Ecología trófica de ungulados en condiciones de insularidad

TESIS DOCTORAL

Por

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SUMMARY

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Currently the main impacts and threats to island communities include bioinvasions and standing out the goats between them. Most of the islands reported in the literature, are ecosystems where vegetation evolved in absence of large herbivores. On the island of Mallorca is well known the ancestral presence of a pre-human endemic ungulate, *Myotragus balearicus*, which suggests that herbivore was a selection factor constantly present to the vegetation in the island. Today, two goats that currently shared habitat and hybridized, have mainly occupied its ecological niche: the Wild Mallorcan Goat and feral domestic goats. The presence of these goats has generated many opinions about its effect on the vegetation of the island. Therefore, the aim of this thesis was to characterize and compare the botanical composition of the diet of the Wild Mallorcan Goat and feral domestic goat in Mallorca. Additionally, the browsing levels on the main components of the vegetation and the habitat use by both goats was evaluated in order to investigate possible differences in their social structure and behavior that help to elucidate the level of resource use and find possible evidences of climate change in the diet of extinct *Myotragus balearicus*. The study was carried out in six areas of the Sierra Tramuntana in Mallorca; three inhabited by the Wild Mallorcan Goat and three by the feral domestic goats. Microhistological analysis of faeces from each goat ecotype in spring, summer and winter for two years as well as the assessment of availability and browsing intensity of the most abundant species of vegetation were performed. Analysis of the feeding and social behavior in both goat ecotypes was conducted through focal in abovementioned seasons. Stomatal density and index of *Buxus sp*. epidermis fragments found in coprolites from extinct *Myotragus* were compared with actual epidermis of *Buxus balarica* and *Buxus semprevirens* to detect a possible manifestation of climate change. The diet of the Wild Mallorcan Goat and feral domestic goat was very similar especially in times of scarcity (Summer). Indeed, the possible damage on vegetation would be subject to an overpopulation of goats that goat ecotype itself. Both goat ecotypes showed a selective dietary behavior, with clear preferences and rejections, but also capable to adapt to availability because they use most species available. Few species are heavily browsed in all periods of the year, although the intensity of browsing by almost all studied species can be considered moderate. Some differences in the feeding behavior of the both goat ecotypes were found, especially related with herd size, suggesting a more efficient use of plant resources in the Wild Mallorcan Goat. The current density and stomatal indexes in *B. balearica* were considerably smaller than those found in *Myotragus* coprolites, which could be due to increased CO_2. This thesis highlights the importance of a properly management of both goat ecotype populations so that ensure the conservation of animal and vegetal species.

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RESUMEN

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Entre los principales impactos y amenazas que sufren hoy las comunidades insulares destacan las bioinvasiones y entre estas sobresalen las de cabras. La mayoría de las islas, reportadas en la literatura, son ecosistemas donde la vegetación evoluciono en ausencia de grandes herbívoros. En la isla de Mallorca se sabe de la presencia ancestral de un ungulado pre-humano endémico, *Myotragus balearicus*, que hace pensar en los herbívoros como un factor de selección siempre presente para la vegetación de la isla. Su nicho ecológico habría sido ocupado hoy principalmente por dos caprinos, que actualmente comparten hábitat y se hibridan, la Cabra Salvaje Mallorquina y la cabra domestica asilvestrada. La presencia de estas cabras ha generado muchas opiniones sobre su efecto en la vegetación de la isla. Por lo que el objetivo de esta tesis fue caracterizar y comparar la composición botánica de la dieta de la Cabra Salvaje Mallorquina y la cabra doméstica asilvestrada en Mallorca, así como del grado del ramoneo sobre los principales componentes de la vegetación y el uso del hábitat realizado por ambas cabras para indagar sobre posibles diferencias de estructura social y de comportamiento que ayuden a dilucidar el nivel de uso de los recursos, así como encontrar posibles evidencias del cambio climático en la dieta del extinto *Myotragus balearicus*. El estudio se llevo a cabo en seis zonas de la sierra Tramuntana en Mallorca, donde tres zonas son habitadas por la Cabra Salvaje Mallorquina y tres por la cabra domestica asilvestrada. Se realizaron análisis microhistológicos de heces de cada ecotipo de cabra en primavera, verano e invierno durante dos años, así como la evaluación de disponibilidad e intensidad de ramoneo de las especies mas abundantes de la vegetación. El análisis del comportamiento trófico y de los grupos de ambas cabras se realizo mediante focales en tres estaciones del año. La densidad y el índice estomático de fragmentos de epidermis de *Buxus sp*. encontrados en coprolitos del extinto *Myotragus* se compararon con epidermis actuales de *Buxus balarica* y *Buxus semprevirens* para detectar una posible manifestación del cambio climático. La dieta de la cabra Salvaje Mallorquina y de la cabra domestica asilvestrada fue

muy similar sobretodo en épocas de escases (verano). Por lo que el posible daño sobre la vegetación estaría condicionado a una sobrepoblación de cabras, mas que al ecotipo de cabra. Ambos ecotipos de cabras mostraron un comportamiento en la dieta de carácter selectivo, con claras preferencias y rechazos pero también capaz de adaptarse a la disponibilidad ya que hace uso la mayoría de especies disponibles. Unas pocas especies son ramoneadas intensamente en todos los periodos del año, aunque la intensidad de ramoneo de la mayoría de especies estudiadas se puede considerar como moderada. Se encontraron algunas diferencias en el comportamiento trófico de ambas cabras, sobretodo en el tamaño de los rebaños, lo que sugiere un uso más eficiente de los recursos vegetales en la Cabra Salvaje Mallorquina. La densidad y el índice estomático de *B. balearica* actual, fue considerablemente menor al encontrado en los coprolitos de *Myotragus,* lo que podría deberse al incremento de CO_2. De este estudio se desprende la importancia de gestionar adecuadamente las poblaciones de ambos tipos de cabras de manera que se asegure la conservación de las especies animales y vegetales.

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INTRODUCCIÓN

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EFECTOS DE CABRAS EN ISLAS

Los ecosistemas insulares y su vulnerabilidad han sido extensamente tratadas en la literatura científica (p.e. Vitousek, Loope & Adsersen 1998; Fernández-Palacios & Morici 2005). Entre los principales impactos y amenazas que sufren hoy las comunidades insulares destacan las bioinvasiones y entre estas sobresalen las de cabras (Mayol *et al.*, 2006). Las evidencias arqueológicas de cabras salvajes (*Capra aegagrus,* Erxleben, 1777) introducidas en las islas del Mediterráneo datan de 9º-8º milenio a.C. (Masseti, 2014). En tiempos mas recientes, las introducciones de cabras en diversas islas las realizaron balleneros y otros marinos de los siglos XVII y XVIII (Coblentz, 1978). El propósito de estas liberaciones, era proporcionar un suministro de carne fresca para futuras visitas. Se sabe que los primeros pobladores mediterráneos alcanzaron las islas Baleares durante la edad de Bronce (Alcover, 2008), momento en el cual se inició la transformación de la fauna insular (Orueta, 2003). Cuando el aislamiento se rompe puede desencadenar un proceso de extinción muy rápido para especies autóctonas. En las islas oceánicas, con un grado de aislamiento muy elevado, este efecto suele ser muy intenso, así por ejemplo en las Canarias la llegada del hombre supuso la desaparición de notables endemismos, en particular reptiles y roedores gigantes (Rando, 2003). En las Baleares, con un grado e aislamiento menor también desapareció parte de la fauna que había evolucionado con anterioridad a la llegada del hombre, entre la que el ejemplo más conocido es *Myotragus balearicus* Bate 1909 (Bover and Alcover, 2003).

Como la disponibilidad de recursos alimenticios es una de las principales fuerzas evolutivas en las poblaciones insulares de vertebrados (McNaughton, 1994) y la cabra doméstica (*Capra hircus*), dispone de una gran plasticidad en el uso de recursos (Vives and Baraza, 2010), ha podido convertirse en el herbívoro dominante en muchas islas (p.e. Coblentz, 1978; Parkes *et al.*, 1996; Campbell and Donlan, 2005).

