are available about its population density in Collserola. The wild boar has also a wide distribution in the Palearctic region and it was also introduced to Australia and California in the domestic form which then established feral populations (Barrett & Pine 1981, Dexter 1998). In Catalonia, as in the rest of Europe, its distribution range has been expanding over the last 30–40 years, and the population density has increased notably (Saez-Royuela & Telleria 1986, Rosell *et al.* 1998). In Collserola, the wild boar minimum population density was calculated at 9 individuals/km^2 (unpublished data from Collserola Park 2008). The genet is a viverrid carnivore introduced into south-western Europe during historical times, probably kept as a household-pest-destroying species against the black rat in northern Morocco and southern Iberia (Morales 1994). Nowadays, it occupies the African sub-Saharan savannas, the Maghreb, the Arabian Peninsula, the Iberian Peninsula, some Balearic Islands, part of France and some sites of North-Western Italy (Gaubert *et al.* 2008). In Collserola, genet minimum population density was calculated at 0.98 individuals/km^2 (Camps-Munuera & Llimona-Llobet 2004). In general terms, in Mediterranean environments the red fox has an omnivorous diet (Fedriani *et al.* 1999), relying on the availability of the different food categories in each habitat. Nevertheless, it was also shown that food from human origin can represent half the food intake in some Mediterranean environments (Cavallini & Volpi 1996). In the case of the wild boar, plant materials can represent over 90% of the food intake, and up to half of this amount may be due to agricultural crops (Gimenez-Anaya *et al.* 2008). In addition, recent analyses carried out in Collserola (Llimona *et al.* 2005, Llimona *et al.* 2007) showed that some wild boar groups have become gradually accustomed to human presence as a consequence of the food supply that humans directly or indirectly provide. These habituated groups of wild boar, which are predominantly females and their young, are especially present in periurban areas during the warmer months of the year, and individuals are significantly heavier than non habituated conspecifics (Cahill *et al.* 2009). In contrast with the red fox and the wild boar, which can be described as habitat-generalist or opportunist species (Harris 1981, Marks & Bloomfield 1999, Cahill *et al.* 2003*b*, Llimona *et al.* 2007, Kotulski & Koenig 2008), and compared with the diet of other medium-sized Palaearctic carnivores, the genet is intermediate between typical generalists and specialists (Virgós *et al.* 1999). In Collserola its diet is mainly composed of birds and rodents (Pasquina & Cahill 2002), being more specialized than foxes or wild boars. With respect to resting site location, this is likely to be important in our study area for red foxes because of the intolerant attitude of the local human population towards the species, as shown in other places (Lucherini *et al.* 1995). The same applies to wild boars, especially during the hunting season. In addition, due to the lack of an efficient physiological cooling mechanism, during the hottest seasons, wild boars are very sensitive to high temperatures and require refuges which contribute to thermoregulation (Heitman & Hughes 1949), so rest-site location is likely to be an important factor for the species. Because genets spent most of their time resting (Palomares & Delibes 1988, Palomares & Delibes 1994), the selection of these sites must be very important. Despite the fact that genets do not suffer special persecution by humans in Collserola, it has been shown that genets select for thickets and hollow trees as preferred resting sites, as it is the case in other Mediterranean habitats because they provide safety from predators or loose dogs (Palomares & Delibes 1994, Camps-Munuera & Llimona-Llobet 2004). Furthermore, on the contrary to wild boars, genets have been shown to prefer warmer places (Virgos & Casanovas 1997). The specific aim of the present investigation was to identify the habitat selection of the three species at three hierarchical levels: 1) at the population-level (1st-order selection); 2) at the study-area scale (2nd-order selection); 3) at the within-*home range* scale (3rd-order selection, Johnson 1980).

MATERIALS AND METHODS

Study Area

Collserola is a metropolitan park (41º27'N, 2º6'E; Fig. 1) and comprises 85 km^2 and belongs to the Catalan Coastal Cordillera, which spreads over about 100 km in a Northeast-Southeast direction, parallel to the Mediterranean sea, roughly 10 km away from the coastline. Altitude ranges from 50 m to 512 m above sea level and the mean yearly rainfall during the study period was 672 mm, with wide seasonal variations. Summer is usually the hottest and driest season (13.2ºC-30.9ºC), whereas spring (3.8ºC-23.3ºC) and autumn (6.5ºC-24.2ºC) are the wettest ones and winters are mild (0.3ºC-17.6ºC). The inner 80% of Collserola is covered by dense woodland (Table I). The Park contains a dense network of temporary streams, most of which are dry year round, except for brief periods after intense rain. The riparian woods are mainly composed of brambles and reeds. The periphery of the Park is formed by more gentle slopes, except the ones facing Barcelona, and the vegetation is mostly patchy scrub. These peripheral areas hold most of the little agricultural activity that remains in Collserola, mainly allotments, orchards, olive groves and cereal fields (8 % of its surface). For a complete description of the Park, see Raspall *et al.* (2004). The Park is constricted by the Besòs (NE) and Llobregat (SW) rivers and by the city of Barcelona (SE). With regard to meso-mammals, the connectivity of the Park with other neighbouring reserves is nowadays virtually inexistent except for two narrow corridors at the northern side, which will also be built up soon. The Park is surrounded by large and dense urban areas, which hold a population of almost four million people, and by a very dense network of transport infrastructures and industrial estates, which isolates and internally fragments the Park (Cahill *et al.* 2003*a*, Raspall *et al.* 2004).

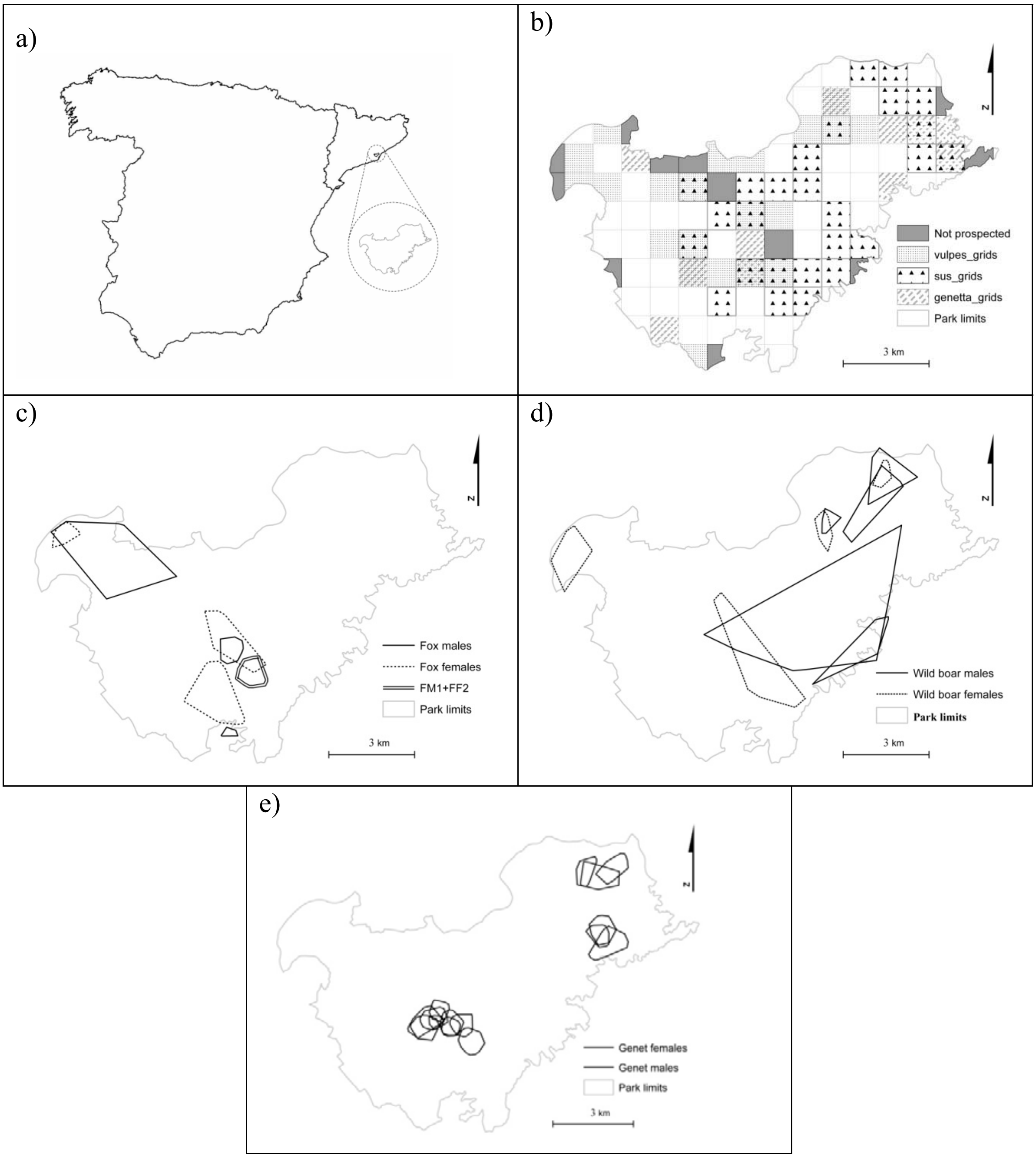

Fig. 1. a, Location of Collserola Park; b, Positive grid squares obtained in the camera-trapping survey; c, red fox *Vulpes vulpes* MCP95; d, wild boar *Sus scrofa* MCP95; and e, genet *Genetta genetta* MCP95.

Nevertheless, in spite of its confinement from other natural reserves, Collserola still supports populations of wild meso-mammals like foxes (*Vulpes vulpes*), genets (*Genetta genetta*), stone martens (*Martes foina*), badgers (*Meles meles*), weasels (*Mustela nivalis*) and also a high density population of wild boars (*Sus scrofa*). It is important to note that although Collserola Park is almost completely isolated from other natural surroundings by the city-belt, and accordingly some areas of Collserola can be classified as suburban habitats, most of the Park remains a wild natural environment.

Camera-trapping survey

The camera-trapping survey took place during 140 days scattered between January and July 2008. The sampling unit was a 1 km^2 quadrat from the UTM coordinate system. The Park was divided into 96 UTM grid squares. The grid squares which contained less than 25% of the Park surface and those which were dominated by urban areas, industrial states and the transport network were excluded from the analyses (n = 12, Fig. 1b). It must be said that surveying these areas was completely impossible due to the high risk of devices being stolen and to the total absence of vegetation to hide them. All the other residential areas mixed with some vegetation coverage were included in the RA habitat. A sampling station (hereafter plot) was placed at the centre of each of the remaining 84 sampled grid squares, which consists of one digital infra-red camera trapping device (Bushnell Trailscout 3.2 MP) baited with 140 g of sardines in vegetal oil scattered over 1 m^2 in front of the camera at a distance of approximately 40-70 cm from the front of the lens. Sardines were distributed among 4-6 excavated holes 1-8 cm deep and the oil was used to impregnate the ground between the plot and the nearby tracks and wildlife crossings in order to attract animals to the plot centre. To avoid the detection and consumption of the bait by birds, and other small animals, sardine pieces were covered with litter, stones, soil, etc. Thus the target animal had difficulties in obtaining the bait and was forced to spend more time in front of the camera, increasing the probability of registering an image. All of the handling was performed using gloves. Eight to twelve plots were randomly placed once each week and the devices were programmed to operate for 24 h a day during four consecutive days (a total of 336 trap-nights). The cameras worked correctly even during the coldest days. When a problem with batteries or memory cards occurred, the plot survey was repeated the following week.

Capture and radio-telemetry

Between 1998 and 2008, eight foxes were radio-tracked. Five of them were trapped using padded leg hold traps (Victor Soft Catch 1.5, Woodstream Corp. Lititz, PA) set on wildlife paths. One additional individual was caught in a box-trap (100x35x35 cm) baited with chicken meat and placed near a henhouse. The remaining two individuals, recovered following vehicle collisions, were also radio-tagged and included in the analysis (FM5 and FF8). Between 2002 and 2008, nine wild boars were monitored. Five of them were trapped using box-traps baited with crushed corn (110x110x240 cm). Additionally, four more boars were also radio-tagged and included in the analysis. Two of them were recovered from accidents (BM2 illegally snared, and BF3 fallen into a well) and the other two individuals were trapped by Park wardens with a blowpipe anaesthetic dart near residential areas and moved to wilder areas to avoid further conflicts with humans (BM1 and BF7). In addition, sixteen genets were trapped and radio-tagged between 1999 and 2001 using wooden box-traps (110x27x27 cm), (Camps-Munuera & Llimona-Llobet 2004). Only adults and sub-adults were trapped and fitted with transmitters (Biotrack

Ltd. and Tinyloc SL.), collars for foxes and genets, and ear-tags for wild boars. All individuals were sexed, weighed to the nearest 0.1 kg and morphometric measurements were taken. Animals were anaesthetized by intramuscular injections of a combination of ketamine and xylazine hydrochloride (Kreeger 1997) or tiletamine and zolazepam hydrochlorides taking into account the recommendations to reduce handling stress to avoid immobilization failure (Fenati *et al.* 2008). Traps were checked and defused every day at dawn to avoid trapping domestic animals, and were activated again at dusk. All the recommendations of the Animal Welfare Protocol of the European Union were followed and no animal was injured during handling.

A portable VHF receiver (R1000, Communications Specialists Inc.) and a hand-held three element Yagi antenna (Biotrack Ltd.) were used for radio-tracking data collection. Locations were taken with the triangulation method (White & Garrot 1990), as direct observation was impossible in most ranges because of the dense undergrowth of the wood. Animal movement can greatly impact the accuracy of telemetry studies (Schmutz & White 1990), so we recorded all bearings for each radiolocation within a 10-minute interval to reduce error associated with animal movement and within 45–135º intervals for cross bearings. Each radio-tracking session consisted of one or two periods of three hours, during which we recorded as many locations as possible. Exceptions to this were the first night after the release of the animal and when a particular animal was difficult to find. In these cases, radio-tracking took place for the whole night. Each individual was followed for at least one session per week, except when the signal was lost.

Radio-tracking data analysis

Given that any estimate of home range must incorporate the entire activity cycle of the animal (Harris *et al.* 1990), both diurnal and nocturnal fixes were used to estimate home range area because. Activity and resting fixes were also merged for analyses because their spatial distributions were not different. Ranges VII software (South *et al.* 2005) was used for radio-tracking data analyses. To avoid auto-correlation in home range estimators caused by unequal time intervals between locations we first randomly deleted locations until they were at least one hour apart in the same night-period (Cavallini 1996, de Solla *et al.* 1999). In order to avoid pseudo-replication, when individual home ranges of the same species overlapped with others simultaneously, a Multi-Response Permutation Procedures test (MRPP, Biondini *et al.* 1988) was performed in order to test for significant differences in space use. If significance was not reached, individuals were considered as members of the same group, and their home range and core foraging area was obtained by merging all fixes. Finally, only fox individuals M1 and F2 shared their home ranges (Z_s = -0.360, n_1 = 29, n_2 = 35, P = 0.272, all other pairs: Z_s max., $P \leq 0.05$).

In spite of criticism (Borger *et al.* 2006), the *Minimum Convex Polygon* (hereafter MCP) is the most frequently employed method in home range studies. Alternatively, the *kernel* estimators (Worton 1989) have performed better than other *home range* estimators with *fixed kernel* performing better than *adaptive kernels* (Seaman & Powell 1996), but it has the problem that the bandwidth selection method has a great influence on the results, which prevents robust comparisons between studies (Laver & Kelly 2008). Thus, home ranges were estimated using both methods in order to provide better comparability with other studies: Minimum Convex Polygon with

95% of locations (thereafter MCP95) and fixed kernel estimator with 95 % of the utilization distribution (thereafter FK95) as recommended by Laver & Kelly (2008). For core foraging areas we also used both methods. We used the UD Plot (Wray *et al.* 1992) to identify the percentage of locations corresponding to core areas at 5 % intervals (Samuel *et al.* 1985) thereafter MCPUD and FKUD for the Minimum Convex Polygon and the Fixed Kernel Foraging Areas respectively.

Habitat data

The 19 layers from the digital cartography of Catalonia (CREAF 1997 and 2002) present in Collserola Park, were condensed into six habitat types for the analyses: riverbank vegetation (RV), pine and oak tree woodlands (WD), shrub (SB), crop fields (CF), herbaceous vegetation (HV), and residential areas (RA, Table I). Pine and oak tree habitats were merged into a woodland habitat association because, in Collserola, oak wood rarely occurs alone but instead is mixed with pine. Transport networks (railways, roads and highways) and industrial estates were excluded from the analyses because they were considered unsuitable habitats for the species.

Habitat association	Vegetation units	Main species included
Riverbank vegetation (RV)	Primeval riverbank vegetation	*Ulmus campestris, Populus nigra, Populus alba*
	Restorated riverbank vegetation	*Ulmus campestris, Populus nigra, Populus alba*
	5 m buffer around water streams	*Rubus fructicosus, Smilax aspera, Arundo donax, Phragmites australis*
	10 m buffer around 1st class rivers	
	15 m buffer around 2nd class rivers	
Woodland (WD)	Pine-dominating wood	*Pinus halepensis, Pinus pinea*
	Esclerophite-dominating wood	*Quercus ilex, Quercus coccifera*
	Deciduous-dominating wood	*Quercus cerrioides, Quecus suber*
Crop field (CF)	Fruit trees	*Prunus dulcis, Ceratonia siliqua, Olea europaea*
	Irrigated fruit trees	*Ficus carica, Prunus avium*
	Vineyards	*Vitis ssp.*
	Dry grass crops	*Hordeum vulgare*
	Irrigated grass crops	*Medicago sativa*
	Small orchards	A variety of fruit and vegetable species
Shrub (SB)	Bush-dominating wood	*Bupleurum fruticosum, Calicotome spinosa, Cistus monspeliensis, Cistus salviifolius, Rosmarinus officinali, Erica multiflora, Genista scorpius*
	Makis-dominating wood	*Quercus coccifera, Chamaerop humilis, Ceratonia siliqua, Rhamus alicoides*
	Wood with poor vegetation coverage	*Erica arborea, Lavandula stoechas, Pistacia lentiscus, Smilax aspera, Quecus coccifera*
Herbaceous vegetation (HV)	Meadow-dominating savannah vegetation	*Hyparrhenietum hirto-pubescens*
	Disused crop fields and fallows	
	Denudated woodlands	
Residential areas (RA)	Neighbourhoods of variable extension inside the Park	
	Lanscaped woods	
	Recreation areas, golf yard	
Not included	Transport infrastructures	
	Industry	

Table I. Correspondence between habitat associations, areas included and plant communities.

We conducted ground surveys and comparisons with digitized aerial photographs to ensure that we correctly classified polygons into each habitat class. Special attention was given to small orchards, which are sometimes omitted from standard cartography. It must be said that RV habitat includes not only the primeval and restored riparian vegetation and the bramble bushes which occupy the riverbed, but also includes torrents, ravines and gullies. Home range, core foraging area and 1 km^2 grid quadrat polygons were used to clip habitat layers using ArcGIS 9.2 (ESRI 2006). For

1st-order analysis the study area (available habitat) was the whole of Collserola Park, while for the 2nd order analysis we had to define several study areas because not all home ranges of each species were contiguous. These arbitrary study areas were defined by drawing a Fixed Kernel with 99% of the distribution of all fixes of the same species merged for all individuals that had contiguous home ranges (one for foxes, two for wild boars and three for genets) with a 500 m buffer around it (Lamberti *et al.* 2006). Then, habitat attributes were exported to DBASE IV files to obtain the proportions of each habitat class (Brunjes *et al.* 2006).

Habitat selection analyses

Compositional analysis (Aebischer *et al.* 1993) was used to study animal preferences of habitat use by replacing all non-used habitat types by a value of 0.03 (Brennan 2004) and cases were weighted by the square root of the corresponding *n* fixes. To evaluate 1st-order selection we compared the habitat percentages of those sampled grid squares which recorded the species presence, with those of the total sampled grid squares. Obviously, the fact that a species was not recorded in a given square does not imply that it was absent from this square, but we interpret that positive sampled grid squares had higher probability of recording the species during the study period due to a higher frequency of use. For 2nd-order selection, the composition of habitats within home ranges (MCP95 and FK95) was compared with that of habitats within the corresponding study area. Finally, for 3rd-order selection we compared the composition of habitats within core foraging areas (MCPUD and FKUD) with that of habitats within the corresponding home range (Beasley *et al.* 2007), but avoiding the less preferred habitat resulting from the second order analysis (Aebischer *et al.* 1993). For third order analysis, we used the individual core foraging areas because only in two cases did the core areas of two individuals partially overlap. The Chandler correction (1995, α = 0.10) was applied for the two-by-two comparisons between habitat types when establishing the significance level. For comparison of sexes in wild boars and genets, a simple MANOVA with log-ratios was used (Aebischer *et al.* 1993). For fox sex comparison we ran another compositional analysis with the individual home ranges, without merging individuals VM1 and VF2, in order to search for differences between sexes, and the same results were obtained. An Excel (Microsoft, Redmond, WA) macro (Smith 2005) was used to carry out the compositional analyses.

RESULTS

Eight red foxes were tracked, four males and four females (Fig. 1c). The average tracking period (± SE) was of 170 ± 30 days, obtaining a mean of 32 ± 7 fixes per individual. On the other hand, nine wild boars were tracked, five males and four females (Fig. 1d), with an average tracking period of 99 ± 35 days, obtaining a mean of 38 ± 8 fixes per individual. Finally, 17 genets were tracked, seven males and 10 females (Fig. 1e). Male M7 was not included in the analysis because only three fixes were recorded before the signal was lost. The average tracking period (± SE) was 259 ± 31 days, obtaining a mean of 117 ± 14 fixes per individual. With respect to the camera-trapping survey, a total of 980 positive images were recorded, 114 (11.6 %) of them corresponding to foxes, 145 (14.8 %) to wild boars and 71 (8.9 %) to genets. A total of 21 plots (25.0 %) recorded fox presence, 26 plots recorded wild boar presence (30.9 %) and genets occurred in 11 of the 84 surveyed plots (13.1 %, Fig. 1b).

Species	**Order**	**Method**	**λ**	**χ^2**	**n**	***df***	***P***
Fox	1st	Grid squares	0.204	33.388	21	5	0.0002**
	2nd	MCP95	0.174	12.229	7	5	0.299
	2nd	FK95	0.401	6.404	7	5	0.6979
	3rd	MCPUD	0.732	2.491	8	4	0.9154
	3rd	FK50	0.287	9.992	8	4	0.4351
Wild boar	1st	Grid squares	0.249	36.155	26	5	0.0001**
	2nd	MCP95	0.051	26.723	9	5	0.0084**
	2nd	FK95	0.153	16.914	9	5	0.0785*
	3rd	MCPUD	0.099	21.106	9	4	0.1066
	3rd	FK50	0.369	8.976	9	4	0.5604
Genet	1st	Grid squares	0.173	19.276	11	5	0.0183**
	2nd	MCP95	0.072	42.149	16	5	0.0002**
	2nd	FK95	0.048	48.484	16	5	0.0002**
	3rd	MCP50	0.063	35.278	16	4	0.0023**
	3rd	FK50	0.110	37.174	16	4	0.0031**

Table II. Compositional analysis results for the red fox *Vulpes vulpes*, the wild boar *Sus scrofa* and the genet *Genetta genetta* for the three levels of analysis. ** show significant differences while * shows marginal differences.

At 1st-order selection scale (population level), we found significant habitat selection for the three species (Table II). Foxes and genets selected at this level for riverbank vegetation in the first term and woodlands in the second term. For the red fox the avoided habitat at this level of analysis was shrubs, while for genets it was crop fields. Otherwise, wild boars selected for woodland in first term and riverbank vegetation in second term, being herbaceous vegetation the avoided habitat. For red fox significant differences were also found between riverbank vegetation and both herbaceous vegetation and shrubs, and between shrubs and woodland. For wild boar significant differences were found between riverbank vegetation and both crops and herbaceous vegetation, as well as between woodland and both shrubs and herbaceous vegetation (Table III)

Considering all fox home ranges and comparing their habitat composition with the percentages of the available habitat (2nd-order selection), we detected no habitat selection different from availability for both methods (Table II). On the contrary, wild boars showed a habitat selection for MCP95 method. Although for the FK95 boars did not reach the level of significance, it showed a marginal significance with a similar selection sequence as for MCP95 (Table II). Boars selected for riverbank vegetation, followed by woodlands, crops, shrubs and herbaceous vegetation, and residential areas were the avoided habitat (Table III). No differences were found between sexes for any of the methods (MCP95: λ = 0.328, F = 1.231, P = 0.461; FK95: λ = 0.301, F = 1.395, P = 0.417). Genets also showed a significant habitat selection for both methods (Table II), with the same selection sequence except for the avoided habitat, which were shrubs for MCP95 and residential areas for FK95. Genets selected for woodland, followed by riverbank vegetation, herbaceous vegetation and crops (Table III).

a) Fox 1st-order	RV	CF	HV	SB	RA	Rank
Riverbank vegetation (RV)						5
Crop fields (CF)	-1.811 ± 0.585					2
Herbaceous vegetation (HV)	-2.486 ± 0.634*	-0.675 ± 0.822				1
Shrubs (SB)	-3.006 ± 0.655*	-1.194 ± 1.059	-0.519 ± 0.824			0
Residential areas (RA)	-0.984 ± 0.490	0.827 ± 0.901	1.502 ± 0.890	2.021 ± 0.631		3
Woodland (WD)	-0.227 ± 0.280	1.585 ± 0.737	2.260 ± 0.794	2.779 ± 0.686*	0.758 ± 0.481	4

b) Boar 1st-order	RV	CF	HV	SB	RA	Rank
Riverbank vegetation (RV)						4
Crop fields (CF)	-2.654 ± 0.463*					1
Herbaceous vegetation (HV)	-2.731 ± 0.501*	-0.077 ± 0.679				0
Shrubs (SB)	-1.790 ± 0.647	0.864 ± 0.815	0.941 ± 0.551			2
Residential areas (RA)	-0.773 ± 0.498	1.881 ± 0.738	1.958 ± 0.714	1.017 ± 0.645		3
Woodland (WD)	0.032 ± 0.084	2.686 ± 0.481	2.763 ± 0.521*	1.822 ± 0.686*	0.805 ± 0.528	5

c) Genet 1st-order	RV	CF	HV	SB	RA	Rank
Riverbank vegetation (RV)						5
Crop fields (CF)	-3.193 ± 0.845					0
Herbaceous vegetation (HV)	-1.501 ± 0.883	1.692 ± 1.162				2
Shrubs (SB)	-1.785 ± 0.813	1.408 ± 1.413	-0.284 ± 0.861			1
Residential areas (RA)	-0.727 ± 0.656	2.466 ± 0.806	0.774 ± 0.889	1.058 ± 0.957		3
Woodland (WD)	-0.141 ± 0.221	3.052 ± 0.921	1.360 ± 1.037	1.644 ± 0.843	0.586 ± 0.716	4

d) Boar 2nd-order	RV	CF	HV	SB	RA	Rank
Riverbank vegetation (RV)						5
Crop fields (CF)	-0.929 ± 0.526					3
Herbaceous vegetation (HV)	-2.366 ± 0.908	-1.438 ± 1.295				1
Shrubs (SB)	-2.120 ± 1.092	-1.120 ± 1.569	0.414 ± 0.671			2
Residential areas (RA)	-2.617 ± 0.822	-1.688 ± 1.212	-0.250 ± 0.510	-0.529 ± 0.936		0
Woodland (WD)	-0.067 ± 0.088	0.861 ± 0.573	2.299 ± 0.908	2.086 ± 1.069	2.549 ± 0.844	4

e) Genet 2nd-order	RV	CF	HV	SB	RA	Rank
Riverbank vegetation (RV)						4
Crop fields (CF)	-2.363 ± 0.584					2
Herbaceous vegetation (HV)	-0.943 ± 0.766	1.421 ± 0.742				3
Shrubs (SB)	-4.886 ± 0.495	-2.523 ± 0.487	-3.944 ± 0.847			1
Residential areas (RA)	-5.062 ± 0.474	-2.699 ± 0.759	-4.119 ± 1.019	-0.175 ± 0.596		0
Woodland (WD)	0.086 ± 0.115	2.450 ± 0.589	1.029 ± 0.813	4.973 ± 0.470	5.148 ± 0.478	5

f) Genet 3rd-order	RV	CF	HV	SB	RA	Rank
Riverbank vegetation (RV)				–		4
Crop fields (CF)	-4.539 ± 0.580			–		0
Herbaceous vegetation (HV)	-3.548 ± 0.806	1.123 ± 1.468		–		1
Residential areas (RA)	-3.607 ± 1.951	1.252 ± 2.219	0.477 ± 3.549	–		2
Woodland (WD)	-0.016 ± 0.135	4.709 ± 0.587	3.668 ± 0.782	–	3.835 ± 2.013	3

Table III. Matrix of means, standard errors and ranking of habitats (only for significant results) for the red fox *Vulpes vulpes*, the wild boar *Sus scrofa* and the genet *Genetta genetta*. a) to c) 1st order-analysis, d) and e) 2nd order-analysis, and f) 3rd-order analysis. For 2nd and 3rd order-analyses nly MCP95 ar shown. * show significant difference after applying Chandler correction.

For 3rd-order analysis, when comparing core foraging areas with the corresponding home ranges, and after removing the less preferred habitat at the 2nd-order selection, no significant habitat selection was found either for foxes or for wild boars for any of the methods. Only genets showed a significant habitat selection at 3rd-order analysis for both methods with a similar selection sequence (Table II). For MCPUD, genets selected for riverbank vegetation, followed by woodland, residential areas and herbaceous vegetation, and crops were the avoided habitats. According to FKUD, genets selected for riverbank vegetation, followed by woodland, crops and herbaceous vegetation, and residential areas were the avoided habitats (Table III).

DISCUSSION

Habitat selection by the red fox in its worldwide distribution range has been studied in a variety of environments, including those where the species is an introduced pest. These include habitats as diverse as Mediterranean areas, alpine habitats, islands or sclerophyllous Australian vegetation. In general terms, foxes living in mountainous areas select woods or forested areas (Weber & Meia 1996, Cagnacci *et al.* 2004, Van Etten *et al.* 2007). Australian foxes mainly select for sclerophyllous vegetation (Phillips & Catling 1991), principally blackberry communities (Marks & Bloomfield 2006, White *et al.* 2006). In North-America, Prince Edward Island red foxes select for agricultural fields, dunes and human-use areas instead of natural areas, because of the availability of human-related food resources (Silva *et al.* 2009). Otherwise, in Mediterranean areas, foxes show high plasticity in habitat selection patterns, selecting scrub woods, maquis shrubs, woods and scrubs, or olive groves and vineyards (Cavallini & Lovari 1991, Cavallini & Lovari 1994, Lucherini *et al.* 1995, Pandolfi *et al.* 1997). Baker & Harris (2007) showed that for urban foxes an increase in urbanization level did not affect habitat use. Contrarily, our results only show a significant habitat selection at population level, but not within the study area (2nd-order analysis) or within the home range (3rd-order selection). In the Eastern and South-Eastern sides of Collserola, where foxes were tracked, shrubs are commonly associated with degraded and anthropogenic environments, and that could be one explanation for the absence of selection towards habitats that are selected in other Mediterranean habitats. Foxes selected riverbank vegetation at the 1st level of analysis. At this level, this could be partially explained because water streams, where riverbank vegetation patches are found, are located predominantly in the lower lands of the Park, then selecting for smoother orography and avoiding the higher hills. In Collserola, riverbank vegetation was shown to be the most concealed habitat for badgers (Molina-Vacas *et al.* 2009a, 2009b), so this habitat type would represent a refuge-rich patch for foxes, where they can hide from human activities during resting time. The lack of significant selection at the 2nd and 3rd-order selection for fox and wild boar (for fixed kernel method) is interpreted as a consequence of the opportunistic behaviour the species. So we consider that both species are similarly opportunistic in Mediterranean habitats.

Wild boar show a tendency to select for concealed habitats for resting (Cargnelutti *et al.* 1995), with special regard to females (Splitz & Jauneau 1995), but are highly variable in habitat choice depending on the habitat they inhabit: forested habitats (Cargnelutti *et al.* 1990, Gerard *et al.* 1991, Abaigar *et al.* 1994, Meriggi & Sacchi 2001), agricultural fields

(Gibson *et al.* 2004, Santos *et al.* 2004) or marshes (Dardaillon 1987). However, Boitani *et al.* (1994) did not find a clear selection pattern for wild boar in Tuscany. Similarly to Meriggi & Sacchi (2000), in Collserola wild boar was more commonly found in those 1x1 km grid squares which contained woodlands at population level (1st-oder selection), where the acorn production, its main food resource, is higher than in other habitats. In agreement with previous studies on wild boar (Splitz & Jauneau 1995, Cargnelutti *et al.* 1995) and feral pigs (Baber & Coblentz 1986, Caley 1997, Dexter 1998, Hayes *et al.* 2009), in Collserola boars selected for riverbank vegetation within the study area, which means that they located their home ranges by actively selecting this habitat, probably because it provides good shelter from humans and also from high temperatures during the summer season. In agreement with this, in a previous study in Collserola, it has been shown that wild boars showed higher levels of feeding activity in such more humid habitats during the summer drought periods (Cahill *et al.* 2003b). These habitats represent the damper environments in Collserola, and wild boars would actively search for these conditions due to their lack of thermo-regulation adaptations to deal with warm weather conditions during summer (e.g. Dardaillon 1987), and also food availability/accessibility, rooting activity, etc (Cahill *et al.* 2003b). As has been recently shown by Keuling *et al.* (2009), in North-East Germany, different behavioural patterns in habitat selection can exist within the same wild boar population. In a similar way, in our case boars can also be divided into two different groups according to their behaviour towards human presence. Individuals BM1 and BF7, which had previously been considered as conflictive due to feeding on rubbish, orchards, gardens, etc. and which were habituated to human presence, had home ranges which included a higher proportion of urban and residential areas than the remaining individuals, and also a lower use of concealed sites as riverbank vegetation. Moreover, individual BM2, despite being trapped feeding in a vegetable garden in a residential area, did not show this habituated behavioural pattern displayed by BM1 and BF7. This human-habituated behavioural strategy has been related to a better body condition, and thus to a higher reproduction rate in recent studies carried out in Collserola Park (Cahill *et al.* 2009).

In the Iberian Peninsula, genet occurrence has been associated with basal habitats, high temperatures and low rainfall (Virgos & Casanovas 1997, Virgos *et al.* 2001). In a similar way, Galantinho & Mira (2009) showed that ecological variables explained the greatest amount of variability of genet occurrence in Mediterranean habitats, in detriment to human influence and livestock activities. The vegetation strata and the high organic content of soils seemed to be the most important factors in genet presence. These factors must be related to a greater abundance of its main prey -food resources- and to a lower risk of predation and competition with other predators –refuge resources- (Virgos & Casanovas 1997, Virgos *et al.* 2001). Despite the fact that in some areas of its distribution there is no evident habitat selection at coarse-grained scale -1st-order selection- (Gaubert *et al.* 2008), in Collserola we found the same selection towards riverbank vegetation as found for foxes, in agreement with other previous studies in Mediterranean habitats (Virgos & Casanovas, 1997, Matos *et al.* 2009). This higher frequency of use of grid squares with abundant riverbank vegetation must be interpreted as a selection towards lowlands as a consequence of the species' affinity for warm and humid places (Virgos &

Casanovas 1997) and also because in these areas they find resting and feeding resources (Matos *et al.* 2009). Otherwise, genets had been commonly associated with woodland and shrub areas (Palomares & Delibes 1994, Virgos & Casanovas 1997, Virgos *et al.* 2001, Rosalino & Santos-Reis 2002, Espírito-Santo *et al.* 2007, Sarmento *et al.* 2010), agreeing with our results at 2nd order (and also 3rd-order for MCPUD), highlighting its arboreal behaviour and reinforcing the idea that genets need good tree/shrub cover to locate their home ranges (and also their core foraging areas). This vegetation coverage must provide suitable preys, such as woodmice, and also inaccessibility from humans to situate their resting sites and latrines (Pla *et al.* 2001, Camps-Munuera & Llimona-Llobet 2004, Espírito-Santo *et al.* 2007).

In general terms, when a habitat selection different from random has been found for any method, analysis level or species, we found that riverbank vegetation or woodland were the preferred habitats. On the contrary, residential areas, herbaceous vegetation and shrubs were the less preferred habitats. These results agree with those obtained by Molina-Vacas *et al.* (2009b) for European badgers, and highlight the idea that those habitats which confer more protection and inaccessibility from humans are positively selected by meso-mammals in such anthropogenic environments as those of Collserola. Thus, due to the high human pressure which Collserola supports, which implies direct (hunting, poaching, road-kills, loose dogs) and indirect negative consequences (territory and connectivity loss, and habitat fragmentation), food does not seem to be the sole factor which determines home range configuration. Probably, in Collserola, concealed sites may also be a limiting resource for free ranging meso-mammals, which would constrain the range of possibilities for habitat selection in conjunction with many other factors. In other Mediterranean areas, riparian habitats showed higher small mammal abundance than the adjacent matrix (Cuesta *et al.* 1991). Otherwise, riverbank vegetation is a linear embranched habitat which crosses all other habitat types and allows mammals to move unnoticed from one patch to another as proposed in previous studies (Virgós 2001, Molina-Vacas *et al.* 2009a, 2009b); and this can partially explain the selection of this habitat for the three species at least for the first level of analysis.