La introducción de cabras en islas puede tener como consecuencia la producción de daños a la vegetación autóctona, llegando a ocasionar importantes pérdidas económicas debido a su competencia con el ganado doméstico y a la transmisión de enfermedades (Suances, 2010).

Debido a los problemas que puede originar, actualmente está clasificada como una de las 100 especies invasoras más peligrosas (Orueta, 2003). La mayoría de las islas, reportadas en la literatura, tienen en común dos notas características, por un lado se trata de ecosistemas, con un elevado número de endemismos faunísticos y botánicos; y por otro, la vegetación evoluciono en ausencia de grandes herbívoros. Un ejemplo de esto, es la introducción de agrimís (*Capra aegagrus creticus*) en la isla de Atalandi, Grecia, con la finalidad de conservarlos y aumentar su población, pero donde ni el agrimí ni otros grandes herbíovos habían estado con anterioridad causando graves daños en la vegetación (Sfougaris *et al.*, 1996).

Ya que el efecto de las cabras ha sido especialmente destructivo en islas que habían evolucionado sin grandes ramoneadores, estas han sido objeto de intensas campañas de erradicación (Parkes, 1990a). Sin embargo, las condiciones en cada sitio no son las mismas por lo que existen casos donde la vegetación insular ha coevolucionado durante largo tiempo con herbívoros autóctonos y la resistencia del sistema es mayor, como ocurre en la cuenca Mediterránea (Seligman y Pervolotsky, 1994) o islas en las que además, la presencia de caprinos domésticos y asilvestrados cuenta con un largo historial (Masseti, 2009). Este podría ser el caso de la isla de Mallorca, donde la presencia ancestral de un ungulado pre-humano endémico, *Myotragus balearicus*, hace pensar en los herbívoros como un factor de selección siempre presente para la vegetación de la isla (Alcover et al. 1999). Su nicho ecológico habría sido ocupado hoy principalmente por caprinos, por lo cual el reto para el mantenimiento del ecosistema sería el de mantener una densidad adecuada, no el de la erradicación total.

De esta forma, se puede pensar en la invasión como un simple reemplazo de especies en el mismo nicho. Sin embargo, en pocas ocasiones se puede comparar la amplitud del nicho trófico de la especie precedente con su sucesora. Esta información sería de gran utilidad para evaluar la sostenibilidad del ecosistema que ha incorporado este nuevo herbívoro. La coexistencia de los herbívoros y las masas forestales es una constante en España desde épocas anteriores al Holoceno

(González Rebollar, 2001). Las islas con valores relativamente altos de diversidad biológica, son especialmente vulnerables a modificaciones de cualquier tipo en el hábitat, y la perdida de un herbívoro puede causar una dramática reducción o incluso la extinción de otras que dependan de ellos (Traveset, 1999).

En Mallorca existen dos tipos de caprinos que actualmente comparten hábitat y se hibridan, la Cabra Salvaje Mallorquina y la cabra domestica asilvestrada. La presencia de estas cabras ha generado muchas opiniones sobre su efecto en la vegetación de la isla (Mayol, 2013). En la actualidad la cabra Salvaje Mallorquina tiene un gran valor cinegético y representa importantes ingresos económicos en la isla, mientras que de la cabra domestica asilvestrada se cazan los cabritos para autoconsumo. Bajo estas condiciones se presentó la oportunidad de abordar la ecología trófica tanto de los dos caprinos que actualmente habitan la isla (cabra doméstica asilvestrada y cabra salvaje) como la de su antecesor (*Myotragus balearicus*).

ESPECIES DE ESTUDIO

Myotragus balearicus

Myotragus balearicus era un pequeño artiodáctilo de porte robusto de la familia Bovidae (subfamilia Caprinae), endémico de Mallorca y Menorca, que se extinguió probablemente hace unos 4.200-4.300 años (Waldren, 1982; Bover and Alcover, 2008). La evolución de este artiodáctilo lo convirtió en un mamífero perfectamente adaptado a los ambientes insulares, desarrollando una serie de cambios en tres tipos de estructuras: el sistema locomotor; el complejo masticador y el diseño del cráneo y la mandíbula (Sondaar *et al.*, 1995; Guerrero, 1996; Köhler and Moyà-Solà, 2009). Se estima que su peso medio se situaría entre los 20 y 50 kg y tenían una altura a la cruz de algo más de 45 cm (Alcover *et al.*, 1999). La ausencia de mamíferos depredadores permitió que el sistema locomotor se adaptase a marchas cortas, con mucha estabilidad en la locomoción y resistencia a la fractura de las extremidades. Adquirió una gran potencia de movimientos, pero perdió capacidad de saltar, de correr y de hacer rápidos movimientos en zig-zag (Guerrero, 1996). Su dentición, con incisivos de crecimiento continuo y molares sumamente hipsodontos, con capas gruesas de esmalte, sugiere que su dieta debió ser de carácter sumamente abrasivo (Alcover *et al.*, 1999).

Su tasa de crecimiento era muy lenta, hasta el punto de limitar temporalmente su desarrollo, singularidad que le habría permitido adaptarse a la escasez estacional de recursos, propia de las islas mediterráneas (Köhler and Moyà-Solà, 2009). Las herbáceas no debieron formar parte significativa de su dieta. La presión de este mamífero sobre la flora isleña trajo como resultado adaptaciones de la misma. Así, muchas especies arbustivas evolucionaron hacia variantes más espinosas, que es una reacción típica defensiva al ramoneo intensivo (Guerrero, 1996). Este es el caso de *Smilax aspera,* es una enredadera con espinas fuertes en los tallos y el rizoma tuberosa, que permite a brotar después de fuertes episodios de herbívoros (Pérez-Obiol *et al.*, 2003).

La extinción del *Myotragus* se dio, a finales del Holoceno, coincidiendo con un momento de grandes cambios en la isla. Por un lado se estaba produciendo un proceso de cambio climático hacia condiciones más xéricas y por otro el hombre llegó al archipiélago entre c. 2300 y c. 2250 BC (Alcover, 2008). La utilización de éste como soporte básico de subsistencia de los primeros habitantes de las islas de Mallorca-Menorca es altamente probable (Guerrero, 1996). Estos primeros pobladores del período pretalaiótico serían responsables de la introducción de las primeras cabras en la isla, probablemente procedentes de la ancestral cabra de Creta o agrimí (*Capra aegagrus*). Poblaciones asilvestradas de esos primeros rebaños darían lugar a la Cabra Salvaje Mallorquina, que conservaría a lo largo del tiempo una cierta distancia genética respecto a la cabra doméstica actual, *Capra hircus* (Manceau *et al.*, 1999). La extición de *Myotragus*, junto con la aridificación del territorio, la introducción de la agricultura y de la ganadería, debió influir en la rarefacción de muchas especies vegetales que hoy en día se consideran relictas en la isla. Este es el caso de *Buxus balearica, Ephedra fragilis* y *Juniperus oxycedrus*, cuyos registros polínicos muestran cómo a finales del Holoceno dejan de ser abundantes en la isla (Yll *et al.*, 1997).

Los resultados obtenidos en el yacimiento de Cova Estreta sobre la composición de la dieta de este caprino, empleando análisis palinológicos de coprolitos, mostraron un herbívoro capaz de consumir plantas tóxicas como el boj (*Buxus*) (Alcover *et al.*, 1999). La proporción de polen de este género en las heces alcanzaba valores del 98%, implicando que si esta hubiese sido la proporción real de planta ingerida, estos animales habrían tenido que haber desarrollado una excepcional capacidad para detoxificar los compuestos secundarios.