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ATROPELLOS DE MAMÍFEROS Y TRÁFICO EN LA RED VIARIA DE UN ESPACIO NATURAL EN EL ÁREA METROPOLITANA DE BARCELONA: QUINCE AÑOS DE SEGUIMIENTO EN EL PARQUE DE COLLSEROLA

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Capítol 4

CAPÍTOL 4

Atropellos de mamíferos y tráfico en la red viaria de un espacio natural en el Área Metropolitana de Barcelona: quince años de seguimiento en el parque de Collserola

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BLACKSPOT,
MAMMALS,
MORTALITY,
ROADKILL,
TRAFFIC

ABSTRACT. – Collserola Park is situated in the middle of the Barcelona metropolitan area, and is surrounded by over four million inhabitants, whose presence exerts strong anthropogenic pressure on this nature area. This study analyzed roadkill data gathered in Collserola since 1991. In total, 991 incidents were recorded, 556 of which involved mammals. Five species make up 72.3 % of all registers; two hedgehog species *Erinaceus europaeus* and *Atelerix algirus* (21.8 %), wild boar *Sus scrofa* (20.7 %), the rabbit *Oryctolagus cuniculus* (16.0 %) and the red squirrel *Sciurus vulgaris* (13.8 %). Analysis of incidents showed a positive relationship between the roadkill rate per km and the daily average density of traffic. Habitat characterisation around roadkill sites showed that open habitat environments were more represented, in the case of rabbit and hedgehog, and that woodland habitats were under-represented. Squirrel presented the opposite situation, with open habitat types being under-represented and woodland being more represented. In the case of the wild boar, the habitat around roadkill sites corresponded largely to what was expected by chance. Seasonal variations were observed in roadkill frequency throughout the year, which did not respond to variations in traffic volume, but rather were attributed to aspects of the biology of the different species. In the case of the squirrel and hedgehog, maxima were observed at the end of spring, whereas in the case of the rabbit there was a reduction in roadkills in summer. These situations reflect seasonal population changes as well as the decreased activity of the squirrel in winter and almost no activity on the part of the hedgehog during this period. Wild boar roadkills in the park showed a more irregular temporal variation, with maxima in June and November, which seems to correspond to several factors: mobility patterns, juvenile dispersion, and the rutting and hunting seasons.

INTRODUCCIÓN

El estudio de los atropellos de fauna está adquiriendo cada vez mayor relevancia en la gestión de espacios naturales y concretamente en el ámbito de la conservación de la fauna (Trombulak y Frissell 2000, Malo *et al.* 2004, Saeki y Macdonald 2004). La continua expansión de las infraestructuras viarias en el territorio y el aumento del tráfico, así como los problemas derivados de seguridad vial, hacen que esta problemática tenga cada vez mayor significación (Bennet 1991, Müller y Berthoud 1997, Forman *et al.* 2003).

En el marco de un proyecto más amplio de estudio del impacto de las infraestructuras de transporte sobre la fauna, que incorpora la fragmentación, el efecto barrera y la conectividad ecológica en el Parque de Collserola (véase Llimona *et al.* 2005), se han analizado los datos de atropellos de fauna recogidos desde 1991. El principal objetivo de este artículo es caracterizar la problemática de los atropellos de mamíferos en Collserola y en especial su relación con los niveles de tráfico.

ÁREA DE ESTUDIO

En medio del área metropolitana de Barcelona se encuentra el Parque de Collserola con 8.500 ha protegidas donde domina el bosque mixto de pino carrasco (*Pinus halepensis*) y encina (*Quercus ilex*). Rodeado por más de cuatro millones de habitantes, el parque está sometido a una gran presión antrópica y existe una extensa red viaria que atraviesa el parque, con una autopista vallada –los ‘Túneles de Vallvidrera’ (la E-9)-, con 7,6 km de su trazado a cielo abierto, unos 70 km de carreteras convencionales y 42 km de pistas forestales abiertas a la circulación. Hay que destacar la existencia de un gran eje viario central, configurado por la autopista E-9, una carretera convencional y una vía férrea vallada, con un importante efecto barrera acumulado, que divide el parque en dos grandes fragmentos de masa forestal (véase Llimona *et al.* 2005).

El tráfico a través del Parque de Collserola responde básicamente a desplazamientos diarios entre los lugares de residencia y de trabajo, entre la capital Barcelona y la comarca vecina del Vallés Occidental, y viceversa, en menor cantidad también se dan desplazamientos vinculados al ocio y a la presencia de merenderos y restaurantes de montaña. El volumen de tráfico que recorre la sierra de Collserola diariamente es muy alto; por ejemplo, tan sólo en la autopista E-9 que atraviesa el parque, se registró en 2005 intensidades medias diarias de tráfico (IMD) superiores a los 33.500 vehículos, y esta tendencia, como sucede en todo el territorio, va en aumento. A pesar del alto grado de antropización de su entorno, hay que destacar el gran interés natural de Collserola así como la existencia de parajes de elevado interés ecológico (Raspall *et al.* 2004).

MÉTODOS

Para realizar el presente estudio nos hemos basado principalmente en (*i*) los registros de atropellos de fauna, (*ii*) los datos de tráfico en la red viaria del parque y (*iii*) la caracterización de los hábitats alrededor de los viales. Como punto de partida, se contaba con una base de datos de atropellos recogidos desde 1991 incorporados en el sistema de información geográfica (SIG-Fauna) del parque. Se trata de información procedente de fuentes diversas, aunque fiables, principalmente de registros y observaciones de técnicos del parque, de guardas forestales, además de diversos seguimientos específicos centrados en diferentes grupos faunísticos. En todos los casos se dispone de la información referida a la especie, al punto exacto de localización del cadáver y la fecha, aunque la mayor parte de los datos no proceden de un seguimiento estandarizado. Se ha considerado oportuno analizar la totalidad de los registros del SIG-Fauna ya que, pese a su heterogeneidad, representan un importante volumen de datos difícilmente obtenibles a partir de un seguimiento específico, y por tanto de gran utilidad desde la perspectiva de la caracterización general y gestión de esta problemática.

Se ha caracterizado el hábitat alrededor de los puntos de atropello de las especies de mamíferos que más incidencias registraron. Para ello se han establecido *buffers* circulares de 100 m de radio alrededor de las localizaciones de atropello y éstos se han cruzado con la cartografía de hábitats del parque usando el programa ArcView 3.2. Asimismo, se ha caracterizado la vegetación a lo largo de la totalidad de la red viaria mediante la creación de un buffer lineal de 100 m de ancho a cada lado de las carreteras y se ha comparado su disponibilidad con los datos obtenidos en relación al hábitat alrededor de las localizaciones de los atropellos.

Por lo que respecta a la información del tráfico, el Servicio de Vías Locales de la Diputación de Barcelona ha facilitado datos detallados de las IMD en los diferentes tramos de la red viaria. Estos tramos son de longitud variable, dado que los criterios de tramificación aplicados están basados en las características de la intensidad de tráfico en las carreteras. Para el análisis de las tasas de atropello, se ha calculado el índice kilométrico de atropellos (IKA) en los mismos tramos de carreteras convencionales considerados para el seguimiento de las IMD, estableciéndose así la relación entre IKA e IMD. Se trata de vías con un carril por sentido, entre cinco y siete metros de ancho de calzada y una IMD entre 1.300 y 10.000 vehículos. La velocidad media de circulación es de entre 50 y 90 km/h y en pocos tramos supera los 90 km/h.

El 86% de los atropellos se concentran en las carreteras convencionales, un 6% de los atropellos proceden de pistas forestales y únicamente un 5% de los datos corresponden a la autopista E-9 que atraviesa el parque. El resto de datos (3%) corresponde a atropellos en viales en zonas urbanizadas dentro del parque. El bajo porcentaje de atropellos registrados en la autopista, lejos de indicar una baja incidencia de esta problemática pone en evidencia la dificultad de detectar los individuos atropellados en esta vía, este hecho provoca un sesgo respecto de la tasa de individuos atropellados en la autopista, motivo por el cual se ha preferido no incluir los registros de ésta en los análisis entre IKA e IMD. Sin embargo, se dispone de datos de IMD en esta vía para cada mes del año, lo que proporciona una información como un indicador de la variabilidad temporal del tráfico en el ámbito del parque a lo largo del año.

Finalmente, en el caso del jabalí *Sus scrofa* (Linnaeus 1758), una de las especies que más atropellos registra en Collserola, se dispone además de datos detallados respecto a los individuos atropellados, ya que en los últimos años esta especie ha sido objeto de un seguimiento intenso en el parque (Cahill *et al.* 2003, Cahill y Llimona 2004). En el presente estudio, se ha comparado la edad de los jabalíes atropellados con la de los individuos muertos por otras causas. La estimación de la edad de los jabalíes muertos se ha basado en la secuencia de erupción dentaria (Monaco *et al.* 2003).

RESULTADOS

La base de datos del SIG-Fauna del parque dispone de 991 registros de atropellos de vertebrados en el ámbito de Collserola acumulados desde 1991. De ellos, 556 registros (56,2 %) corresponden a mamíferos, mientras el resto corresponden a aves (21,1 %), reptiles (14,8 %) y anfibios (7,4 %). En total se han detectado 17 especies diferentes de mamíferos atropelladas (Fig. 1), aunque cinco de ellas concentran el 72,3 % de los registros; las dos especies de erizo (21,8 % de atropellos: principalmente *Erinaceus europaeus* Linnaeus, 1758 y ocasionalmente *Atelerix algirus* (Lereboullet, 1842), consideradas juntas como 'erizo' en los análisis, ya que no siempre se ha podido determinar la especie), el jabalí (20,7 %), el conejo *Oryctolagus cuniculus* (Linnaeus, 1758) (16,0 %) y la ardilla roja *Sciurus vulgaris* Linnaeus, 1758 (13,8 %). Otras especies de mamíferos detectadas son la gineta *Genetta genetta* (Linnaeus, 1758), el zorro *Vulpes vulpes* (Linnaeus, 1758), la comadreja *Mustela nivalis* Linnaeus, 1766, el tejón *Meles meles* (Linnaeus, 1758) o la garduña *Martes foina* (Erxleben, 1777) (Fig. 1).

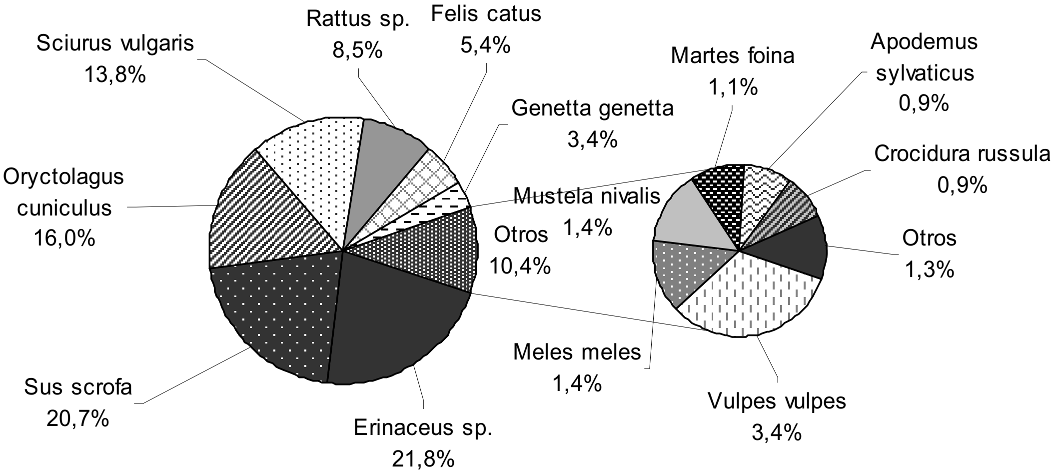

Fig. 1. Distribución de los atropellos por especies en el Parque de Collserola. Datos 1991-2006 (n= 556).

Se han caracterizado los hábitats alrededor de los puntos de atropello de las especies con mayor número de registros; erizo, jabalí, conejo y ardilla (Tabla I). Se observa que los puntos de atropello de jabalí y ardilla se localizan mayoritariamente en ambientes forestales (57,1 % y 67,3 % del hábitat alrededor de puntos para las dos especies respectivamente), al contrario de lo que sucede en el caso del erizo y el conejo, que se han encontrado principalmente en ambientes abiertos (cultivos, prados, matorral bajo), que representan el 34,7 % y el 48,0 % del hábitat respectivamente para estas especies. En la Fig. 2 se observa la 'selección' del hábitat por las especies a partir de la comparación de la proporción de hábitat alrededor de los puntos de atropello con la disponibilidad de éste considerada a partir de la caracterización del hábitat alrededor de la totalidad de las carreteras en el Parque de Collserola. Así, el conejo muestra una selección favorable hacia los ambientes abiertos, con un 26,9 % más de lo que se encuentra disponible y discrimina los ambientes forestales (-30,9 %). Lo mismo sucede en el caso del erizo, que selecciona ambientes abiertos (14,6 %) mientras que los ambientes forestales presentan una menor representación de la esperada (-24,6 %). La ardilla presenta un 13,2 % más de ambiente forestal alrededor de los puntos de atropello de lo que cabría esperar dada la disponibilidad del hábitat y se aprecia una selección negativa de los ambientes abiertos (-8,3 %). A diferencia de las anteriores, en el caso del jabalí los puntos de atropello no parecen relacionarse preferiblemente con ningún tipo de hábitat en concreto, sino muestra una distribución muy parecida a la disponible con tan solo ligeras desviaciones como un +3,1 % en el forestal y un -5,0 % por lo que se refiere a los ambientes abiertos (Fig. 2).

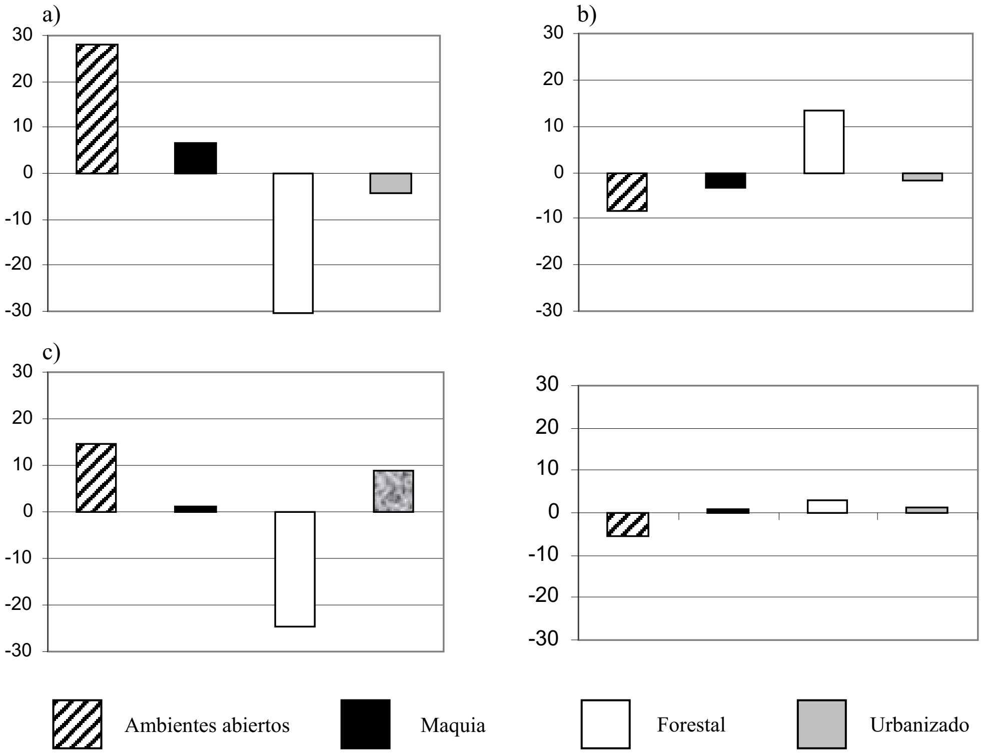

Fig. 2. ‘Selección’ del hábitat alrededor de los puntos de atropello de las especies más afectadas por esta problemática en Collserola (a, conejo; b, ardilla, c, erizo; y d, jabalí). La ‘selección’ se define por la comparación entre la proporción (%) observada alrededor de los puntos y la disponible alrededor de la red viaria.

Ambiente	Jabalí	Erizo	Conejo	Ardilla
Ambientes abiertos	14,5	34,7	48,0	11,5
Maquia	4,7	5,0	10,4	0,6
Forestal	57,1	29,4	23,7	67,3
Urbanizado	23,7	31,1	17,9	20,6
Total	100,0	100,0	100,0	100,0

Tabla I. – Proporción (%) de ambientes alrededor de los puntos de atropello (buffer 100 m de radio) de las especies más afectadas por esta problemática en el Parque de Collserola (jabalí, erizo, conejo y ardilla).

La tasa de atropellos (IKA) muestra grandes diferencias entre distintos tramos de la red viaria del parque, con valores entre 0,2 y 17,4 (Fig. 3), mostrándose el IMD como un factor determinante; se observa una relación entre el IKA y la IMD que se ajusta a una curva logarítmica asintótica ($r^2 = 0{,}82$, n = 16 tramos) y que alcanza un umbral a partir de una IMD de 10.000 (Fig. 4). Por otro lado, la distribución de los atropellos de mamíferos a lo largo del año muestra una curva con el máximo a finales de primavera y principios de verano (Fig. 5). La distribución mensual de atropellos no se relaciona con la intensidad de tráfico ($r^2 = 0{,}03$), reflejada por los datos del peaje de la autopista E-9, ya que la IMD se mantiene muy constante en casi todos los meses con la única excepción de agosto cuando los niveles de tráfico se reducen en un 45% (Fig. 5) coincidiendo con el período de vacaciones.