Estudios recientes han confirmado la presencia de un elevado porcentaje de *Buxus balearica*, pero también han mostrado que la dieta en ese yacimiento era más diversificada (Bartolomé *et al.*, 2011). Precisamente la diversificación de la dieta es una de las estrategias que siguen los caprinos para evitar episodios de toxicosis (Provenza et al., 2003, Baraza et al. 2008; 2009) y son comunes los estudios sobre dietas de cabras asilvestradas en otras islas que presentan espectros con varias decenas de especies vegetales (Parkes, 1984; Mitchell et al., 1985; Chimera et al., 1995). Sin embargo, para poder generalizar la composición de la dieta de *Myotragus* es necesario aumentar el muestreo y extenderlo a otros yacimientos de la isla. Los estudios preliminares realizados abren nuevos interrogantes sobre la interacción entre *Myotragus* y la vegetación, como puede ser la resistencia de los arbustos dominantes al ramoneo o el posible papel dispersor del animal. Profundizar en estos aspectos ayudaría a explicar porque algunas especies se rarifican tras la desaparición de un herbívoro que las consume intensamente y contribuiría a facilitar la toma de decisiones para la conservación de sistemas actuales basados en la relación pasto-herbívoro. El estudio de coprolitos de *Myotragus* ofrece también la posibilidad de detectar manifestaciones del cambio climático en algunas especies vegetales. La oportunidad de disponer de tejidos vegetales de varios miles de años de antigüedad, como son los fragmentos de epidermis contenidos en las heces, permitiría compararlos con tejidos actuales de la misma especie. Algunas variables microanatómicas como la densidad de estomas son sensibles a factores como el incremento de CO2 en la atmósfera (Peñuelas et al., 1990). En estudios previos de Bartolomé *et al.* (2011) de coprolitos se observaron con claridad los estomas de las epidermis de *Buxus balearica*, de forma que en esta especie se podían realizar comparaciones. Este tipo de estudio junto con los de herbivoría permitieron determinar como algunas especies amenazadas o relictas responden al cambio global actual.

El escenario de cambio que se produjo a mediados del Holoceno tiene grandes similitudes con la realidad actual, donde a los posibles efectos del calentamiento global se sumaría el paulatino abandono de las actividades ganaderas tradicionales. Así nos encontramos con un herbívoro endémico, la Cabra Salvaje Mallorquina, que habría ocupado probablemente el nicho trófico de Myotragus y coexistido durante varios miles de años con la vegetación de la isla y con los rebaños domésticos introducidos por el hombre moderno. Durante este proceso, la cabra salvaje se habría adaptado a una vegetación mediterránea provista de defensas químicas y físicas y a un hábitat abrupto poco accesible al ganado.

Cabra Salvaje Mallorquina ó *Boc balear* (*Capra hircus [aegagrus]*)

La llegada de la cabra a Mallorca se habría producido con la llegada de los primeros pobladores humanos en la época pretalaiotica. Estas poblaciones de cabras, tuvieron que estar necesariamente sometidas a un manejo inicial de domesticación o de retención en cautividad. Milenios después de su asilvestramiento en un nuevo ambiente, han sido descritas en varios casos como especies naturales nuevas, siendo reconocidas como tales por sus diferencias respecto de la especie ancestral continental de la cual derivaban (*Capra aegagrus*) (Seguí, 2014, en prensa).

Los núcleos asilvestrados de aquellas cabras que muy probablemente en los primeros tiempos, convivieron y compitieron con *Myotragus*, colaborando en su desaparición, al ser las cabras animales más fuertes y bien adaptados a la explotación humana (Lapena, 2009). Algunos autores la consideran una raza endémica de la isla perteneciente a la especie *Capra hircus* (Alcover, 2010), mientras que para otros autores pertenecería aún a la especie *Capra aegagrus* (Seguí y Payeras 2002; Masseti 2009b).

En el momento actual se reconoce en la Sierra de Tramuntana una población geográficamente fragmentada que coincide a grandes rasgos con lo que agricultores y cazadores locales denominan cabra "mallorquina" o "fina", la cual desarrolla su ciclo biológico sin intervención humana. Históricamente se ha documentado la presencia de poblaciones totalmente salvajes próximas a dicha morfología también en las Sierras de Llevant. Todas estas poblaciones constituian una fuente de caza, aunque también han servido como recurso genético para la ganadería, al igual que el agrimi en Creta (Husband and Davis, 1984), gracias a la captura de ejemplares vivos con la modalidad tradicional de perros y lazo (*ca i llaç*), la cual perdura hoy en día (Seguí, 2014 en prensa).

En los años 1970-80, únicamente los payeses mallorquines y los cazadores de *ca i llaç* eran capaces de diferenciar esta cabra fina de las domesticas asilvestradas. A partir de entonces las poblaciones de cabras comenzarían a aumentar y los forestales hablan entonces de un evidente daño sobre la vegetación (Vives and Mas, 2014).

(Seguí *et al.* (2005) realizaron un estudio sobre la Cabra Salvaje Mallorquina, efectuado sobre 25 microsatélites, el cual mostró que se encuentra bien definida genéticamente, siendo diferenciable de las cabras asilvestradas de origen doméstico y naturales estudiadas como comparación. Las menores distancias genéticas se encontraron con cabras ibéricas y con la cabra de Creta, cosa que indica un origen mediterráneo y parece descartar el norteafricano.

Los animales suelen medir alrededor de 1,25 m de largo y 70 cm de alto a la cruz y a menudo no sobrepasan los 40 kg de peso, excepción hecha de algunos machos cabríos (*bocs*) que en su plenitud, sobrepasan los 50 kg. La coloración es roja amarronada, con una franja negra que va de medio cuello a la cola por encima de la espalda y que en algunos machos se cruza con otra franja que va de pata a pata por encima de la cruz. La cabra mallorquina suele ser siempre cornuda y en general los cuernos están bien desarrollados, entre los viejos machos cabríos hay cornamentas verdaderamente notables (Seguí and Payeras, 2002).. Tienen una estructura social matriarcal, con una hembra adulta y una o dos de sus hijas y sus respectivos cabritos. Los machos jóvenes permanecen hasta los dos años en el grupo familiar, y posteriormente se segregan y reagrupan con machos adultos. Pueden formarse grupos de machos subadultos y adultos, de hasta 40 individuos, especialmente en la época anterior al celo. No se forman sin embargo rebaños grandes de ambos sexos. El celo es en el mes de mayo, si bien según el año va de finales de abril hasta junio. Con menor intensidad se produce un segundo periodo de septiembre a octubre, donde se cubren hembras que no quedaron preñadas. Los cabritos nacen a partir del mes de diciembre hasta enero, si bien pueden observarse partos localizados en torno al mes de abril (Martínez *et al.*, 2014).

Ecológicamente, la cabra salvaje mallorquina presenta una tasa de reproducción inferior a las cabras asilvestradas de origen doméstico (Martínez *et al.*, 2014 en prensa). Los partos dobles son muy escasos, y las hembras tardan dos años al alcanzar la madurez reproductiva. La alimentación es también más selectiva que la de las cabras domésticas, causando un menor impacto sobre la vegetación (Orueta, 2003). En los años noventa, se inicia un intento de utilizar esta cabra con fines ganaderos, pero el intento fracasó, ya que eran poco productivas en comparación con las domesticas. También en los noventa cuando se expande socialmente la caza con rifle (Vives and Mas, 2014). Su caza con carácter general solo está permitida en cotos con Certificado de Calidad de Caza Mayor (Martínez *et al.*, 2014).

La Cabra Salvaje Mallorquina aparece en la Lista Roja de la Unión Mundial para la Naturaleza, junto con otros endemismos insulares del Mediterráneo muy cercanos desde el punto de vista genético, como la antes mencionada cabra de Creta o agrimí (Giannatos *et al.*, 2006). La singularidad de esta cabra le ha permitido adquirir un gran valor biológico (Seguí *et al.*, 2005) y ha despertado un gran interés como especie cinegética, siendo en los cotos de caza donde se conservan las poblaciones más puras, gracias al descaste de animales domésticos asilvestrados. Según la Dirección General de Caza del Gobierno Balear esta cabra ancestral se encuentra actualmente aislada en varios cotos de las sierras mallorquinas de Tramuntana y Artá, donde se estima una población para el año 2014 de unos 1.030 individuos en poblaciones controladas.