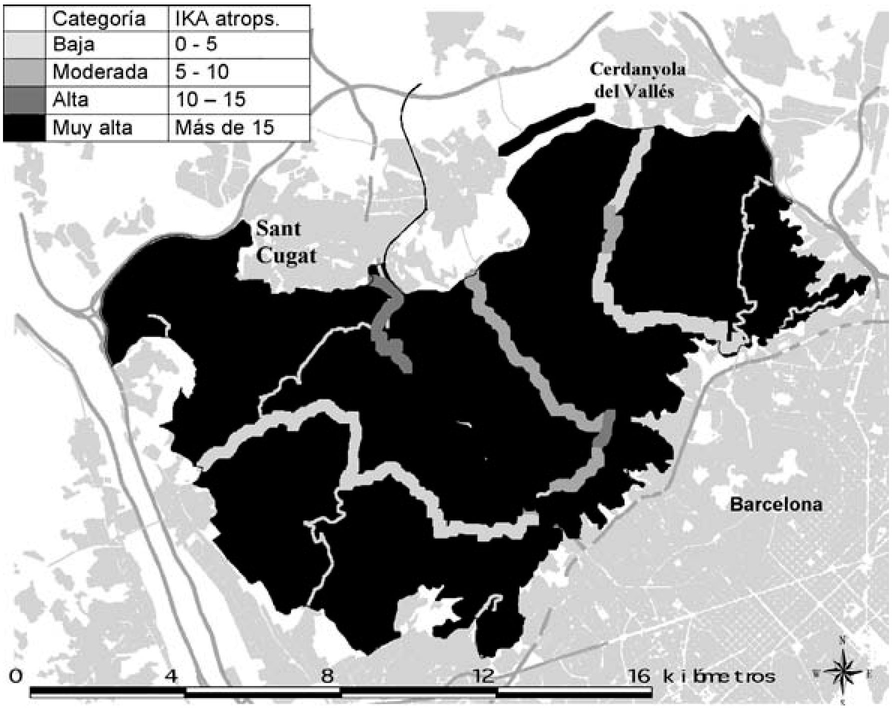

Fig. 3. Vista de la tasa de atropellos (IKA) de mamíferos en distintos tramos de las carreteras convencionales del Parque de Collserola.

La distribución temporal de los atropellos por especies muestra diferencias entre éstas (Fig. 6): así, en el caso del conejo, los atropellos se concentran en la primera mitad del año con un 70 % de las incidencias registradas, mientras que la ardilla muestra un patrón que se concentra durante la primavera con un máximo destacado en el mes de mayo y escasas incidencias entre noviembre y febrero. Una situación parecida sucede en el caso del erizo con una clara concentración de atropellos entre marzo y julio período en que se registra el 65 % de las incidencias. Para el erizo y el conejo se percibe una reducción de las incidencias de atropello durante el mes de agosto, coincidiendo con el único mes en que se produce una reducción significativa del tránsito (Fig. 5). Sin embargo, en el caso de la ardilla y el jabalí no se aprecian disminuciones durante dicho mes. Por lo que se refiere al jabalí, el patrón de atropellos a lo largo del año es más irregular en Collserola, con un máximo durante el mes de junio cuando se registra el 20,0 % de las incidencias y un mínimo en el mes de abril con tan solo el 1,7 % (n = 115). Se aprecia también un segundo pico de atropellos en noviembre (13,0 %) y, en cambio, el mes de diciembre es el segundo mes que menos incidencias registra (2,6 %).

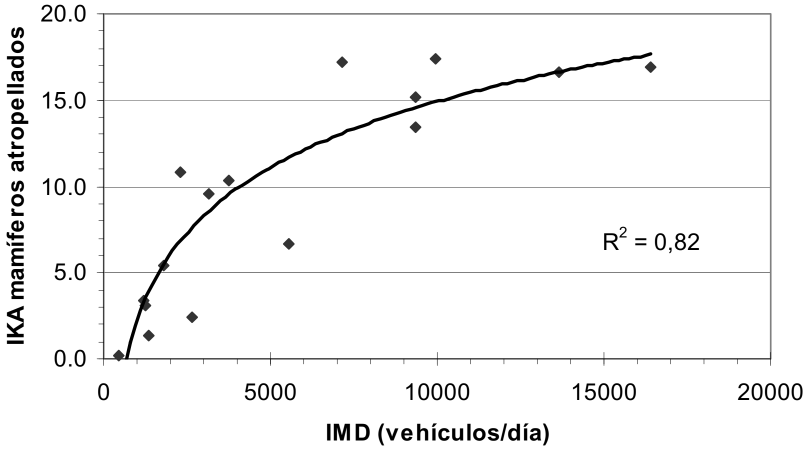

Fig. 4. Relación entre la tasa de atropellos de mamíferos por kilómetro (IKA) con la intensidad media diaria de tráfico (IMD) del mismo tramo en Collserola (n = 16 tramos).

En cuanto a la edad de los jabalíes atropellados, destaca la elevada proporción de jóvenes (6-12 meses) en comparación con la de los individuos muertos por otras causas (Fig. 7), representando el 29,5 % (n = 44) y el 14,0 % (n = 225) de las dos muestras respectivamente. Comparación mediante chi-cuadrado entre las cinco categorías de edad no da diferencias significativas (*P* > 0,05), dado que las dos categorías de mayor edad suman pocos individuos, por este motivo se han agrupado las tres categorías '1-2 años', '2-3 años' y 'más de tres años', en una sola de 'más de un año', ya que presentan proporciones muy similares entre sí en ambas muestras (atropellos y otras causas, Fig. 7). Comparación de las tres categorías (0-6 meses, 6-12 meses y más de un año) sí muestra diferencias significativas entre ellas (χ^2 = 6,21, *gl* = 2, *P* < 0,05, n = 269), que se atribuye a la mayor proporción de jabalíes de 6-12 meses de edad entre los atropellados en comparación con los muertos por otras causas, ya que las comparaciones chi-cuadrado 2x2 *a posteriori* entre las categorías contempladas solamente resultan significativas (*P* < 0,05) cuando se incluye la categoría de 6-12 meses, mientras las demás comparaciones no lo son (*P* > 0,05).

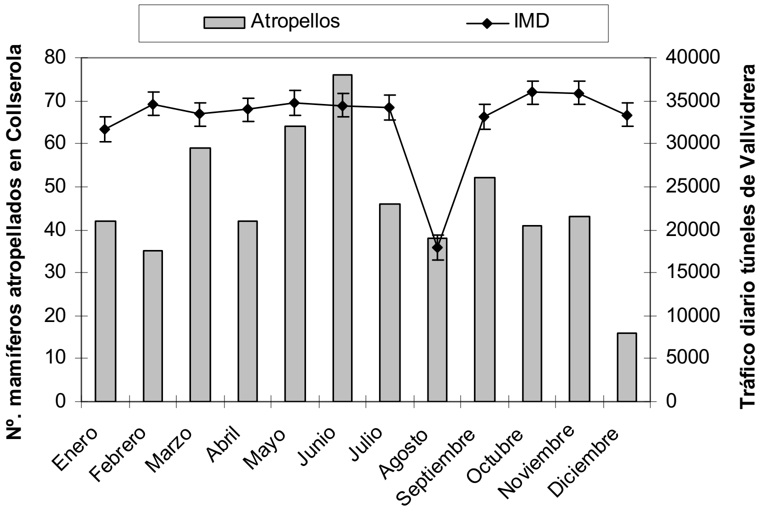

Fig. 5. Distribución mensual de los atropellos de mamíferos en el Parque de Collserola (n = 554) en comparación con el nivel global de tráfico en este ámbito indicado por el paso de vehículos en el peaje de la autopista de los túneles de Vallvidrera, situado en el centro de Collserola (Intensidad Media Diaria IMD: se indica el promedio mensual ± error típico de los cuatro años 2002-2005. Fuente datos IMD: web del Departamento de Política Territorial y Obras Públicas, Generalitat de Catalunya.

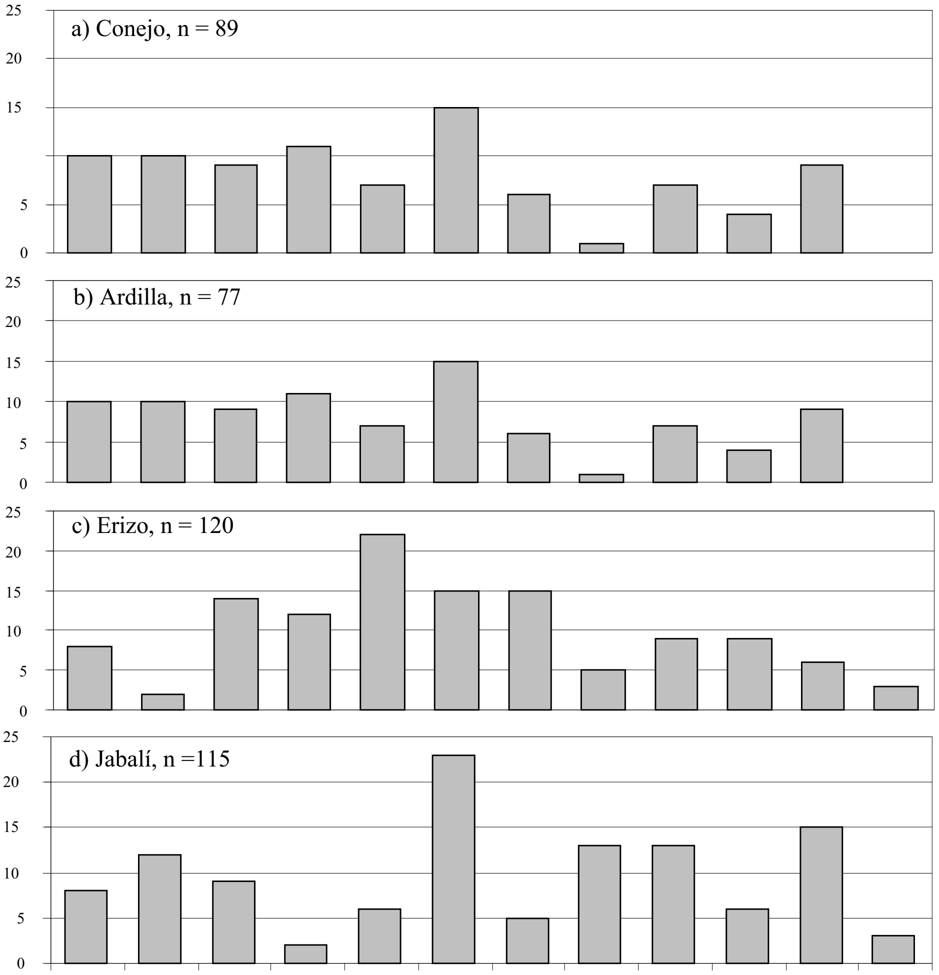

Fig. 6. Distribución mensual de atropellos de mamíferos en el Parque de Collserola para las especies con mayor número de incidencias (a, conejo; b, ardilla; c, erizo; d, jabalí).

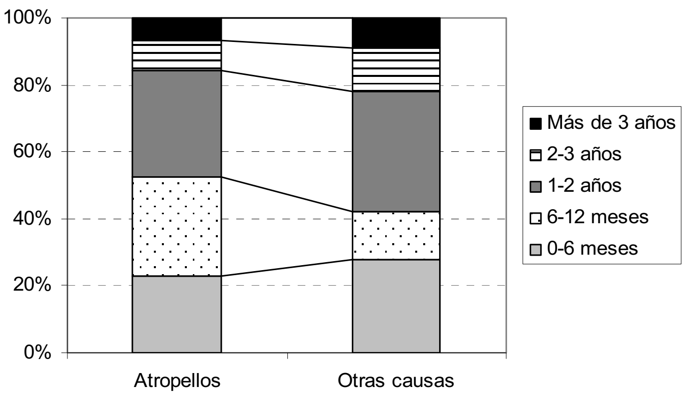

Fig. 7. Comparación de las categorías de edad de jabalíes muertos por atropello en carreteras y por otras causas en el Parque de Collserola durante el período 2002-2006 (atropellos n = 44, otras causas n = 225).

DISCUSIÓN

La revisión de casi un millar de registros de atropellos de fauna recogidos desde 1991 en el Parque de Collserola ha permitido caracterizar esta problemática en un espacio natural periurbano, destacándose la frecuencia de mamíferos entre las incidencias registradas. La proporción de mamíferos (56 %) resulta muy elevada si se compara con datos de otros estudios en los que ésta ronda el 33 % (PMVC 2003), situación que se debe a su mayor detectabilidad en el contexto de un seguimiento mayoritariamente pasivo. No obstante, en Collserola los mesomamíferos se han revelado como un grupo muy adecuado para caracterizar el fenómeno de los atropellos y la disponibilidad de información detallada sobre los niveles de tráfico ha permitido establecer algunas relaciones entre este factor y los atropellos en las vías del parque.

La relación que se observa entre la tasa de atropellos de mamíferos y los niveles de tráfico (IMD) en el parque coincide en gran parte con la descripción teórica de Müller y Berthoud (1997), según la cual las tasas de mortalidad suelen incrementarse progresivamente con el aumento de tráfico, hasta llegar a un umbral en que éste disuade a los animales del intento de cruce. En su modelo teórico, dichos autores indican la presencia de un umbral de atropellos cuando el tráfico es de entre 5.000 y 10.000 vehículos al día, mientras que con datos empíricos en Collserola se aprecia un umbral más cercano a los 10.000 vehículos. En Collserola, el 44 % (n = 16) de los tramos de carretera estudiados tienen IMD por encima de los 5.000 vehículos, con lo cual se puede considerar que representan un peligro importante para la mayoría de las especies que intentan cruzarlos, e incluso es probable que ejerzan un importante efecto barrera ya que, además del riesgo de atropello para los individuos que intentan cruzar, probablemente otros ni siquiera lo intentan cuando se alcanzan IMD por encima de los 10.000 (Müller y Berthoud 1997), tal y como se aprecia en Collserola por el estancamiento de la tasa de atropello (Fig. 4).

La relación entre IMD y tasa de atropello se manifiesta en Collserola a nivel de tramo, siendo lógicamente más frecuentes las incidencias en los tramos más transitados, sobre todo los que se encuentran cerca de la ciudad de Barcelona (Fig. 3). Por otro lado, se observa en Collserola que, gracias a los datos de la autopista (la E-9), el nivel de tráfico es muy constante a lo largo de los meses del año, produciéndose únicamente una reducción notable durante el mes de agosto, cuando muchas de las personas del área metropolitana hacen sus vacaciones y se alejan de la ciudad. A pesar de la regularidad mensual en el tráfico, se observan claras fluctuaciones en la tasa de atropello de las principales especies de mamíferos implicadas –erizo, jabalí, conejo y ardilla-, siendo especialmente estacional en el caso del conejo y la ardilla. Distintos estudios anteriores han subrayado las posibilidades de interpretación o extrapolación de las variaciones temporales en la tasa de atropello a posibles tendencias o fluctuaciones en las poblaciones animales (Fahrig *et al.* 2001, Baker *et al.* 2004, Widenmaier y Fahrig 2005). Siendo constante el tráfico, es probable que las fluctuaciones temporales de atropellos en Collserola respondan a factores propios de la biología de las distintas especies, como serían las variaciones estacionales en cuanto a su abundancia, los patrones de actividad o de movilidad (uso del hábitat, dispersión, etc.), e incluso de la composición de la población (edad, experiencia de los individuos). En el caso de la ardilla y el erizo los atropellos se concentran en primavera y principios de verano, sobre todo en mayo, hecho que, en el caso de la ardilla, coincide con los máximos poblacionales según muestran seguimientos realizados en áreas cercanas al parque (Real *et al.* 1995). En contraste, los meses de invierno apenas registran atropellos coincidiendo con una disminución de su abundancia y también de la actividad de las dos especies, especialmente en el caso del erizo que suele estar hibernando en esta época. Reeve y Huijser (1999) atribuyen el mayor número de atropellos de erizos en verano al aumento de desplazamientos de los machos en esta época cuando buscan hembras para aparearse. En Cataluña aún existen pocos datos sobre el período de apareamiento del erizo, pero algunos autores lo sitúan mayoritariamente entre mayo y junio (Ruiz-Romero 1995), lo cual también coincide con el pico de atropellos observado en Collserola (Fig. 6). Por su parte, el conejo muestra en Collserola un patrón algo menos estacional, con menor frecuencia de atropellos en verano y otoño, que posiblemente se debe a una caída de la población en esta época a causa de bajas por enfermedades, o a causa de la actividad cinegética en otoño.

Estudios anteriores indican una mayor frecuencia de accidentes de tráfico ocasionados por jabalíes durante el período de octubre a enero, con un máximo en el mes de noviembre (DGT 2004, Markina 1999). Esta situación parece relacionarse principalmente con la actividad cinegética, con más accidentes en las temporadas con más batidas y en días posteriores a las cacerías (Markina 1999). El pico otoñal también coincide con la época de celo del jabalí (Fernández-Llario 2005), de manera que ambos factores, caza y celo, implican un aumento considerable de los desplazamientos del jabalí con el consecuente incremento del riesgo de atropello. En Collserola se aprecia también un pico de atropellos de jabalí durante el mes de noviembre (segundo mes con más atropellos), aunque su distribución a lo largo del año es bastante irregular, con grandes diferencias según el mes (Fig. 6). Por ejemplo, el mes de junio es con diferencia el que más incidencias registra, mientras que durante mayo y julio, en cambio, son mucho menos frecuentes. Dada la estabilidad del nivel de tráfico, cabe pensar que estas variaciones respondan también a factores ligados a la biología del jabalí en el parque, sobretodo los relacionados con su movilidad. En este sentido, del presente estudio es interesante remarcar la mayor proporción de individuos de entre seis y 12 meses de edad entre los jabalíes muertos por atropello en comparación con los muertos por otras causas, ya que esta franja de edad corresponde en gran parte con la fase de su dispersión natal (Truvé y Lemel 2003). Por otro lado, se ha observado que existe un aumento de los desplazamientos de jabalíes en Collserola durante el mes de junio, probablemente a consecuencia de cambios en el uso del espacio con la llegada del verano (Cahill 2000), lo cual podría contribuir al aumento de atropellos en este mes. También cabe señalar que, del patrón de actividad nocturna de esta especie en Collserola, se solapan determinadas horas de gran volumen de tráfico en las carreteras del parque con los desplazamientos del jabalí, especialmente entre las ocho y las diez de la tarde (Fig. 8). En un estudio de 2.020 colisiones entre vehículos y jabalíes realizado por la Dirección General de Tráfico (DGT 2004), el 65 % de las incidencias ocurrieron entre las 19:00 h y las 24:00 h. En cambio, la tasa de accidentalidad fue cuatro veces inferior durante las 00:00 h y las 06:00 h (DGT 2004), situación que refleja por supuesto el reducido volumen de tráfico, pero también puede contribuir a ello una menor movilidad de los jabalíes durante estas horas, tal y como se ha observado en Collserola (Cahill *et al.* 2003).