Esta situación ha impulsado un ambicioso plan de conservación promovido por la misma Dirección General de Caza y la Conselleria de Medi Ambient del Gobierno Balear (Decreto 91/2006 del Gobierno Balear), y continuado en la actualidad por el Departament de Medi Ambient del Consell de Mallorca. Por otro lado existen movimientos en contra de la proliferación de cabras en la sierra, argumentando una degradación de la vegetación y el suelo y suponiendo un daño mayor al causado por edificaciones o incendios (Mayol, 2013).

En la actualidad, grupos defensores de la Cabra Salvaje Mallorquina apuntan que esta cabra se ha ido mezclando con la cabra doméstica en los últimos siglos provocando dos efectos dañinos: por un lado, la proliferación de individuos asilvestrados sin un depredador natural que los controle; y por otro, la creación de híbridos que hacen peligrar la especie autóctona. Para intentar solventar este problema nació la Asociación de Caza Mayor y Preservación de la Cabra, compuesta por cazadores que, realizan descastes eliminando a los ejemplares híbridos. En el año 2006 esta asociación cazó en doce fincas públicas (6.200 hectáreas), con un total de 126 jornadas y 2.229 observaciones totales (con un 27 por ciento de animales finos), disparando 1.326 tiros y consiguiendo un total de 868 abatimientos de ejemplares híbridos (Lapena, 2009).

Ante esta situación organizaciones como la *Associació de caçadors de cabrits amb cans i llaç* (Asociación de cazadores de cabritos con perros y lazo) exhortan al Govern balear a detener la eliminación sistemática de la población de cabra salvaje mallorquina fuera de los cotos. Asimismo, abogan para establecer convenios de colaboración entre la Conselleria de Medio Ambiente y dicha asociación a fin de que con el método tradicional de perros y lazo, se controle, sin coste económico para la administración, la población de Cabra Mallorquina Salvaje. Por otra parte este grupo sugiere incorporar en la normativa que regula las zonas protegidas, aquellas modificaciones que permitan esta actividad de gestión de población caprina autóctona, así como la actividad de aventura de la captura sin muerte, y liberación posterior, de los adultos (machos cabríos) con fin comercial (comentario personal del presidente de la asociación).

En este sentido se aprecia en la literatura que la cabra lleva miles de años ocupando espacios naturales, por lo que formaría parte de un equilibrio ecológico en el que tendría un papel en el control de fuego, la activación de semillas, la fertilización, o el control de ciertas especies vegetales (Martínez Martínez *et al.* en prensa). Sin embargo, la sobrepoblaciones podrían llegar a ser perniciosas por su efecto de sobrepastoreo (Parkes *et al.*, 2002; Orueta, 2003; Campbell and Donlan, 2005; Vilà *et al.*, 2006). El caso de la vegetación de las Baleares mayores, modelada bajo la presión del *Myotragus* durante el Cuaternario, y posteriormente por las cabras, constituye un ejemplo de especies introducidas desde tiempos antiguos que han evolucionado en las islas hasta generar "neoendemismos" de valor genético, que pueden tener valor cultural o aprecio social (Orueta, 2003).

En este sentido, surge la necesidad de desarrollar normas en base a la realidad actual, las cuales se tendrían que basar en estudios que analicen la ecología trófica de esta especie para una ordenación de la caza apropiada, ajuste de cargas ganaderas, y control de la presión de ramoneo sobre la vegetación.

Cabra domestica asilvestrada (*Capra hircus*)

La cabra doméstica (*Capra hircus*) es una especie extendida por todo el mundo. Tradicionalmente se le considera una especie domesticada hace unos 10.000 años a partir de ejemplares de *Capra aegagrus* Erxleben, 1777 (Fernández *et al.*, 2006), aspecto que se ha comprobado recientemente mediante técnicas moleculares (Naderi *et al.*, 2008). Tiene una fuerte tendencia a formar colonias salvajes, lo que unido a su gran fertilidad y a su gran adaptación al medio (Parkes *et al.*, 1996), la convierte en una especie potencialmente invasora (Orueta, 2003).

En tiempos más recientes, fueron introducidas a la isla de Mallorca, razas ganaderas que con el posterior abandono de la actividad ganadera, en los años 1950-60 (Vives and Mas, 2014) de forma accidental o intencionada fueron liberadas, estas cabras domésticas acabaron hibridándose con las cabras salvajes locales (Seguí *et al.*, 2005). La población de la cabra doméstica asilvestrada presente en la Serra de Tramuntana no es homogénea genéticamente (Seguí *et al.*, 2005). Son animales relativamente gregarios, las hembras suelen ir con las crías separadas de los machos. Tienen rangos vitales bastante pequeños en torno a 1 km^2, aunque los de los machos son mayores que los de las hembras (Parkes et al., 1996). La fenología de los partos varía mucho en función de las localidades, desde poblaciones con partos a lo largo de todo el año, a patrones de dos o cuatro eventos anuales o a una única estación de partos (Parkes, 1984). Las hembras se pueden reproducir durante su primer año de vida y volver a quedar preñadas poco después del parto, ya que la lactancia no interrumpe el estro, por lo que cada hembra suele dar a luz entre uno y dos cabritos al año (Frau, 2011).

Existe poca información sobre esta cabra asilvestrada en Mallorca. Vives y Baraza (2010) realizaron un análisis sobre la situación de esta cabra en la isla y mencionan que ambas poblaciones, salvajes (*C. aegagrus* [hircus] ssp) y asilvestradas (*C. hircus*), constituyen un recurso cinegético. La explotación de la cabra, que vivía libre en la sierra, como recurso cinegético es muy antigua (Payeras and J., 1998; Seguí *et al.*, 2005). De hecho, todavía hoy se conservan prácticas cinegéticas ancestrales como la modalidad antes mencionada para la cabra salvaje de “ca i llaç”, una técnica de captura en vivo absolutamente selectiva (Seguí et al. 2005). De este modo, las cabras son un recurso cinegético que puede aportar rentas a los propietarios de unas fincas que sin ellas no podrían mantenerlas.

Sin embargo el modelo de gestión es muy diferente en función de si se trata de cabras asilvestradas o Cabras Salvajes Mallorquinas. De la cabra asilvestrada se aprovechan básicamente los cabritos, que se destinan al autoconsumo y además se han promovido campañas de erradicación. Bajo este sistema, no existe aliciente económico y los controles administrativos son prácticamente nulos; por lo que la población está sesgada hacia las hembras reproductoras. Según las estimaciones de la *Conselleria de Medi Ambient* para el periodo 2006-2009, la población de cabras asilvestradas en Mallorca se estructura en un 26% de machos, un 52% de hembras y el 22% restante, cabritos.

Desde el año 2006, se realizan continuos programas de descaste en la sierra Tramuntana y Llevant, tanto por la conselleria de Medio Ambiente como a nivel particular en los cotos privados de caza, que abaten un mínimo de 3.500 ejemplares al año, sin embargo, las poblaciones de cabras asilvestradas hoy en día prevalecen y su censo es difícil de estimar. En 2010, la Conselleria de Medio Ambiente, a través de agentes forestales, cazadores voluntarios y otros colaboradores, abatió a un total de 735 cabras en fincas públicas. Sólo en el parque natural del Llevant se cazaron 300 ejemplares, de los cuales más de la mitad fueron hembras y el resto cabritos y machos cabríos. Durante los tres primeros meses de 2011 realizaron 150 capturas. A los casi 900 ejemplares capturados durante todo el año 2010 y parte de 2011 por el Govern en las fincas públicas de la Tramuntana y el Llevant, se sumaron los individuos abatidos en las fincas privadas, en cotos de caza mayor y menor que efectúan aprovechamiento cinegético. El ejecutivo calcula que en las campañas de descaste en estas fincas se abaten entre 2.500 y 4.500 cabras al año. Además, el Consell también organiza actividades de descaste en sus fincas, abatiendo entre 100 y 200 ejemplares anuales (Frau, 2011).