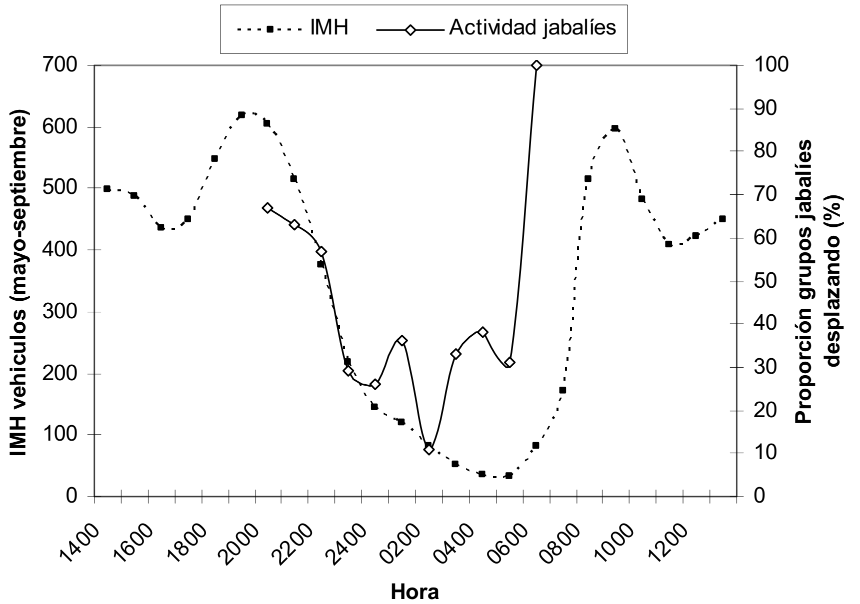

Fig. 8. Intensidad media de vehículos por hora (IMH) en 14 tramos de distintas carreteras del Parque de Collserola en comparación con la actividad nocturna de grupos de jabalíes durante la misma época del año (mayo-septiembre). Fuente datos: IMH – Servicio de Vías Locales de la Diputación de Barcelona; actividad jabalíes – adaptado de Cahill *et al.* 2003.

La caracterización de los hábitats alrededor de los puntos de atropello de las diferentes especies indica la relación de esta problemática con el uso del hábitat. Esto supone también una disgregación geográfica, de manera que el conejo y el erizo se relacionan principalmente con ambientes abiertos -cultivos, prados, matorral bajo, zonas agrícolas- que coinciden con zonas periféricas del parque, como en su vertiente barcelonesa, donde se localizan también algunos de los tramos de carretera con mayores valores de IMD. En este sentido, cabe destacar el descenso de la mortalidad en agosto de conejo y erizo (Fig. 6), que parecen beneficiarse de la reducción importante del tráfico que se da en este mes (Fig. 5). En cambio, la ardilla, especie forestal, se atropella con más frecuencia en ambientes boscosos que, por otro lado, corresponden principalmente al interior de Collserola. En el caso del jabalí, no se aprecian desviaciones con respecto a la esperada en cuanto a la tipología de hábitat en los puntos de atropello, situación que refleja por un lado su gran capacidad de desplazamiento (desvinculación entre punto de atropello y hábitat) y, por otro lado, su capacidad de aprovechar una mayor variedad de ambientes en el parque (Cahill *et al.* 2003).

Es sabido que en algunos casos la mortalidad por atropello puede superar la mortalidad por causas naturales como la depredación y las enfermedades (Forman y Alexander 1998), como ha sucedido en Países Bajos y Gran Bretaña con el tejón *Meles meles*, (Linnaeus, 1758) (Van der Zee *et al.* 1992, Clarke *et al.* 1998). En Collserola, los atropellos se añaden a otros impactos y pueden complicar más la situación de determinadas especies ya vulnerables a causa de otras problemáticas como la pérdida de hábitat, como ocurre en el caso del tejón (Rafart 2005). Lo mismo parece suceder con el erizo y la ardilla, especies que han registrado un descenso de las incidencias en los últimos años en el parque, aunque de momento no es posible saber si éste es debido a los atropellos o simplemente reflejan esta tendencia poblacional. No obstante, los atropellos pueden significar una causa importante de mortalidad en áreas periurbanas en el caso de la ardilla (Shuttleworth 2001), y para el erizo pueden amenazar las poblaciones ya debilitadas por otras causas (Huijser 1999). Actualmente, al igual que parece ocurrir en Collserola, existen indicios de regresión del erizo en lugares fuertemente humanizados, tanto zonas urbanas como agrícolas, tal y como sucede en el Reino Unido (MTUK 2005). En el caso del conejo y el jabalí no se considera que los atropellos tengan efectos significativos sobre sus poblaciones en Collserola. Se estima, por ejemplo, que la proporción media de la población de jabalí muerta por atropello anualmente en el parque no supera el 5 %, en este caso podrían ser más significativas las repercusiones que pueden tener los atropellos en relación a la siniestralidad viaria.

La distribución de los atropellos en las carreteras no se da al azar, sino que sigue un patrón agregado que se debe a numerosos factores en función de las características de la carretera, el hábitat, la especie, etc. (Clevenger *et al.* 2003). En Collserola, se han detectado una serie de tramos con una tasa de atropellos por kilómetro superior a la media, los denominados ‘tramos negros’. En el parque se ha observado que los atropellos son más frecuentes en tramos de carretera que cruzan zonas conocidas de paso natural de fauna, como las rieras y los torrentes, pero también en las curvas con reducida visibilidad (Fig. 9), o donde la presencia de taludes impide que los animales salgan a tiempo de la calzada (véase también Malo *et al.* 2004). La localización de estos tramos negros en las carreteras permite desarrollar propuestas de medidas correctoras en el parque. En este sentido, ya se han realizado actuaciones como la colocación de carteles informativos específicos en los diferentes accesos al parque que llaman la atención de los conductores sobre la presencia de la fauna y a la problemática de los atropellos. Por otro lado, se ha establecido un límite de velocidad de 50 km/h en las carreteras del parque (excluyendo la autopista), e incluso algunos tramos con un límite de 30 km/h. Además, a raíz del presente estudio se han propuesto medidas para conseguir una limitación efectiva de la velocidad, seleccionando tramos problemáticos donde implantar pasos de cebra elevados o semáforos activados por el exceso de velocidad. Por otro lado, la identificación de tramos negros, junto con información territorial obtenida mediante métodos de radioseguimiento a partir de otros estudios desarrollados por el parque (véase Llimona *et al.* 2005), ha permitido también plantear la ubicación estratégica de pasos específicos para intentar reducir el impacto del tráfico sobre la fauna en Collserola.

Fig. 9. Tramo negro de atropello de mamíferos en la carretera de la Rabassada, Parque de Collserola. Las líneas blancas discontinuas indican la presencia de torrentes.

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ASSESSING DIFFERENCES IN THE MESO-MAMMAL COMMUNITY COMPOSITION BETWEEN NEIGHBOURING NATURAL AREAS BY MEANS OF TRANSECT SURVEYS: AN INFORMATION THEORY APPROACH

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Capítol 5

CAPÍTOL 5

Transect survey to assess meso-mammal species composition between neighbouring metropolitan natural areas

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KILOMETRIC ABUNDANCE INDEX, MEDITERRANEAN HABITATS, MESO-MAMMAL, SHANNON-WEAVER DIVERSITY INDEX, SIGN SURVEY, SPECIES COMPOSITION.

ABSTRACT. – The increasingly common fragmented ecosystems may force meso-mammals to live in metapopulations. Additionally, the complex mosaic of patches which compose the landscape matrix offer different resistance to animal movement. As a consequence, not only the Euclidean distance, but other factors would affect the connectivity between patches. The aims of the present study was to assess the similarity in the occurrence of six meso-mammal species between Collserola and three neighbouring natural reserves and to compare their relative species abundances. For these purposes we surveyed nine different habitat fragments of landscape by means of linear transects looking for animal scats and trails. For data analyses an approach of the information theory was used on the basis of the Shannon-Weaver diversity index. Kilometric abundance index was also calculated to compare between areas. The stone marten was the species of which most scats were recorded, followed by the red fox, the European badger and the weasel. Otherwise, the rabbit was only absent in one of the areas, while the wild boar was present in 60 % of them. According to the meso-mammal species composition and abundance, the W-axis is the best candidate to set a connectivity corridor for meso-mammals from the Park of Collserola outwards, while the NE-axis is the worst option.

INTRODUCTION

In the densely populated Europe, large mammals are confronted with a very fragmented landscape, and most of the areas they inhabit are island-like reserves threatened with total isolation from other reserves. The study of fragmented ecosystems is based on island biogeography (MacArthur & Wilson 1963) and metapopulation dynamics models. Both theories assume a binary landscape performance based on the habitat and the matrix. It is assumed that the matrix is uniform (inhospitable, homogeneous and ecologically irrelevant) and isolates the habitat. This is the reason why both models are exclusively based on the Euclidean distance between patches as the main parameter for predictions (Prevedello & Vieira 2010). However, terrestrial habitat patches are commonly surrounded by a complex mosaic of matrix patches which differ in their resistance to animal movement between habitat patches. Hence, habitat patches would be more or less isolated than indicated by the distance alone, depending on the resistance of the matrix involved (Laurance 2008, Ricketts 2001). The degree to which the landscape facilitates or impedes movement among patches defines landscape connectivity (Taylor *et al.* 1993). The effects of the matrix on landscape connectivity will depend on the species composition and landscape configuration of the matrix patches. Matrices that differs dramatically in structure and microclimate from the primary habitat tend to be most hostile to native species (Laurance 2008) and therefore less permeable for the fauna. Matrix quality generally increases with increasing structural similarity with habitats patches (Prevedello & Vieira 2010). One method to assess the modified lands (matrix) which surround suitable habitat fragments (patches) of landscape is to rate the composition and abundance of animal species, so that the more similar the composition between the suitable habitat and the matrix, the less altered would be the landscape if all other aspects of the patch remain constant (size, shape and distance between patches). Then, a higher connectivity between patches would appear.

Prevedello & Vieira (2010) showed that matrix type effects were strongly species-specific, with different species responding differently to matrix type in 96 % of the studies comparing species or group of species. Since our goal was to describe the possible landscape connectivity in relation to meso-mammals, we used their presence and abundance as elements which will characterize the habitat structure involved in patches and matrices.

Wild ungulate species are considered key species for ecosystem functioning because of their widespread distribution, key role in ecosystem functioning, and home-range size (Bruinderik *et al.* 2003). Otherwise, rabbits also play an important role in Mediterranean ecosystems. They conspicuously alter plant species composition and vegetation structure through grazing and seed dispersal. Moreover, rabbit burrows provide nest sites and shelter for vertebrates. In addition, rabbits serve as prey for a number of predators (Delibes-Mateos *et al.* 2008). In another way, large and medium-sized carnivore species are even more sensible to connectivity lose, not only due to their space needs, but because they use to live at low population densities, they are specially threatened by human activities and because they play an important role in ecosystems functioning as predators (Virgós *et al.* 2002, Mangas *et al.* 2008, Mortelliti & Boitani 2008). Consequently, these species can be very useful for comparing the quality of neighbouring natural areas. The presence and abundance of these species would depend on structural and microclimatic aspects which should be preserved for the species conservation.

The increase in human population around the green areas is a widespread phenomenon in Mediterranean large cities (e.g. Roma Natura, Parco Agricola Sud Milano), and evidently isolation risk would jeopardize fauna populations. The understanding of the effects that this process has on the natural biotas has become a crucial cue for their conservation (Saunders *et al.* 1991). During the last four decades the metropolitan area of Barcelona has been dramatically increasing (from 3.6 million people in 1972 to 4.2 in 1997), with the corresponding fragmentation of habitats and connectivity loss (Paül & Tonts 2005). The Park of Collserola is located in the centre of the metropolitan area of Barcelona city, which occupies an extension of 636 km^2 and which has a population density of 5,060 inhabitants/km^2. Consequently, the Park is nowadays almost completely isolated from other neighbouring natural areas (Molina-Vacas *et al.* 2009). As a result, the probability of a successful dispersion of a wild meso-mammal from one habitat of the Park to another outside is very low. Since isolated protected areas fail to function as viable ecosystems (Paül & Tonts 2005), the conservation managers need appropriate tools which help them to evaluate which of the possible connectors provide more connectivity. Three possible corridors were proposed to connect the suitable habitat of the Park of Collserola (hereafter, origin patch) with three other suitable neighbouring natural areas (hereafter, target patches). The habitats found inside the matrix surrounding suitable habitat fragments (origin and target patches) and located in these connectivity axes characterize corridors of fauna (hereafter corridor matrix). As stated above, it seems plausible to think that the higher the species similarity between contiguous areas (patches and matrices), the greater the degree of landscape connectivity can be achieved. Our main goal was to find a criterion that, by means of species composition and abundance, allow the comparison between patches and matrices, in a way that conservation managers could decide which of the three possible axes would furnish the better connectivity. For this survey, we sampled three areas (thereafter “sampled areas”) in each of the three proposed connectivity axes: one area lied at the internal periphery of the Park (origin patch), another one lied in the target patch (Natural Parks of Montserrat, St.Llorenç and Serra Marina) and the third one lied in the matrix between the origin and the target patches.

Transect survey sampling for mammal scats or other trails is becoming a largely used method in recent studies (Kasper *et al.* 2007, Lyra-Jorge *et al.* 2008), with a high success for wild carnivores in Mediterranean habitats (Rogers *et al.* 1997, Crooks 2002, Mortelliti & Boitani 2008, Matos *et al.* 2009). The occurrence of six medium-sized mammals in the sampled areas was studied by means of this technique. Large differences in meso-mammal species occurrence and/or abundance between such close and historically connected areas would mean that the transformations suffered by the matrix have reduced significantly the connectivity between them. On the contrary, small or no differences would mean that the isolation is uncompleted or too recent for detection.

The concept of entropy, taken from the information theory (Shannon & Weaver 1949), has been largely used in the study of biological problems, with special regard to those related to ecological processes (Margalef 1957, MacArthur & Wilson 1963, de Pablo *et al.* 1982). Human activity produces an alteration of the habitat which can be assimilated to an ecological process, and the changes in the species occurrence and/or abundance that such alteration produces can be measured through the entropy values.

The specific objectives of the present study were 1) to compare the relative abundances (Kilometrical Abundance Index, KAI) of the studied carnivore species with those obtained in other related studies, and 2) to evaluate the similarity in the occurrence and abundance of 6 mammal species in the three sampled areas (origin, corridor and target patches) inside each of the proposed connectivity axes by means of an information theory approach. To our knowledge, this is the first time this technique is used in relation to landscape connectivity.

MATERIALS AND METHODS

Study Areas

The Park of Collserola (41º27'N, 2º6'E, Fig. 1a) is an 85 km^2 natural space belonging to the Catalan Coastal Cordillera. This space is naturally separated from the rest of the cordillera by the rivers Besòs to the NE and Llobregat to the SW. Its South-Eastern limit is formed by the city of Barcelona and the rest of its perimeter is almost closed by a belt of cities and highways. Altitude ranges from 50 to 512 m above sea level. Even though some areas of Collserola can be classified as sub-urban habitats, most of it retains the features of a wild natural space. According to neighbouring natural areas distribution surrounding the Park of Collserola and regarding the physical limitations that landform and human settlements impose, three theoretical connectivity axes where proposed to re-connect the Park of Collserola (origin patches, Fig. 1b), with three other natural areas (target patches, Fig. 1b). a) Western axis (hereafter, *W-axis*), 16 km long, connects Collserola with the Mountain of Montserrat (41º36'N, 1º48'E), which is a 35 km^2 Natural Park with altitudes ranging from 250 m to 1224 m. Despite being a very touristic place, Montserrat bears with a considerably lower human pressure than Collserola do, and it contains a larger area of crops than the other three parks. b) North-western axis (*NW-axis*), 18 kilometres long, connects the Park with St.Llorenç Natural Park (37º42'N, 3º5'E). This park has a surface of 94 km^2 and maximum altitude reached at 1057 m. c) North-Eastern axis (*NE-axis*) only four kilometres long, which connects Collserola from another metropolitan park with high human pressure, the Serra Marina Natural Park (37º36'N, 3º18'E). This park, with a surface of 44 km^2 and a maximum altitude of 535 m, had suffered human-hand fires during the last two decades which caused a great damage to habitat quality and vegetation coverage. Montserrat and St.Llorenç parks bear lower levels of human pressure than Collserola or Serra Marina, which *a priori* would be considered an important factor for deciding which of the proposed connectivity axes would be the preferable. In addition, there we also prospected the naturalized areas found between each pair of origin and target patches (the *corridor* matrix areas), which were called W-corridor, NW-corridor and NE-corridor respectively. Except for altitudinal differences, vegetation structure, composition and weather conditions were similar between all sampling areas (n = 9) placed in the study areas. Climate was typically Mediterranean, with a mean annual temperature and rainfall of about 14ºC and 700 mm respectively, with wide seasonal variations in both factors. Summer is usually the hottest and driest season, whereas spring and autumn are the wettest ones and winters are mild. The prevalent vegetation, present in the matrix, is woodland, largely dominated by the Aleppo pine (*Pinus halepensis*) and the holm oak (*Quercus ilex*), with very dense undergrowth. Then, disposed as a mosaic, there are patches of Mediterranean scrubs, herbaceous vegetation, riparian habitats,