Después del pasado incendio en Julio de 2012 que arrasó con 2.335 hectáreas de la sierra Tramuntana, se comenzó con una eliminación radical de cabras asilvestradas, con el argumento de que éstas impedirían la regeneración vegetal de las zonas quemadas. Hasta la fecha no se conoce información precisa del numero de cabras exterminadas pero la asociación de cazadores estima que son más de un millar (comentario personal).

Son muchas las opiniones sobre la situación de la cabra asilvestrada en la isla y a pesar de no existir estudios científicos que avalen el daño sobre la vegetación, en la prensa local suelen aparecer como principal causa de erosión y deforestación, arrasando la flora endémica y amenazando seriamente el desarrollo de las plantas reforestadas en fincas afectadas por incendios (Serra, 2013; Sansó, 2013). Las recomendaciones casi siempre van en la dirección de disminuir las poblaciones de cabras asilvestradas y potenciar la Cabra Salvaje Malorquina con la reintroducción de ejemplares puros.

En suma, en la isla se dan una serie de circunstancias que dotan al debate sobre la gestión de la cabra asilvestrada, de una especial transcendencia. Por una parte, la vegetación está adaptada a la herbivoría, no sólo por tratarse de vegetación típicamente mediterránea, lo cual ya es en principio garantía de cierto grado de adaptación (Perevolotsky, 1994); sino porque además efectivamente la vegetación local ha evolucionado y ha estado históricamente en contacto con grandes herbívoros (Alcover *et al.*, 1999). Por otra parte, la existencia de poblaciones de cabras recientemente asilvestradas, en interacción con poblaciones caprinas autóctonas de introducción ancestral, introduce el debate sobre la necesidad de erradicar a las primeras, para evitar la hibridación que pondría en peligro la conservación de las segundas (Seguí *et al.*, 2005). Los pocos estudios que comparan ambos ecotipos describen un comportamiento social muy similar entre las poblaciones salvajes y asilvestradas (Shackleton y Shank, 1984). No existen estudios que los comparen desde el punto de vista de la ecología trófica.

ECOLOGÍA TRÓFICA DE CABRAS

Selección de dieta

Son muchos los estudios de que se han realizado sobre los efectos negativos de los grandes herbívoros en las especies vegetales, especialmente en ecosistemas insulares (p.e. Coblentz 1978; Parkes 1990; Parkes, Macdonald & Leaman 2002; Forsyth *et al.* 2003). Los caprinos han sido clasificados como una especie con hábitos alimenticios intermedios, adaptados tanto al pastoreo como al ramoneo, exhibiendo cambios en la selectividad de la dieta en función de la disponibilidad de forraje, su valor nutritivo y de la estación (Van Soest *et al.*, 1991; Papachristou, 1997; Osoro *et al.*, 2013). Pero cuando se introducen en islas sin grandes herbívoros suelen aparecer como generalistas o oportunistas que concentran su alimentación en las especies más palatables y abundantes hasta poner en riesgo su supervivencia (Coblentz, 1978). Comparados con otros rumiantes domésticos, los caprinos seleccionan las partes y porciones más nutritivas de las plantas, y en una selección dada entre gramíneas, hierbas y arbustos, suelen preferir los arbustos (Basha *et al.*, 2012; Osoro *et al.*, 2013). Son muchos los trabajos que muestran una mayor cantidad de especies leñosas en la dieta (p.e. Barroso *et al.*, 1995; Bartolomé *et al.*, 1998; Aldezabal and Garin, 2000). En ciertas circunstancias, sin embargo, el componente de hierba puede llegar al 80% o más (Luginbuhl and Pietrosemoli Castagni, 2007). Mas aun, debido a esta versatilidad, los caprinos son capaces de controlar especies invasoras, mientras que al mismo tiempo seleccionan una dieta capaz de satisfacer sus requerimientos nutricionales (Jáuregui *et al.*, 2009).

El efecto del herbivorísmo puede incluso ser positivo para la dispersión de semillas en muchas especies (Malo and Suárez, 1996), y se ha documentado en diversos hábitats mediterráneos, como dehesas (Malo and Suárez, 1995), jarales (Malo and Suárez, 1996), o estepas semiáridas (Cerván and Pardo, 1997). No obstante, la elevada presión de herbivoría puede representar una limitación para la regeneración natural de muchas especies leñosas arbóreas y arbustivas, especialmente las más palatables y que no tienen capacidad de rebrotar (Charco, 2002). Este problema afecta especialmente a muchas plantas endémicas (Zamora *et al.*, 1996). Por esas razones, el conocimiento de las relaciones que existen entre fitófagos y la vegetación es esencial para la gestión racional del medio ambiente natural y la conservación de la biodiversidad y los paisajes (Andersson *et al.*, 2000; Vera, 2000; Pedroli *et al.*, 2007).

La disponibilidad de alimento en las áreas mediterráneas, suele decrecer en los periodos de invierno y verano. En invierno por la disminución de vegetación herbácea y la perdida de hojas en las leñosas caducifolias (Charco, 2002; Galmes, J., Conesa, M.A., Cifre. J ., Gulías .J.Medrano.H., 2010). El verano también suele ser una estación crítica debido a que el material herbáceo (principalmente gramíneas) incrementa el contenido de componentes de la pared celular, disminuyendo su digestibilidad (Martínez, 1994).

Según la teoría conocida como *Optimal Foraging Theory*, enunciada por primera vez por McArthur y Pianka (1966), los animales consumen todo lo que les permite su capacidad de ingestión, pero para conseguirlo eligen aquellos alimentos que satisfacen de forma óptima sus necesidades nutritivas. Incluso, como ponen de manifiesto investigaciones más recientes (Provenza, 2003; Provenza *et al.*, 2003), son capaces de "aprender" a ingerir cantidades moderadas de alimentos con diversas toxinas, tanto de forma directa como inducida por el hombre. De ahí el interés que siempre ha habido en la comunidad científica por comprender los hábitos de selección de dieta de las diferentes especies animales. Se trata de comprender cómo cambia la dieta al variar la disponibilidad de alimentos en el medio, el estado fisiológico del animal, la competencia con otras especies o cualquier otro elemento o proceso del sistema (Fernández-Olalla and San Miguel Ayanz, 2007).

Los "*alimentos preferidos*" son aquellos que son proporcionalmente más abundantes en la dieta de un animal que en el medio donde se alimenta. Análogamente, cuando un alimento es menos abundante en la dieta de un animal que en su entorno se dice que es un "*alimento rechazado*". Si la proporción es igual a la unidad, se afirma que el fitófago no muestra ni preferencia ni rechazo por esa planta, es decir, que se trata de un "*alimento indiferente*" (Petrides, 1975).

Se sabe que son numerosos los factores que afectan la preferencia relativa de los alimentos. Heady (1964) propone cinco grupos de factores influyentes en la preferencia mostrada por los animales: a) la palatabilidad de las especies vegetales; b) sus especies acompañantes; c) el clima, el suelo y la topografía; d) el tipo de animal y, por último, d) su estado fisiológico. Ellis *et al.* (1976) mencionan que la preferencia depende del tamaño y forma de la planta, de su contenido nutricional, de su novedad con relación con otros recursos presentes, del estado reproductivo y fisiológico del consumidor y de la temperatura y humedad del medio.

Con el fin de cuantificar el grado de preferencia por un alimento han surgido una serie de algoritmos denominados índices de selección, en que comparan la utilización de un recurso con su disponibilidad en el entorno. Fernández-Olalla y San Miguel Ayanz (2007) hacen una descripción de los conceptos que contemplan los índices de selección (abundancia, disponibilidad,

disponibilidad relativa, consumo y consumo relativo) y donde detalla el proceso general a seguir en cualquier estudio de selección de dieta el cual se puede resumir en la Figura 1.