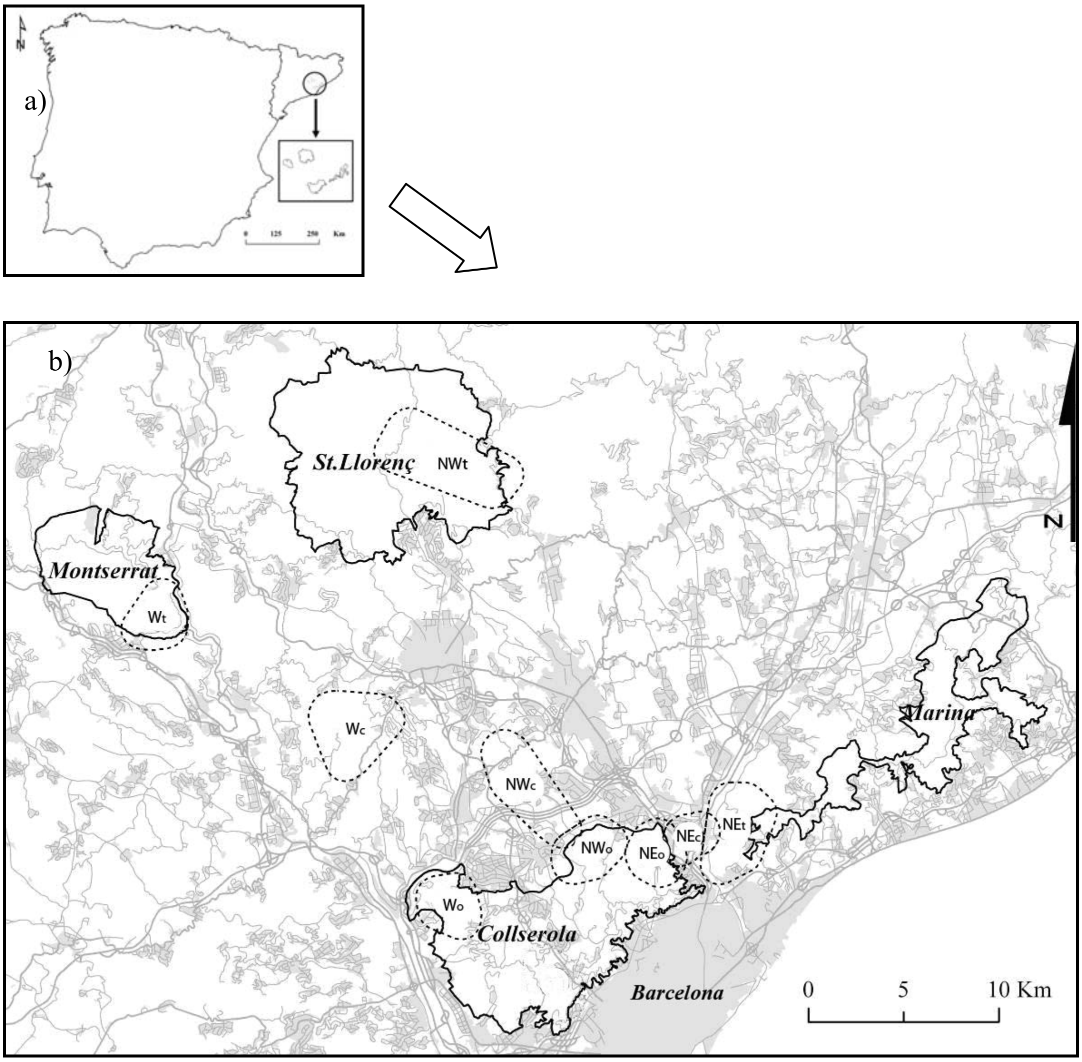

Fig. 1. a) The four parks included in the study located in the frames of the Iberian Peninsula and Catalonia. b) Map containing the shapes of the four Parks (solid line) and the nine study areas (dotted lines) with the corresponding codes. Soft grey colour represents urbanized areas, dark grey thick line represents primary roads, while dark fine line represents secondary roads. The *W-axis* is composed by sampled areas W$_o$ (origin), W$_c$ (corridor matrix) and W$_t$ (target patch); the *NW-axis* by NW$_o$, NW$_c$ and W$_t$; and the *NE-axis* by NE$_o$, NE$_c$ and NE$_t$ respectively.

agricultural lands and urbanized areas (for a detailed description of Collserola vegetation see Raspall *et al.* 2004). Sampling areas were placed in those patches more similar to the natural habitats of the protected areas.

Data acquisition

Survey was conducted during the winter of 2005, fitting with the mating season in most of the species and coinciding with the maximum activity peaks of badger latrines in Collserola: between January-February and between April-May (Bonet-Arbolí 2003). In addition, during winter people living close or inside the Park show less recreational activities, and climatic conditions are suitable to detect animal tracks (the weather is not extremely rainy or dry). It consisted in a total of nine sampling areas, where transects were placed. Three of them were located inside Collserola Park (W, NW and NE origin patches), three more were placed inside each target park (W, NW and NE target patches) and, three more transects were settled in well-preserved patches in the corridor matrix corresponding three potential axes (W, NW and NE axis, Fig. 1b). In Mediterranean environments carnivore scats appear at low frequencies and, with some exceptions commented below, are known to be more frequently placed near paths. Accordingly, instead of placing transects randomly inside each zone, they were conducted on foot following foot paths chosen *ad hoc* (Cavallini 1994, Barja *et al.* 2001, Mangas *et al.* 2008, White *et al.* 1993) with a width not allowing vehicle passage (< 2 m). This method reduces the possibility of classifying as absent a present species. Transects consisted in a group of 2 m-width tracks with a minimum length of 200 m each one, which in total summed approximately 5000 m per sampling area. All transects were surveyed once by the same researcher with proved experience in mammal scat finding and identification. Faeces and latrines were assigned to the species only when a perfect match with existing descriptions occurred (underestimate) to prevent mistaking the scats of domestic cats and dogs as those of wild carnivores. Faeces identification was made on the basis of the aspect, length, diameter, shape, odour and placement (Cavallini 1994). Linear transects were conducted with the aid of a GPS covering. Presence/absence and the number of scats (scats, droppings or latrines) per kilometre were recorded for each wild carnivore species considered in the study: the red fox (*Vulpes vulpes*), the European badger (*Meles meles*), the stone marten (*Martes foina*) and the weasel (*Mustela nivalis*). Despite being presumably present in most of the areas surveyed (Palomo & Gisbert 2002), the Genet (*Genetta genetta*) was not considered in the present study because genets use to place their latrines in tree branches or other features not necessarily following linear structures (Mangas *et al.* 2008, Galantinho & Mira 2009). According to the relative abundance along each transect of different trails (droppings, dens, tracks, or digging and rooting activity) the presence/absence and relative abundances of wild boar (*Sus scrofa*) and rabbit (*Oryctolagus cuniculus*) were also recorded (0 absent, no trails; 1 rare, from 1 to 3 trails for the wild boar and from 1 to 5 for the rabbit; 2 common, from 4 to 6 for the wild boar and from 6 to 8 for the rabbit; and 3 abundant, more than 6 for the wild boar and more than 8 for the rabbit).

Data analysis

Based on the data obtained with transect surveys, we have characterized the structure of each connectivity axis (*NE-axis, NW-axis* and *W-axis*) as an abundance matrix, with the species arranged in rows and the sampled habitats (origin patch, corridor matrix and target patch) in columns (see Appendix). The entropy obtained from the information theory was used as a measure of the structural changes in the different sampled habitats within each connection axis (Pineda *et al.* 1988). The total entropy theorem formula is the following (see Appendix, Shannon & Weaver 1949):

$$H(E.P) = H(P|E) + H(E) = H(E|P) + H(P)$$

Where $H(E.P)$ represents the total entropy of the matrix, i.e. of a connectivity axis. $H(E)$ represents the biodiversity of meso-mammal community in the connectivity axis and $H(P)$ represents the biodiversity of the sampled areas in each connectivity axis. Losey (1978) was followed to test the null hypotheses H_0: $H(E) = H(E)_{max}$ and H_0: $H(P) = H(P)_{max}$ (Table II and Appendix). $H(E|P)$ indicates the manner in which different habitats are occupied by the different species, which is independent of their respective distributions throughout the different sampled areas. If each sampled area represents a different environmental scenario, a higher specificity in location for each species would be reflected by entropy values increasingly smaller. $H(P|/E)$ indicates the manner in which each species is distributed in the different habitats and it is independent of the distribution of each species in the different sampled areas. It attains a minimum value when a species occupies only one sampled area, independently of the distribution of the remaining species. Therefore $H(P|E)$ shows the uncertainty which remains associated to the sampled areas once their biodiversity is known (Fig. 2 shows a graphic relation between all this parameters). If these two last parameters are weighted to the biodiversity of meso-mammal community in the connectivity axis, and to the biodiversity of occupied sampled areas, respectively, two indexes of connectivity can be obtained between the sampled areas which compose the connectivity axis, with values ranging between zero and one. Hence, these indexes are comparable between different axes:

$$C(E) = H(E|P)/ H(E)$$

$$C(P) = H(P|E)/ H(P)$$

Therefore, it is possible to study the degree of connectivity of the different axes by using the nomenclature of matrices and considering the parameters of the information theory.

Additionally, using only data of carnivore faeces, Kilometrical Abundance Index was calculated for each species and sector and used as a general estimator of species relative abundance (KAI, Sobrino *et al.* 2009; García-Peiró *et al.* 2009).

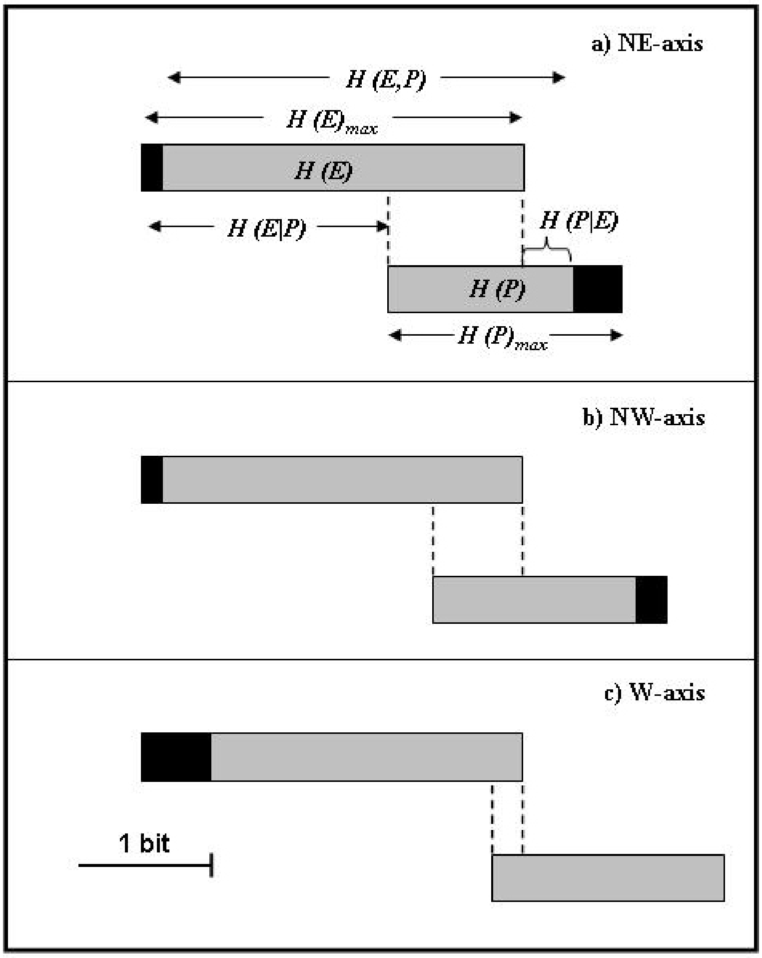

Fig. 2. Representation of the parameters calculated by means of the information theory: a NE-axis; b NW-axis; and c W-axis. The sizes oh the rectangles reflect calculated values in table II. Discontinuous lines show the degree of correspondence between the species and the sampled areas. Figures are made to scale, so they are comparable between axes.

RESULTS AND DISCUSSION

Species abundance in the different sampled areas

A total of nine linear transects were sampled, totalling about 5,000 m in each one, covering a total distance of 45,475 m. Overall, 34 carnivore faeces were found. None of the species was detected at the nine sampled areas (Table I). The least recorded species was the weasel (three sampled areas), followed by the badger and the fox (four sampled areas), the stone marten and the wild boar (five sampled areas). Finally, the rabbit was only undetected in one target patch (St.Llorenç NP). The stone marten was the species of which most scats were recorded, followed by the red fox and the badger, while weasel was the species with fewest faeces found (Table I). All connectivity axes showed the presence of all studied species.

a)

Axis	**Sampled area**	***V.vulpes***		***M.meles***		***M.foina***		***M.nivalis***		**Total**
		n	*KAI*	*n*	*KAI*	*n*	*KAI*	*n*	*KAI*	*N*
W-axis	**W$_o$**	0	0	1	0.2	3	0.6	0	0	5
	W$_c$	2	0.4	0	0	2	0.4	0	0	5
	W$_t$	1	0.2	0	0	3	0.6	0	0	5
NW-axis	**NW$_o$**	0	0	0	0	0	0	0	0	0
	NW$_c$	3	0.6	2	0.4	1	0.2	0	0	7
	NW$_t$	0	0	2	0.4	0	0	2	0.4	4
NE-axis	**NE$_o$**	0	0	1	0.2	0	0	0	0	1
	NE$_c$	0	0	0	0	0	0	1	0.2	0
	NE$_t$	3	0.6	0	0	3	0.6	1	0.2	7
	Total	9	0.2	6	0.13	12	0.27	4	0.09	34

b)

Axis	**Sampled area**	***S. scrofa***	***O. cunniculus***
W axis	**W$_o$**	1	1
	W$_c$	0	1
	W$_t$	0	1
NW axis	**NW$_o$**	2	1
	NW$_c$	2	3
	NW$_t$	1	0
NE axis	**NE$_o$**	3	1
	NE$_c$	0	1
	NE$_t$	0	1

Table I. a) Obtained number of recorded faeces (*n*) and Kilometric Abundance Index related to 100 km (KAI) for each carnivore species and sampled area. b) Relative abundances of wild boar and rabbit

Obtained results showed that the stone marten and the red fox were the most detected species, while the weasel was the less detected, agreeing with previous studies in Mediterranean habitats (Sobrino *et al.* 2009, García-Peiró *et al.* 2009). In general terms, obtained KAI were much higher than those obtained for the same species in Mediterranean habitats using direct methods, e.g. spotlight monitoring or casual encountering (Ballesteros *et al.* 1998, Sobrino *et al.* 2009, García-Peiró *et al.*

2009). This highlights the usefulness of this method because of to the high results/costs ratio due to the high detectability of carnivore faeces following linear structures such as paths. Otherwise, in spite of its utility, this method failed in the detection of some species of previous known presence at some of the sampling areas (e.g. the European badger). So, we recommend to periodically repeat the surveys in the same sampling areas in order to complete gaps in species occurrence and to achieve data to assess the evolution of the populations

Connectivity axes and degree of permeability from the Park of Collserola

The species abundance in different sampled areas may reflect the structure of meso-mammal community in the three studied axes. Thus, the disposition of numerical elements in the matrix may reflect the correspondence between the species and the sampled areas. So, a high correspondence would mean that the connectivity is minimal (Fig. 2). This is reflected in the low uncertainty of species sampled area location and, simultaneously, in the low uncertainty over the community of meso-mammals in a given sampled area. This is reflected in the highest values of the *C(P)* and *C(E)*.

The NE and the NW connectivity axes, show an *H(E)* value near-maximal (Table II), which indicate that the species are equally represented for each set of sampled areas in each axis. However, the W-axis show an *H(E)* value which is significantly lower than the maximum possible (Table II), and

	NE-axis	NW-axis	W-axis
$H(E)$	2.45	2.44	**<u>2.12</u>**
$H(E)_{max}$	2.58	2.58	2.58
X^2	2.64	3.83	11.04
Df	5	5	5
P	0.76	0.57	0.05
$H(P)$	**<u>1.26</u>**	1.38	1.58
$H(P)_{max}$	1.58	1.58	1.58
X^2	6.23	5.30	0.12
Df	2	2	2
P	0.04	0.07	0.94
$H(E.P)$	2.79	3.22	3.29
$H(E/P)$	1.52	1.84	1.71
$H(P/E)$	0.34	0.78	1.18
$C(E)$	0.62	0.75	0.81
$C(P)$	0.27	0.57	0.75

Table II. Values of entropy parameters calculated from species composition to three connectivity axis. *E* means species composition and *P* means sampled area. The meaning of variables in order: entropy of variable species $H(E)$, maximum entropy of variable species ($H(E)_{max}$); entropy of variable sampled area $H(P)$; maximum entropy of variable sampled area ($H(P)_{max}$); total matrix entropy $H(E.P)$; connectivity index ($C(P)$). The first chi-square tests the null hypothesis H_0: $H(E) = H(E)_{max}$ opposite to the alternative hypothesis H_A: $H(E) \neq H(E)_{max}$. The second Chi-square test the null hypothesis H_0: $H(P) = H(P)_{max}$ opposite to the alternative hypothesis H_B: $H(P) \neq H(P)_{max}$. (Losey 1978). Significant values are shown in underlined bold letter.

consequently the species are not equi-represented in the set of sampled areas. There are three species which subtract entropy: the badger and the wild boar, which only appear in the origin patch, and the weasel, which was only detected in the target patch. This is the only axis where the stone marten was present, with a relative high abundance, in the three sampled areas (Table I). Regarding biodiversity, all axes presented all studied species considering the three sampled areas ($H(E)_{max}$). Nevertheless, while these species are equally represented in the NW and NE axes, this is not the case of W-axis, mainly due to an overrepresentation of the stone marten.

With respect to the sampled areas in each axis ($H(P)$), the minimum value was found in the NE-axis (Table II) because in its corridor only one species was detected, the rabbit, and with a low abundance index. Nonetheless, the low value reached in NW-axis, was caused by the opposite situation (Table II). In this case the corridor patch showed the presence of all species (but the weasel) and had an abundance index higher to those obtained in the two other sampled areas (origin and target patches, Table I). The W-axis showed the maximum uncertainty value, i.e. the meso-mammal community is homogeneously distributed in the three sampled areas.

Considering the connectivity index, the W-axis has the higher value, followed by the NW-axis. Finally, the NE-axis reaches only the 27% of its maximal potential value (Table II). Consequently, the W-axis is the best candidate to set a connectivity corridor for meso-mammals from the Park of Collserola outwards. In terms of the information theory, this high connection probability is a consequence of the fact that the presence of a given species in this axis provides little information about the area where it could be found ($H(P|E)$). The species that contribute the most to this uncertainty are the stone marten, the rabbit and the fox, in this order. The opposite scenario happens in the NE-axis. In this case, the fox, the stone marten and the weasel are indicative species of the target patch, whereas the badger and the wild boar are indicative of the origin patch. Only the rabbit was present in the three sampled areas of this axis (Table I). From the perspective of the distribution of meso-mammals species in the sampled areas of each axis ($H(E|P)$), the lowest uncertainty is found along the NE-axis, followed by the W-axis, and finally by the NW-axis (Table II). Therefore, the community of meso-mammals found in each one the sampled areas of the later axis is the most homogeneous. Nevertheless, when this figure is weighted to the biodiversity of the respective axis, the highest connectivity is found again in the W-axis.

In addition, the matrix of the W-axis holds smaller and more scattered human settlements as well as a lower density of transversal infrastructures than the NW-axis (Fig. 1b). On the other hand, in spite of the fact that the NE-axis is by far the shortest one, it presents two great obstacles concerning the connection with Collserola. First, its corridor patch is isolated from both the origin and the target patches. And second, the target patch suffered several forest fires few years ago and the vegetation is still not recovered. In addition, the W-axis runs parallel to the river Llobregat, which may have been used for the mammals for their movements, resulting in a greater homogeneity. The NW-axis presents a higher human population density than the other two, but an intermediate degree of isolation, and this is reflected in the obtained results for the connectivity parameters.