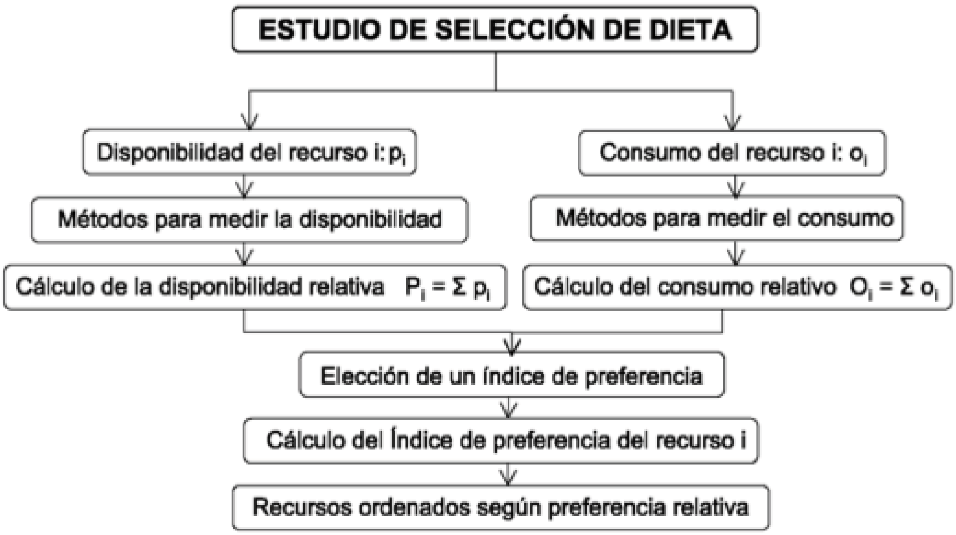

Figura 1. Protocolo para el estudio de la selección de dieta (tomado de Fernández-Olalla and San Miguel Ayanz, 2007).

Existen diversos índices de selección (p.e. Ivlev, Savage, Scott, etc.), aunque muchos de ellos son modificaciones sucesivas de los anteriores (p.e. Jacobs). Manly *et al.* (1993) hacen una revisión del problema de la selección de recursos por parte de los animales y una discusión estadística pormenorizada de los problemas derivados de la medición de las preferencias.

Algunos de los principales problemas en la gestión de ungulados salvajes son los relacionados con la determinación de la carga admisible y la minimización de los daños producidos sobre la vegetación (Orueta, 2003). Los ungulados de interés cinegético son fundamentalmente herbívoros, y si la hierba es escasa o de baja calidad llegan a ramonear intensamente (Caballero, 1985; Rodríguez y Molerá, 1985; Alvarez y Ramos, 1991, 1992; Alvarez et al., 1991). Así, si las cargas son altas y los periodos de bache alimenticio prolongados, el efecto del ramoneo llega a impedir la regeneración de la vegetación leñosa (y con ello su persistencia a medio plazo) y pueden producir fuertes degradaciones en sus especies más palatables (Soriguer, 1988; Gallego et al., 1993; San Miguel et al., 1994).

Defensa de la vegetación

Conocer la dieta de las cabras es necesaria para conocer cómo funciona el sistema, sin embargo, no resulta suficiente, porque también hace falta saber cómo van a reaccionar las plantas o comunidades vegetales a ese consumo y, en definitiva, cuál va a ser el efecto de estos fitófagos sobre ellas (Schowalter, 198l). La capacidad de tolerar la herbivoría puede ser el resultado de diversas respuestas de las plantas y su historial.

La tolerancia de las plantas a la herbivoría refleja el grado en que una planta puede volver a crecer y reproducirse después del daño de los herbívoros (Zamora *et al.*, 2004). Factores autoecológicos, así como la influencia de los competidores y mutualistas, afectan el nivel de tolerancia de la planta (Traveset, 2002). Las plantas pueden compensar la pérdida de hojas por el ramoneo incrementando la tasa fotosintética en las hojas que quedan. Sin embargo, pueden verse afectadas negativamente por la pérdida de nutrientes, según la edad y los tejidos que hayan sido extraídos (Escorcia, 2008).

El ramoneo moderado, incluso en la vegetación de un bosque, puede constituir un efecto estimulante, induciendo un aumento de la producción de biomasa, aunque a costa de una pérdida de vigor y de nutrientes almacenados en las raíces. El grado de estimulación depende del tipo de planta, de la disponibilidad de nutrientes y de la humedad (Dyer *et al.*, 1993). Además, el ramoneo también hace aumentar la intensidad de luz que llega a las hojas jóvenes de las capas inferiores, entre otros efectos beneficiosos (Zamora *et al.*, 2004).

La vegetación en la isla de Mallorca ha estado sometida a presión de ramoneo desde tiempos inmemoriales, incluso desde antes de la llegada del hombre a la isla, por lo que la vegetación muy seguramente ha evolucionado en la presencia de grandes herbívoros y desarrollado mecanismos de defensa que le han permitido permanecer en la vegetación.

Comportamiento social y trófico

El comportamiento alimentario de las cabras al pastoreo se puede definir como la relación entre la sensación de satisfacción producida por la ingestión de la comida y las sensaciones proporcionadas por cada componente de la ración una vez ingerido en el organismo (Ganskopp, 1995). Una de las ventajas adaptativas del ganado caprino es la capacidad de bipedestación, que consiste en poder incorporarse apoyándose solamente con los miembros posteriores, permitiéndoles buscar brotes en las ramas de árboles y arbustos a una altura de hasta 2 metros, pero este comportamiento se suspende a favor de retomar el pastoreo horizontal cuando los brotes de hojas ya se han agotado (Call *et al.*, 2006). La prensión de éstos la llevan a cabo con los labios (principalmente el superior, el cual puede obturar con facilidad) y los dientes incisivos. Las cabras prefieren ingerir alimentos que se coman rápidamente, así que la cantidad tomada en cada bocado es de unos 4 g para la hierba y unos 2 g para las plantas seleccionadas en el pastoreo selectivo. En el caso de plantas con espinas, la cabra no arranca los brotes que más le gustan sino los que puede (Nastis, 1994).

Se ha calculado que el ganado caprino en pastoreo puede destinar a esta actividad de 7 a 10 horas diarias, haciéndolo con mayor intensidad al amanecer y al anochecer y de menor intensidad a media mañana y en la tarde, además de poder recorrer diariamente distancias para tal efecto de hasta 10 km (Arnold and Dudzinski, 1978). La actividad típica del pastoreo comprende movimientos de avance con interrupciones, que puede dividirse en dos tipos de acciones: las alimentaciones y los intervalos de movimientos entre alimentaciones. El animal avanza con movimientos sistemáticos hacia la derecha e izquierda mientras se realiza el pastoreo que puede ser interrumpido para dar lugar a una búsqueda visual del forraje deseado o por otros factores de perturbación siendo éstas interrupciones más largas en los momentos de inicio y final de la actividad (Ganskopp, 1995 ; Vallentine, 2001).

Diferentes actividades como el pastoreo, rumia, descanso, caminar y beber agua se desarrollan en permanente transición a lo largo del día, vinculado con el mantenimiento y supervivencia del animal (Arnold et al., 1978). Éstas actividades suceden en períodos alternados en el día, existiendo diferencias en la duración, intensidad y desarrollo, dependiendo de las condiciones extrínsecas e intrínsecas del animal (Hodgson, 1981).

Existe diferencias en el comportamiento del pastoreo de los animales dependiendo de la especie y raza, la condición fisiológica, y el tipo de organización social en la cual están inmersos los individuos dentro del hato, afectándose por éstas causas el tiempo utilizado en el ramoneo (Arnold et al., 1978).

Para cada uno de los individuos de un rebaño caprino existe un espacio individual o vital, que es el área donde se encuentra y que necesita para realizar actividades básicas en relación a su mantenimiento y subsistencia. Este espacio depende de su posición social al interior del rebaño, y está caracterizado por ser la distancia mínima que se establece entre el individuo y los demás miembros del grupo. Existe sociabilidad en el pastoreo donde el comportamiento de los animales de igual especie es afectado por un conflicto entre actividades individuales y grupales. En un grupo el comportamiento es gobernado por el deseo gregario existiendo un lazo social de deseo de realizar el pastoreo con sus iguales y por otro lado existe una facilitación social donde se imita las actividades de los iguales, existiendo un aumento en el tiempo dedicado al pastoreo en grupo en relación a los animales cuando pastorean solos (Arnold and Dudzinski, 1978; Vallentine, 2001).

El efecto gregario determinaría que los animales pastoreen en las mismas áreas y durante los mismos períodos diurnos lo cual lleva a determinar tasas de ingestión semejantes de pastoreo entre los individuos de un mismo hato, llevando a la formación de hábitos de pastoreo (Vallentine, 2001 ; Wilson, 1969). La iniciación de movimientos en un hato son realizados por animales menos gregarios y más independientes, que generalmente pastorean a espaldas de los otros animales o más alejados de éstos (Vallentine, 2001).

El conocimiento del comportamiento y sus efectos, sobre la población de la Cabra Salvaje Mallorquina como sobre la cabra domestica asilvestrada, puede ser de gran utilidad para el seguimiento continuo que permita aportar soluciones para la gestión de ambas cabras. Diversos autores concuerdan que el comportamiento y los hábitos de alimentación de cabras salvajes y asilvestradas son muy similares (p.e. Shackleton & Shank 1984; García-González & Cuartas 1989; Mancilla-Leytón *et al.* 2013), por lo que el estudio de estas cabras podría ser muy similar.

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OBJETIVOS

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Dado que la dieta de *Myotragus* del yacimiento de Cova Estreta se basaba en un elevado consumo de boj balear, aunque no de forma exclusiva, este podría ser de gran utilidad para encontrar posibles evidencias del cambio climático, ya que este arbusto todavía existe en la isla y sus epidermis se han conservado en los coprolitos de *Myotragus*. Trabajos anteriores sobre selección de dieta por cabras salvajes y asilvestradas muestran un espectro botánico muy amplio, que cabría esperar tanto en la Cabra Salvaje Mallorquina como en la doméstica asilvestrada (Parkes, 1984; García-González and Cuartas, 1989; Sfougaris *et al.*, 1996; Aldezabal and Garin, 2000). Por otro lado, estudios recientes sobre ecología trófica de diversos herbívoros en simpatría muestran cómo las dietas son parecidas entre las especies más próximas filogenéticamente (Miranda *et al.*, 2009). Otros estudios mencionan similitudes entre cabras salvajes y domesticas en la estructura social de los rebaños (Shackleton and Shank, 1984). Esto permite suponer que entre la cabra doméstica y la salvaje la similitud será muy grande y la competencia por los recursos también. Hasta el momento no se conocen trabajos previos sobre la selección de la dieta de la Cabra Salvaje Mallorquina, sus efectos sobre la vegetación, ni sobre la competencia con la cabra doméstica asilvestrada, ni del comportamiento social y trófico.

Por lo tanto, el **objetivo general de esta tesis es:**

Caracterizar y comparar la composición botánica de la dieta de la Cabra Salvaje Mallorquina y la cabra doméstica asilvestrada en Mallorca, así como del grado del ramoneo sobre los principales componentes de la vegetación y el uso del hábitat realizado por ambas cabras para indagar sobre posibles diferencias de estructura social y de comportamiento que ayuden a dilucidar el nivel de uso de los recursos, así como encontrar posibles evidencias del cambio climático en la dieta del extinto Myotragus balearicus.

Estos aspectos se han abordado en seis zonas habitadas por estos ungulados en la sierra Tramuntana en la isla de Mallorca. De las seis áreas, tres de ellas están ocupadas por la cabra domestica asilvestrada, donde se realizan descastes para control poblacional. Otras tres están ocupadas por la Cabra Salvaje Mallorquina, de estas últimas, dos son cotos de caza, Formentor y La Victoria y el tercero, Bunyola, es una finca donde la caza sólo se emplea para controlar las incursiones de cabras domésticas asilvestradas pero no con interés comercial. Las cabras salvajes sobreviven todo el año con los recursos de las fincas, sin ningún tipo de suplementación alimentaria, pero sometidos a control de enfermedades.

Este objetivo general puede desglosarse en una serie de objetivos específicos que se detallaran a continuación:

Objetivos específicos

1. Determinar las preferencias alimentarías de la Cabra Salvaje Mallorquina y la cabra domestica asilvestrada **(Capítulo 1)**.

2. Estimar la disponibilidad de alimento y el uso de los diferentes hábitats que ocupa la Cabra Salvaje Mallorquina y la cabra domestica asilvestrada **(Capítulo 2**).

3. Evaluar el impacto del ramoneo sobre los principales componentes de la vegetación y sobre las especies singulares en particular **(Capítulo 2)**.

4. Analizar de forma comparativa la estructura social y el comportamiento trófico de la Cabra Salvaje Mallorquina y la cabra doméstica asilvestrada **(Capítulo 3)**.

5. Detectar posibles manifestaciones de cambio climático a partir de comparaciones sobre la densidad de estomas en las epidermis de especies vegetales actuales que también aparezcan en la dieta de Myotragus (*Buxus balearica*) **(Capítulo 4)**.

En el objetivo 4, se analiza una posible manifestación del cambio climático a partir de la especie que formó parte de la dieta del extinto Myotragus, (*Buxus* sp.). El nicho de *Myotragus* ahora lo ocuparían las cabras tanto salvajes como domesticas, las cuales continuarían ejerciendo una presión de ramoneo (objetivo 2) sobre las distintas especies, sobretodo arbustivas, del matorral mediteráneo. La composición botánica de la dieta de cabras salvajes y asilvestradas nos indicaría la similitud entre ambas dietas (objetivo1) y de una posible competencia por los recursos. Según la bibliografía el comportamiento trófico de cabras salvajes y asilvestradas presenta grandes similitudes, por lo que se esperaría observar encontrar un alto grado de similitud en los dos ecotipos de cabras (objetivo 3). Esto ayudaría a tomar decisiones en cuanto a la gestión de estas cabras en la isla.

Capitulo 1

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Diet selection of wild and feral goats in the Mediterranean island of Mallorca

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Diet selection of wild and feral goats in the Mediterranean island of Mallorca.

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Abstract

Goats were probably the first domesticated ungulate introduced widely by the early settlers of the islands. The Mallorcan Wild Goat was probably introduced in the island during the first human colonization, more than four thousand years ago who would probably have taken the trophic niche of *Myotragus balearicus* and coexisted with the vegetation of the island and with domestic herds introduced by modern man. The deterioration of traditional livestock during the last decades has led to the proliferation of feral domestic goat herds likely compete with wild goats for food resources and threaten not only their survival but also of some plant species. Both goats are considered the cause of many problems, including damage to reforestation, plantations, crops and endemic species. The study was conducted in six areas in the Serra de Tramuntana, three of them are occupied by feral goats and the others by Mallorcan wild goats. The vegetation availability was determined by measuring the cover, of the major abundance species. The botanical composition of the diet was determined by microhistological analysis of feces, during three seasons of the year (spring, summer and winter) for two consecutive years in each area. Kulzynski's similarity index has been employed to compare both goat diets. The Savage index was used to calculate foraging preferences of wild and feral goats, for each plant specie in each area and season. *Ampelodesmos mauritanica* was clearly the dominant species in all places, ranging from 39 to 45 % of relative plant cover. A total of 22 plant species were identified in the feces of goats. Mostly they were woody dicots. The major species were *A. mauritanica* (12 to 16%) and *O. europaea* (11 to 14%). Diet composition between feral and wild goats was very similar. *O. europaea* was clearly the most preferred species, and *A. mauritanicus* and *P. lentiscus* the most refused. Species significantly more preferred by feral goats than wild goats were E. multiflora and *P. angustifolia* and species more preferred by wild goats than feral goats were

Cistus sp. and *P. halepensis*. Both Wild Mallorcan goat as feral domestic goats showed a intermediate diet selective. Goats showed clear preferences and rejections that were maintained throughout the year. However they are also able to adapt to availability. Nonetheless, some differences in diet that might suggest that the wild goat has a better adaptation to certain plant species, possibly because it has habited the island by long time before than feral goat.