The W-axis is the best candidate to set a connectivity corridor from the perspective of biodiversity (both in the meso-mammal community and in the sampled areas in the axis) as well as from the perspective of the landscape of the surrounding matrix.

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APPENDIX

From a matrix with *c* observations (columns) and *r* variables (rows):

$$\begin{array}{ccccc|c}
u_{11} & u_{12} & u_{13} & \dots & u_{1c} & u_{1.} \\
u_{21} & u_{22} & u_{23} & \dots & u_{2c} & u_{2.} \\
u_{31} & u_{32} & u_{33} & \dots & u_{3c} & u_{3.} \\
\cdot & \cdot & \cdot & \dots & \cdot & \cdot \\
\cdot & \cdot & \cdot & \dots & \cdot & \cdot \\
\cdot & \cdot & \cdot & \dots & \cdot & \cdot \\
u_{r1} & u_{r2} & u_{r3} & \dots & u_{rc} & u_{r.} \\
\hline
u_{.1} & u_{.2} & u_{.3} & \dots & u_{.c} &
\end{array}$$

the following expressions are used with the Sahnnon-Weaver formula for the u_{ij} values ($i = 1, 2, 3, \dots c$):

$$H(E) = -\sum_{i=1} p_{i.} \log_2 p_{i.} = -\sum_{i=1} \frac{u_{i.}}{\sum_i \sum_j u_{ij}} \log_2 \frac{u_{i.}}{\sum_i \sum_j u_{ij}}$$

which may be expressed as follows for computer calculation:

$$H(E) = -\sum_{i=1} \left(\sum_{j=1} p_{ij} \right) \log_2 \left(\sum_{j=1} p_{ij} \right)$$

$$H(E)_{\max} = -\log_2 r$$

and equally,

$$H(P \mid E) = \sum_{i=1} \left[-\sum_{j=1} p_{ij} \log_2 (p_{ij} \mid p_{i.}) \right]$$

$$H(P) = -\sum_{j=1} \left(\sum_{i=1} p_{ij} \right) \log_2 \left(\sum_{i=1} p_{ij} \right)$$

$$H(P)_{\max} = -\log_2 c$$

$$H(E \mid P) = \sum_{j=1} \left[-\sum_{i=1} p_{ij} \log_2 \left(p_{ij} \mid p_{.j} \right) \right]$$

$$H(E.P) = -\sum_{i=1} \sum_{j=1} p_{ij} \log_2 p_{ij.}$$

Discussió general

Ecologia espacial del teixó als parcs de Collserola i Montserrat

Als parcs de Collserola i Montserrat s'han trobat densitats poblacionals properes a les obtingudes al sud i oest de la Península Ibèrica i que es corresponen amb les poblacions europees de baixa densitat (Revilla Palomares 2002, Rosalino *et al.* 2004, Kowalczyk *et al.* 2000, Virgós i Casanovas 1999). Comparant els resultats obtinguts en aquests dos parcs, també s'ha observat com poblacions de teixó molt properes i que viuen en ambients molt semblants en quant a vegetació, clima, sòl, etc., poden diferir en la densitat poblacional i també en el patró d'organització social. Aquestes diferències molt probablement estiguen ocasionades per la major proporció de conreus de fruiters a Montserrat, el que deixaria una major quantitat d'aliment accessible. A més, la població de Collserola es troba físicament pràcticament aïllada de la resta d'àrees naturals veïnes; així mateix, també pateix una major influència antròpica, el que es tradueix en més molèsties a les teixoneres i major risc d'atropellament i furtivisme.

La diferència entre la mida dels dominis vitals (*home range*) de mascles i femelles és major a Collserola que a Montserrat: els dels mascles de Collserola són entre quatres i cinc vegades més extensos que les de les femelles, mentre que a Montserrat són menys dels doble. Aquestes diferències entre les dues àrees estudiades en quant a la proporció de la mida dels dominis vitals entre sexes es deu a que els mascles exploten diferents àrees del seu domini vital en diferents èpoques de l'any, probablement per tenir accés a varis territoris de femelles. Per tant totes les evidències indiquen que els mascles són més mòbils que les femelles; i que aquestes són un factor clau en l'organització espacial dels mascles

En efecte, els resultats obtinguts en aquest capítol suggereixen que en baixes densitats poblacionals, on les femelles campen solitàries o en petits grups, els mascles necessiten abastar les àrees de màxima activitat de vàries femelles per tal d'incrementar les seues oportunitats d'aparellament; el que només pot ser assolit amb baixes densitats, ja que la probabilitat de trobar un altre mascle agressiu és menor. Aquesta estratègia espacial dels mascles només resulta rendible si els territoris de les femelles no són massa grans, com és el cas d'ambdues àrees d'estudi probablement degut a l'existència de recursos tròfics suficients. Mentre que quan aquests són insuficients, com és el cas al nord d'Europa i al sud de la Península Ibèrica, les femelles necessiten àrees majors per satisfer els seus requeriments nutricionals (Rodriguez *et al.* 1996, Broseth *et al.* 1997, Revilla i Palomares 2002) i els mascles són incapaços d'abastar més d'un domini vital d'una femella; donant lloc a parelles com a unitat bàsica de l'organització social. Pel contrari, en poblacions d'elevades densitats, com és el cas de Gran Bretanya i Irlanda, on cohabiten diverses femelles juntes compartint territori, un sol domini vital resulta suficient per assegurar un major nombre d'oportunitats d'aparellament. En aquests casos, la probabilitat de trobar-se amb un mascle veí agressiu és més elevada. Per aquest motiu a un mascle li resulta més avantatjós formar part d'un grup de vàries femelles.

Selecció de l'hàbitat dels meso-mamífers en ambients mediterranis del NE de la Península Ibèrica

A les nostres àrees d'estudi, degut un procés de degradació progressiva de la vegetació de ribera madura, aquesta ha substituïda per vegetació de ribera degradada, composada principalment per bardisses i canyissars (*Rubus ulmifolius, Smilax aspera, Rubia peregrina, Arundo donax, Phragmites australis*, etc.). En el cas dels teixons, aquest hàbitat ha esta seleccionat tant per a construir les teixoneres com per als dominis vitals, però no per als nuclis d'alimentació (*core areas*); açò implica que els teixons tenen en compte les mateixes característiques del paisatge per establir el domini vital que per construir un cau, però seleccionen un tipus diferent de clapa (agrícola) per als nuclis d'alimentació. Aquet fet suggereix que la selecció dels ambients de ribera no esta relacionada amb estratègies tròfiques. Per tant els recursos tròfics no serien l'únic factor que determina la configuració del domini vital i suggereix que la disponibilitat de llocs adients per construir caus podria ser un factor limitant (Rosalino 2005) com prediu la hipòtesi de dispersió dels caus (*SDH, Sett Dispersion Hypothesis*, Doncaster i Woodroffe 1993), especialment en aquells ambients amb elevat risc de predació o persecució per l'home.

En termes generals, considerant totes les espècies de meso-mamífers estudiades, quan la selecció de l'hàbitat és diferent de l'esperada a l'atzar, en tots els casos s'ha trobat una selecció vers els ambients de ribera o forestals. Pel contrari, les àrees residencials i les de vegetació herbàcia i arbustiva han estat seleccionades negativament. Aquests resultats remarquen la idea que les zones forestals en alguns casos, i sobretot la vegetació de ribera, confereixen una major protecció i inaccessibilitat front als humans, i per aquest motiu són seleccionades als ambients antropitzats, com és el cas de Collserola. Per tant, degut a la forta pressió antròpica directa (cacera, furtivisme, atropellaments, gossos solts) i indirecta (pèrdua de territori i de connectivitat, fragmentació de l'hàbitat) que suporta el parc de Collserola, la existència d'ambients de difícil accés per a l'home podrien ser un factor limitant per la supervivència de poblacions de meso-mamífers. Aquest fet, entre d'altres factors, constreny el ventall de possibilitats de selecció d'hàbitat d'aquestes espècies. D'altra banda, la vegetació de ribera es distribueix en clapes lineals ramificades que travessen la resta d'hàbitats, la qual cosa permet als animals moure's entre clapes d'hàbitats sense ser detectats (Virgós 2001), el que podria explicar parcialment la selecció d'aquests hàbitats a nivell dels dominis vitals.

La protecció, promoció i manteniment dels ambients de ribera i de les clapes agrícoles han de ser una prioritat en el disseny dels plans de protecció que tinguen en consideració les espècies de meso-mamífers.

Atropellaments de mamífers en un ambient metropolità

Les morts per atropellament també són un factor important en el deteriorament de les poblacions de meso-mamífers, especialment per a aquelles espècies menys abundants. En alguns casos les morts per atropellament poden superar a les morts naturals com la predació i les malalties (Van der Zee *et al.* 1992, Clarke *et al.* 1998, Forman i Alexander 1998). A Collserola els meso-mamífers han esdevingut un grup faunístic molt adient per caracteritzar el fenomen dels atropellaments. La disponibilitat d'informació detallada sobre els nivells de trànsit ens ha permès establir algunes relacions entre els atropellaments i la xarxa viaria del parc.

La relació observada entre la taxa d'atropellament de mamífer i els nivells de trànsit (Intensitat Media Diària, IMD) de Collserola segueix un increment progressiu d'acord amb la descripció teòrica de Müller i Berthoud (1997), fins arribar al llindar dels 10.000 vehicles diaris, que dissuadeix els animals de creuar la carretera i crea aleshores un efecte barrera. Malgrat això, quasi la meitat dels trams de carretera estudiats tenen valors per sobre dels 5.000 vehicles, el que representa un perill important per a la majoria d'espècies que tracten de creuar (Müller i Berthoud 1997). A Collserola, la relació entre els IMD i les taxes d'atropellament es manifesta a nivell de tram, sent més freqüents en els més transitats, especialment els que es troben properes a la ciutat de Barcelona. Sent el tràfic constant, és probable que les fluctuacions temporals dels atropellaments a Collserola responguen a factors propis de la biologia de les distintes espècies, com són les variacions estacionals en quant a abundància, els patrons d'activitat o mobilitat (ús de l'hàbitat, moviments dispersius, etc.), o de composició de la població (edat, experiència dels individus, etc.).

La distribució dels atropellaments a Collserola no ha estat a l'atzar, sinó que segueix un patró agregat, que es deu a diversos factors en funció de les característiques de la via de transport, l'hàbitat, l'espècie, etc. (Clevenger et al. 2003). Han estat detectats una sèrie de trams negres amb taxes d'atropellament per quilòmetre superiors a la mitja; aquests llocs es troben amb major probabilitat als trams que travessen zones de pas natural de fauna com són valls, rieres i torrents, i també les corbes de visibilitat reduïda. La localització d'aquests trams permetrà el desenvolupament de mesures correctores adequades per part dels gestors del parc.

Avaluació de les diferències en la comunitat de meso-mamífers entre àrees naturals veïnes mitjançant transectes en cerca de rastres

Collserola, al igual que altres parcs, pateix un procés d'aïllament com a conseqüència de l'alteració que el creixement urbà provoca en el territori que envolta els parcs que gaudeixen de cert grau de protecció administrativa. Per pal·liar el seu aïllament, des del parc de Collserola, s'havien proposat tres vies de connexió: la via de l'oest que el connectaria amb Montserrat; la via del nord-oest, que el connectaria amb San Llorenç del Munt i l'Obac; i la via del nord-est, que el connectaria amb la Serra de Marina. L'aïllament s'associa fonamentalment a les característiques que presenta la matriu que envolta les clapes d'hàbitat adient, tant des del punt de vista de les barreres físiques que conté (construcció de vivendes, carreteres, vies de ferrocarril, etc.), com des del de la modificació de l'estructura del paisatge (composició i configuració). En relació a la modificació del paisatge, utilitzem com a criteri l'estat en el que es troben les poblacions de meso-mamífers, en termes de diversitat i abundància, i ho comparem amb la diversitat i abundància que presenten la resta de parcs citats anteriorment. És a dir, que per a cada via de connexió comparàvem la població del parc de Collserola (origen de la connexió) amb la de cadascun dels parcs (destí de la connexió), i també amb la de la matriu que es troba entre ells. Tenint en compte el baix nombre de rastres detectats, s'ha emprat la teoria de la informació com a eina d'anàlisi.

Als parcs de Collserola, Montserrat, Sant Llorenç del Munt i Serra Marina, s'ha trobat que la fagina és l'espècie amb major presència de rastres, mentre que la mostela és la que s'ha detectat un menor nombre de vegades. Els valors d'abundància que hem obtingut amb l'índex quilomètric d'abundància (*Kilometrical Abundance Index, KAI*) són majors que els obtinguts mitjançant mètode directes de cens per a les mateixes espècies en ambients mediterranis (Ballesteros *et al.* 1998, García-Peiró *et al.* 2009, Sobrino *et al.* 2009); això subratlla la utilitat d'aquest mètode en termes del balanç entre resultats i esforç de mostreig, degut a la gran detectabilitat dels rastres de meso-mamífers al llarg d'elements lineals, com són els camins de passejada.

Els resultats indiquen que la via de l'oest és la que presenta les poblacions de meso-mamífers més semblants (tant en diversitat com en abundància) en les tres àrees mostrejades (origen, matriu i destí). Des de la perspectiva de la biodiversitat (d'espècies i d'àrees de mostreig) i també des de la de la matriu circumdant, aquesta via de connexió de l'oest ha resultat ser el millor candidat per establir un corredor per re-connectar el Collserola, i evitar en la mesura del possible els efectes de la fragmentació i la pèrdua de connectivitat en aquest grup faunístic. O el que seria el mateix en termes de la teoria de la informació, és la via que mostra una major incertesa quan coneixem les poblacions de meso-mamífers que són presents al llarg de la via (origen, matriu i destí). D'altra banda, el paisatge que conforma aquesta via també mostra una topografia més adient per realitzar aquesta re-connexió, amb una matriu relativament poc ocupada i amb poques artèries de trànsit (autopistes, autovies, ferrocarrils) que circulen de forma transversal a la via de connexió. A més, aquesta via compta amb la presència del riu Llobregat, que corre paral·lel a la via i que podria ajudar d'una forma natural a aquesta reconstrucció, sent utilitzat pels mamífers en els seus moviments de manera natural. D'altra banda, la connectivitat de l'eix del nord-est, que connectaria Collserola amb Serra Marina, malgrat ser l'eix més curt, presenta dos gran obstacles. D'una part la clapa de corredor (matriu) està aïllada dels dos parcs; i d'altra part, la Serra Marina va patir una sèrie d'incendis dels que la vegetació encara no s'ha recuperat. Pel contrari, la clapa de corredor (matriu) de l'eix del nord-oest, que connectaria Collserola amb Sant Llorenç del Munt, suporta una major població humana que les dels altres dos corredors.

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Conclussions generals

CONCLUSIONS GENERALS

- El promig de l'àrea de màxima activitat obtinguda per ambdós parcs ha estat semblant a l'obtingut anteriorment per altres poblacions de baixa densitat, tant a la Península Ibèrica com a altres habitats europeus. Però, tot i ser poblacions molt properes, s'han trobat notables diferències en la densitat poblacional, nombre d'individus per cau i mida de l'àrea del domini vital. Sent la població de Collserola la menys densa, la que presenta menor nombre d'individus per cau i també on els mascles abasten àrees molt majors que no pas les femelles. Així mateix, tant la mida de grup com la densitat de la població tendeix a ser major en les zones agrícoles que no pas en les més forestals.
- Els mascles han resultat ser més mòbils que les femelles, ja que exploten diferents àrees en diferents moments. Les femelles semblen ser el recurs principal que guia l'organització social dels mascles. De manera que a Collserola la unitat territorial bàsica seria una femella solitària i seria el primer individu en instal·lar-s'hi en una àrea desocupada d'acord amb la riquesa de recursos de la mateixa.
- La presència de vegetació de bardissa cobrint els espais de ribera del Parc és un factor clau per la presència i distribució dels mamífers de mida gran i mitjana del Parc. Aquest ambient en general inaccessible per a l'esser humà i enormement ramificat connecta unes clapes d'hàbitat amb altres a l'hora que confereix protecció durant el desplaçament. També ha resultat ser clau per a la ubicació dels caus de toixó. D'altra banda, els espais forestals, dominants al Parc, afavoreixen també la presència de meso-mamífers, especialment el porc senglar i el gat mesquer; mentre que les petites plantacions de fruiters i els horts familiars resulten clau per a l'alimentació dels toixons. Pel contrari els ambients residencials i els espais oberts de vegetació herbàcia solen ser els menys freqüentats pel conjunt d'espècies. Per aquest motiu és d'especial importància la inclusió dels petits conreus ortofrutícoles i de la franja de bardissa i vegetació de ribera que envolta les rieres i torrents del Parc en els plans de protecció del Parc de Collserola
- Al Parc de Collserola s'ha observat una relació entre els atropellaments de mamífer i els nivells de trànsit (IMD), que es manifesta a nivell de tram de carretera. A més del trànsit, els cicles d'activitat i mobilitat de les espècies afectades hi tenen influencia en les taxes d'atropellament. Així mateix, s'ha observat també diferències entre espècies pel que fa a la temporalitat i distribució dels atropellaments, sent l'esquirol i l'eriçò els més estacionals, sent atropellats més a sovint durant la primavera.
- Malgrat ser un ambient força influenciat per la presència humana, Collserola encara alberga una bona comunitat de meso-mamífers. Entre els mamífers, la fagina és l'espècie amb major presència en totes les zones estudiades, seguida de la guineu, el teixó i la mostela. D'acord amb la composició i abundància d'espècies, l'eix de l'oest sembla ser el més idoni per a la ubicació d'un corredor ecològic per a la meso-fauna de Collserola.

Resums

RESUMS

Capítol 1. Ecologia espacial del teixó europeu (*Meles meles*) en hàbitats mediterranis del nord-est de la Península Ibèrica I: extensió del domini vital, distribució espacial i organització social

Malgrat que hi ha alguns estudis sobre l'organització social del teixó en ambients mediterranis sub-humits, plantacions de sureres i boscos atlàntics (al sud, oest i nord de la Península Ibèrica respectivament), el present estudi és el primer realitzat en boscos mediterranis del nord-est de la Península Ibèrica, concretament als parcs de Collserola i Montserrat. Els dominis vitals de 13 teixons adults (sis femelles i set mascles) va ser examinada amb l'objectiu d'aportar resultats per poder comparar-los amb estudis previs, i així avançar en la comprensió de l'organització social del teixó, amb especial atenció sobre les poblacions de baixes densitats en ambients mediterranis. El promig de l'àrea de màxima activitat ha estat de 307,6 ha ± 96,4 (± EE) i 72,8 ha ± 15,1 per a mascles i femelles respectivament per al Mínim Polígon Convex amb el 95% de localitzacions (MPC95), i de 287,4 ha ± 79,1 i 85,1 ha ± 26,6 per al Kernel Fix amb el 95% de localitzacions (KF95), amb diferències entre parcs. A més, els dominis vitals dels mascles de Collserola han estat quatre vegades majors que les femelles, mentre que a Montserrat aquesta diferència només és de 1,5. D'altra banda, els grups socials a Collserola han estat formats per un a tres individus, mentre que a Montserrat tots mantenien un mínim de tres individus. Aquestes diferències apunten a patrons d'organització social diferents, associats a diferències en la densitat poblacional (0,6 ind./km^2 a Collserola i 1,9 ind./km^2 a Montserrat) i en les condicions d'estructura del paisatge entre ambdós parcs. Els resultats obtinguts indueixen a considerar que la configuració espacial dels mascles de teixó està condicionada per la distribució de les femelles en l'espai.

Capítulo 1. Ecología espacial del tejón europeo (*Meles meles*) en hábitats mediterráneos del nordeste de la Península Ibérica I: tamaño del dominio vital, distribución espacial y organización social

Pese a que existen algunos estudios sobre la organización social del tejón en ambientes mediterráneos subhúmedos, alcornocales y bosques atlánticos (al sur, oeste y norte de la Península Ibérica respectivamente), el presente estudio es el primero realizado en bosques mediterráneos del nordeste peninsular, concretamente en los parques de Collserola y Montserrat. Los dominios vitales de 13 tejones adultos (seis hembras y siete machos) ha sido examinada con el objetivo de aportar resultados para poder compararlos con estudios previos y así avanzar en la comprensión de la organización social del tejón, con especial atención sobre les poblaciones de bajas densidades en ambientes mediterráneos. El promedio del dominio vital ha sido de 307,6 ha ± 96,4 (± EE) y 72,8 ha ± 15,1 para machos y hembras respectivamente para el Mínimo Polígono Convexo con el 95% de localizaciones (MPC95), y de 287,4 ha ± 79,1 y 85,1 ha ± 26,6 para el Kernel Fijo con el 95% de localizaciones (KF95), con diferencias entre parques. Además, los dominios vitales de los machos de Collserola han sido cuatro veces mayores que las hembras, mientras que en Montserrat ésta diferencia sólo es de 1,5. Por otra parte, los grupos sociales en Collserola se han constituido por entre uno y tres individuos, mientras que en Montserrat todos mantenían un mínimo de tres individuos. Éstas diferencias apuntan a patrones de organización social diferentes, asociados con diferencias en la densidad poblacional (0,6 ind./km^2 en Collserola i 1,9 ind./km^2 en Montserrat) y en las condiciones de la estructura del paisaje entre ambos parques. Los resultados obtenidos sugieren que la configuración espacial de los machos de tejón esta condicionada por la distribución de las hembras en el espacio.

Capítol 2. Ecologia espacial del teixó europeu (*Meles meles*) en hàbitats mediterranis del nord-est de la Península Ibèrica II: selecció de l'hàbitat

Els teixons tenen una gran adaptabilitat per viure sota diferents règims tròfics (quantitat i varietat), i per presentar diversos patrons d'organització social en funció de la densitat poblacional i la distribució dels recursos. Aquestes característiques permeten a l'espècie avenir-se a viure en una gran varietat d'ambients diferents al llarg de la seva vasta distribució europea. En conseqüència la selecció de l'hàbitat dels teixons ha estat objecte d'estudi en gran part del seu rang geogràfic, tant a nivell de territoris individuals com a nivell de la localització dels caus (teixoneres). Diverses versions de la Hipòtesi de la Dispersió dels Recursos (*Resource Dispersion Hypoyhesis, RDH*) han estat proposades per tal d'explicar la selecció de l'hàbitat dels teixons. En aquest treball s'ha dut a terme una anàlisi composicional per avaluar les preferències d'hàbitat dels teixons al nord-est de la Península Ibèrica. Amb aquest propòsit s'han emprat les dades corresponents al radio-seguiment de 13 individus adults ràdio-marcats en dos parcs propers a la ciutat de Barcelona (en base al domini vital i també dels nuclis d'alimentació). D'altra banda, també s'ha emprat la localització de 39 teixoneres al Parc de Collserola per a l'estudi de la selecció de l'hàbitat. Pel que fa als dominis vitals, els teixons van seleccionar en primer lloc la vegetació de ribera i varen evitar les àrees residencials. En relació als ambients de localització de les teixoneres es van obtenir resultats similars. En canvi, els teixons varen seleccionar els conreus com a nuclis d'alimentació. D'acord amb estudis previs, els resultats obtinguts en aquest treball mostren que en ambients mediterranis els teixons seleccionen els hàbitats més en funció de la capacitat d'obtenir un refugi protector, que no pas per la disponibilitat d'aliment, ja que els recursos tròfics no són un factor limitant en l'àrea d'estudi. Es conclou que se selecciona el mateix hàbitat tant per a l'establiment dels caus, com dels dominis vitals (la vegetació de ribera), mentre que les clapes agrícoles defineixen els nuclis d'alimentació. Aquest resultats es corresponen amb els postulats de la Hipòtesi de la Dispersió de les Teixoneres (*Sett Dispersion Hypothesis, SDH*).

Capítulo 2. Ecología espacial del tejón europeo (Meles meles) en hábitats mediterráneos del nordeste de la Península Ibérica II: selección del hábitat

Los tejones tienen una gran adaptabilidad para vivir bajo diferentes regimenes tróficos (en cantidad y variedad), y por presentar diversos patrones de organización social en función de la densidad poblacional y de la distribución de los recursos. Éstas características permiten a la especie adaptarse a vivir en una gran variedad de ambientes diferentes a lo largo de su amplia distribución europea. En consecuencia la selección del hábitat de los tejones ha sido objeto de estudio en gran parte de su rango geográfico, tanto a nivel de territorios individuales como a nivel de la localización de las madrigueras (tejoneras). Diversas versiones de la Hipótesis de la Dispersión de los Recursos (*Resource Dispersion Hypoyhesis, RDH*) han sido propuestas para explicar la selección del hábitat de los tejones. En éste trabajo sa ha realizado un análisis composicional para evaluar las preferencias de hábitat de los tejones al nordeste de la Península Ibérica. Para éste propósito se han utilizado los datos correspondientes al radio-seguimiento de 13 individuos adultos radio-marcados es dos parques cercanos a la ciudad de Barcelona (a nivel de dominios vitales y también a nivel de los núcleos de forrajeo). Por otra parte también se ha utilizado la localización de 39 tejoneras en el Parque de Collserola para el estudio de la selección del hábitat. A nivel de los dominios vitales, los tejones seleccionaron en primer lugar la vegetación de ribera y evitaron las áreas residenciales. A nivel de los ambientes donde se ubicaban las tejoneras, se obtuvieron resultados similares. En cambio, los tejones seleccionaron los cultivos a nivel de los núcleos de forrajeo. De acuerdo con lo obtenido en estudios previos, los resultados obtenidos en éste trabajo muestran que en ambientes mediterráneos los tejones seleccionan los hábitats más en función de la capacidad de proporcionar un refugio protector, que por la disponibilidad de alimento que proporcionen, ya que los recursos tróficos no son un factor limitante en el área de estudio. Se concluye que se selecciona el mismo hábitat tanto para el establecimiento de las tejoneras, como para el de los dominios vitales (la vegetación de ribera), mientras que los parches agrícolas definen los núcleos de forrajeo. Estos resultados se corresponden con los postulados de la Hipótesis de la Dispersión de las Tejoneras (*Sett Dispersion Hypothesis, SDH*).

Capítol 3. Selecció de l'hàbitat de tres espècies de meso-mamífer en un parc mediterrani aïllat i altament antropitzat: una aproximació multi-nivell

Atès que la selecció de l'hàbitat és un aspecte del cicle vital dels animals, el seu estudi en ambients antropitzats ens pot ser d'utilitat per entendre com els meso-mamífers responen al fet de viure en ambients mediterranis suburbans. S'ha emprat l'anàlisi composicional per avaluar la selecció de l'hàbitat de guineus, porcs senglars i gats mesquers en un parc metropolità altament humanitzat al nord-est de la Península Ibèrica a tres nivells d'anàlisi: població, domini vital (*home range*) i nuclis d'alimentació (*core foraging area*). Per aquest propòsit s'han emprat les dades ràdio-telemètriques de vuit, nou i 16 individus de cada espècie respectivament, i també les dades obtingudes mitjançant una campanya de trampeig fotogràfic. Al primer nivell d'anàlisi s'ha trobat una selecció significativa per a totes tres espècies. Les guineus i els gats mesquers seleccionen la vegetació de ribera, mentre que els porcs senglars seleccionen els ambients forestals. La guineu no mostra cap selecció significativa ni al 2^{on} ni 3^{er} nivell d'anàlisi, mentre que els porcs senglars mostren una selecció només al 2^{on} nivell, seleccionant de nou la vegetació de ribera. Els gats mesquers mostren una selecció significativa en ambdós, 2^{on} i 3^{er} nivell, i en ambdós casos els ambients forestals són també els preferits. En termes generals, la vegetació de ribera i els ambients forestals han estat seleccionats positivament. Pel contrari, les zones residencials i fins a cert punt, també ambients herbacis i arbustius, han estat evitats. Es discuteixen els resultats per espècies tot considerant les respectives particularitats ecològiques de cadascuna.

Capítulo 3. Selección del hábitat de tres especies de meso-mamífero en un parque mediterráneo aislado y altamente antropizado: una aproximación multi-nivel

Dado que la selección del hábitat es un aspecto del ciclo vital de los animales, su estudio en ambientes antropizados nos puede ser de utilidad para entender cómo los meso-mamíferos responden al hecho de vivir en ambientes mediterráneos suburbanos. Se ha utilizado el análisis composicional para evaluar la selección del hábitat de zorros, jabalíes y jinetas en un parque metropolitano altamente humanizado al nordeste de la Península Ibérica a tres niveles de análisis: población, dominio vital (*home range*) i núcleos de alimentación (*core foraging area*). Con éste fin se han usado los datos radio-telemétricos de ocho, nueve y 16 individuos de cada especie respectivamente, y también los datos obtenidos mediante una campaña de trampeo fotográfico. Al primer nivel de análisis se ha encontrado una selección significativa para las tres especies. Los zorros y las jinetas seleccionan la vegetación de ribera, mientras que los jabalíes seleccionan los ambientes forestales. El zorro no muestra ninguna selección significativa ni al 2º ni 3er nivel de análisis, mientras que los jabalíes muestran una selección sólo para el 2º nivel, seleccionando de nuevo la vegetación de ribera. Las jinetas muestran una selección significativa para ambos, 2º y 3er nivel, siendo los ambientes forestales los preferidos también en ambos casos. En términos generales, la vegetación de ribera y los ambientes forestales han sido seleccionados positivamente. Por el contrario, las zonas residenciales y hasta cierto punto, también los ambientes herbáceos y arbustivos, han sido evitados. Se discuten los resultados por especies considerando las respectivas particularidades ecológicas de cada una.

Capítol 4. Atropellaments de mamífers i trànsit a la xarxa viària d'un espai natural a l'àrea metropolitana de Barcelona: quinze anys de seguiment al Parc de Collserola

El Parc de Collserola està situat al centre de l'àrea metropolitana de Barcelona, envoltat per més de quatre milions d'habitants que exerceixen una gran pressió antròpica sobre aquest espai natural. En el present estudi s'han analitzat les dades d'atropellaments a les carreteres de Collserola recollits des del 1991. En total s'han enregistrat 991 incidències, de les quals 556 es corresponen a mamífers. Cinc especies concentren el 72,3 % de tots els registres: ambdues espècies d'eriçò *Erinaceus europaeus* i *Atelerix algirus* (21,8 %), el porc senglar *Sus scrofa* (20,7 %), el conill *Oryctolagus cuniculus* (16,0 %) i l'esquirol *Sciurus vulgaris* (13,8 %). Les anàlisis de les incidències mostren una relació positiva entre la taxa d'atropellaments per quilòmetre i la intensitat mitjana diària de trànsit. Quant a la caracterització de l'hàbitat al voltant dels punts d'atropellament, s'observa una major representació d'ambients oberts en el cas del conill i l'eriçò, i una infra-representació de l'hàbitat forestal. L'esquirol mostra una situació inversa, amb una menor representació d'ambients oberts i una major presència del forestal. En canvi, en el cas del porc senglar, l'hàbitat dels punts d'atropellament es correspon en gran mesura al que caldria esperar per atzar. D'altra banda, s'ha observat una estacionalitat dels atropellaments al llarg de l'any, la qual no respon a variacions en el volum del trànsit, sinó que s'atribueix a aspectes de la biologia de les diferents espècies. En el cas de l'esquirol i també dels eriçons, s'observen màxims d'atropellaments a finals de primavera, mentre que en el cas del conill se n'aprecia una reducció a partir de l'estiu, situació que reflectiria tant canvis poblacionals estacionals com una minva d'activitat durant l'hivern en el cas de l'esquirol, o quasi nul·la per a l'eriçò en aquesta època. Els atropellaments de porcs senglars al parc mostren una variació temporal més irregular, amb màxims al juny i al novembre, la qual cosa sembla respondre a factors diversos: patrons de mobilitat, dispersió juvenil, i les èpoques de zel i cacera.

Capítulo 4. Atropellos de mamíferos y tráfico en la red viaria de un espacio natural en el área metropolitana de Barcelona: quince años de seguimiento en el parque de Collserola

El Parque de Collserola está situado en el centro del área metropolitana de Barcelona, rodeado por más de cuatro millones de habitantes que ejercen una gran presión antrópica sobre este espacio natural. En este estudio se han analizado los datos de atropellos en las carreteras de Collserola recogidos desde 1991. En total se han registrado 991 incidencias, de las cuales 556 corresponden a mamíferos. Cinco especies concentran el 72,3 % de todos los registros: las dos especies de erizo *Erinaceus europaeus* y *Atelerix algirus* (21,8 %), el jabalí *Sus scrofa* (20,7 %), el conejo *Oryctolagus cuniculus* (16,0 %) y la ardilla roja *Sciurus vulgaris* (13,8 %). El análisis de las incidencias muestra una relación positiva entre la tasa de atropellos por kilómetro y la intensidad media diaria de tráfico. En cuanto a la caracterización del hábitat alrededor de los puntos de atropello, se observa una mayor representación de ambientes abiertos en el caso del conejo y el erizo y una infrarepresentación del hábitat forestal. La ardilla muestra una situación inversa, con una menor representación de los ambientes abiertos y una mayor presencia del forestal. En cambio, en el caso del jabalí, el hábitat en los puntos de atropello corresponde en gran medida a lo que se esperaría al azar. Por otro lado, se ha observado una estacionalidad de los atropellos a lo largo del año, la cual no responde a variaciones en el volumen de tráfico, sino que se atribuye a aspectos de la biología de las diferentes especies. En el caso de la ardilla y los erizos se observan máximos de atropellos a finales de primavera, mientras en el caso del conejo se aprecia una reducción de atropellos a partir del verano, situación que reflejaría tanto cambios poblacionales estacionales como una menor actividad en invierno en el caso de la ardilla, o casi nula para el erizo en esta época. Los atropellos de jabalíes en el parque muestran una variación temporal más irregular, con máximos en junio y noviembre, lo cual parece responder a factores diversos: patrones de movilidad, dispersión juvenil, y las épocas de celo y caza.

Capítol 5. Avaluant les diferències en la composició de meso-mamífers entre àrees naturals veïnes mitjançant transectes: una aproximació de la teoria de la informació

Els cada cop més comuns ecosistemes fragmentats forcen els meso-mamífers a viure en meta-poblacions. A més, el complex mosaic de clapes de que es composa la matriu paisatgística, pot oferir diferents graus de resistència al pas d'animals. Conseqüentment, la connectivitat entre clapes no depèn exclusivament de les distàncies euclidianes, sinó també d'altres factors. El objectius d'aquest estudi són avaluar la semblança en la presència de sis espècies de meso-mamífers entre el Parc de Collserola i tres reserves naturals circumdants; així com comparar llurs respectives abundàncies relatives. Per aquest propòsit s'han sondejat nou fragments d'hàbitats diferents del paisatge mitjançant transectes lineals en cerca d'excrements d'animals i altres rastres. Per a l'anàlisi de les dades s'ha emprat una aproximació de la teoria de la informació en base a l'índex de diversitat de Shannon-Weaver. També s'han calculat els respectius índex quilomètrics d'abundància per a la comparació entre àrees. La fagina ha estat l'espècie de la que s'ha recollit un major nombre de rastres, seguida de la guineu, el teixó i la mostela. D'altra banda, el conill ha estat absent només en una de les àrees, mentre que el porc senglar ha estat present en el 60 % d'elles. D'acord amb l'abundància i composició d'espècies de meso-mamífer, l'eix oest resultaria el millor candidat per establir un corredor de fauna des del Parc de Collserola, mentre que l'eix del nord-est seria la pitjor opció.

Capítulo 5. Evaluando las diferencias en la composición de meso-mamíferos entre áreas naturales vecinas mediante transectos: una aproximación de la teoría de la información

Los cada vez más comunes ecosistemas fragmentados, fuerzan a los meso-mamíferos a vivir en meta-poblaciones. Además, el complejo mosaico de parches de que se compone la matriz paisajística, puede ofrecer diferentes grados de resistencia al paso de animales. Consecuentemente, la conectividad entre parches no depende exclusivamente de distancias euclídeas, sino también de otros factores. Los objetivos de éste estudio son evaluar la semejanza en la presencia de seis especies de meso-mamífero entre el Parque de Collserola y tres reservas naturales circundantes; así como comparar sus respectivas abundancias relativas. Para éste propósito se sondearon nueve fragmentos de hábitat diferentes del paisaje mediante transectos lineales en busca de excrementos y otros rastros. Para el análisis de los datos se ha utilizado una aproximación de la teoría de la información en base al índice de diversidad de Shannon-Weaver. También se han calculado los respectivos índices quilométricos de abundancia para la comparación entre áreas. La garduña ha sido la especie de la que se han recogido un mayor número de rastros, seguida del zorro, el tejón y la comadreja. Por otra parte, el conejo sólo ha estado ausente en una de las áreas, mientras que el jabalí estuvo presente en el 60 % de ellas. De acuerdo con la abundancia y composición de especies de meso-mamífero, el eje oeste resultaría el mejor candidato para establecer un corredor de fauna desde el Parque de Collserola, mientras que el eje del nordeste sería la peor opción.