Introduction

Ecosystems of the Mediterranean basin have been intensively modified by human activity since Neolithic times. Especially the Mediterranean islands have suffered a radical change in their biodiversity. Extinction of endemic mammals has been reported in numerous islands (Masseti, 2009). Today, the fauna of these islands is characterized by continental generalist mammals. In the case of wild ungulates, all of them came from feral domestic animals or continental game introduced in Neolithic or later (Schule, 2012). Goats were probably the first domesticated ungulate introduced widely by the early settlers of the islands. They are considered animals extremely generalists with the potential of feral existence and their introduction on islands have had severe effects on their flora and fauna (Coblentz, 1978; Giourga *et al.*, 1998; Pafilis *et al.*, 2013). But some islands have acted as a refuge of these ancient goats that today are considered subspecies or ecotypes still of high genetic purity related with the goat ancestor (*Capra aegagrus*). That is the case of Cretan wild goat (*Capra aegagrus cretica*) or Mallorcan wild goat (*Capra hircus* [*aegagrus*]). Nowadays, most of these animals survive on the islands thanks to protective measures (Masseti, 2009) mainly focused to prevent hybridization with more recent goat introductions that had led to new populations of feral goats (Sfougaris *et al.*, 1996; Seguí *et al.*, 2005).

On the other hand, vegetation in many Mediterranean islands had evolved with endemic herbivorous mammals before the arrival of man, such as *Mammuthus lamarmorae* in Sardinia, several species of dwarf elephants (*Elephas sp.)* in different islands, *Cervus cretensis*, in Crete, *Cervus astylodon* in Ryukyu, *Phanorius minutus* in Chipre and *Myotragus balearicus* in Mallorca and Minorca (Burleigh and Clutton-Brock, 1980; Bover *et al.*, 2008; Schule, 2012). The vegetation of these islands would be adapted to grazing by large herbivores so the introduction of goats could be supported better than on islands where there was never herbivorous mammals. In addition, modifications on plant communities and landscapes by humans during the Holocene have led to resilient Mediterranean ecosystems which in some cases provided stability, while fostering diversity and productivity (Seligman y Pervolotsky, 1994; Blondel, 2006).

The Mallorcan Wild Goat was probably introduced in the island during the first human colonization, more than four thousand years ago (Alcover, 2008) who would probably have taken the trophic niche of *Myotragus balearicus* and coexisted with the vegetation of the island and with domestic herds introduced by modern man (Seguí *et al.*, 2005). During this process, the wild goat would have adapted to Mediterranean vegetation provided with chemical and physical defenses and also to abrupt habitat no accessible to livestock. The deterioration of traditional livestock during the last decades has led to the proliferation of feral domestic goat herds likely compete with wild goats for food resources and threaten not only their survival but also of some plant species. Both goats are considered the cause of many problems, including damage to reforestation, plantations, crops and endemic species (Mayol, 2013). About the impact over endemic species is remarkable the results of Botey (2005) about *Naufraga balearica* in Mallorca, a supposed sensitive species to herbivorism, which population decreased due to the grass competition when it was fenced in order to prevent the herbivore damage. All thes arguments have generated an intense social debate on goat management (Vives and Baraza, 2010).

It is known that goats recently introduced in oceanic islands include a lot of species in their diets, mainly woody species, but only few species formed the bulk of the diet threatening its survival (Parkes, 1993; Chimera *et al.*, 1995) . But the trophic ecology of goats in Mediterranean islands with a large history of herbivory is not well known. In these islans, vegetation is dominated by woody species, mainly shrubs with a diversity of chemical, physical and spatial strategies to prevent browsing effects. That implies that patterns of diet selection are not regular in space or time (Edenius *et al.*, 2002) and differences in these chemical and physical defenses and species availability also influence the diet selection by herbivores (Illius *et al.*, 1999; Dziba *et al.*, 2003; Jansen *et al.*, 2007). In general evergreen browse is preferred as a source of fodder by goats even when more nutritious food is available (Landau *et al.*, 2002), and spiny species can also be selected, even more than non-spinescent (Basha *et al.*, 2012). In this context, one can expect that goats act as an intermediate feeder and not as a generalist, with preference and rejection for some species and indifference for some other but including most of available plants in their diets but none of them stand in excess.

The aim of this study was to know the botanical composition and preferences through the year by both goat ecotypes in Mallorca Island. Also the objective is to address the processes of insular adaptation and facilitate decision making for the conservation of current systems based on plant-herbivore relationship.

Material and methods

Study area

The study was conducted in six areas in the Serra de Tramuntana, a mountain range located in the north of the island of Mallorca. The mountain range has an approximate length of 90 km running southwest-northeast, with a surface of 800 km^2. The highest peak is the Puig Major, with 1.445 m a.s.l. (39° 48′ 27″ N. 2° 47′ 36″ E). The entire mountain range was listed as a World Heritage Site by UNESCO in 2011.

The climate is typically Mediterranean, with two rainy seasons (spring and fall), a hot dry summer and a dry winter not very cold. Spatial variation of rainfall is significant, with a maximum located around 1400-1600 mm per year in the central sector of the mountain, while driest points of the coast did not exceed the 300-350mm. The annual average temperature ranges from 16 to 18 ºC in the lower parts of the mountain. The six areas considered are located in the lower part of the mountain range between 77 and 439 m.a.s.l. (Table 1).

Table 1. Description of study areas

Area name	Location	Altitude (m.a.s.l.)	Shrubland area (%)	Pine forest area (%)
Formentor	39°56.997" N 003°09.633"E	147	46	54
Victoria	39°51.860" N 003°09.694"E	89	60	40
Bunyola	39°41.696" N 002°42.692"E	439	9	91
Banyalbufar	39°41.079" N 002°32.275"E	393	2	98
Trapa	39°36.044" N 002°21.543"E	315	38	62
Sant Vicenç	39°55.540" N 003° 03.122"E	77	99	1

Animal management

In the Sierra de Tramuntana there are two types of goats. One is clearly a feral domestic goat, (*Capra hircus L.*) scattered throughout the mountain for decades. They are animals that show no racial standard. These animals are not subjected to any form of management, except for some sporadic attempts to control populations by the island authorities. The other would be an example of a new species or ecotypes obtained by returning some ancient domestic populations to wild status thousands of years ago. That has occurred with other goats and sheep that currently roam wild in other Mediterranean islands, like the mouflon or agrimi (Masseti, 2009; Seguí, 2014 in press). These goats have survived more or less isolated in some peninsulas of the island and have maintained a racial standard. These animals are considered as *Capra aegagrus* species by some authors because their wild status and morphological differences from other goat populations (Seguí y Payeras, 2002; Masseti, 2009), but some others argue that they are just feral populations of ancient domestic stocks and should be included in the domestic species *Capra hircus* (Giannatos et al., 2007). Currently is recognized by Safari Club International as Mallorcan wild goat or Balearean Boc and their populations and hunting activities are regulated by the Decree 91/2006 of Consell de Mallorca Government.

Of the six areas selected in this study, three of them are occupied by feral goats and the others by Mallorcan wild goats (Figure 1). Two of the latter, Formentor and La Victoria, are hunting estates and the third one, Bunyola is another estate where hunting is only employed to control the incursions of feral domestic goats but not with commercial interest. The wild goats survive year round with the resources of the estates, without any food supplementation but subjected to disease control. In both cases, wild and feral, the stocking rate was estimated from animal counting in each area and period and the information was contrasted with the owners of estates when it was possible.

Vegetation availability and microhistological analysis of feces

The vegetation availability was determined by measuring the cover (Cummings & Smith 2000), of the major abundance species along 5 transects of 20 m length placed in the respective habitats of each area and repeated three times a year during two consecutive years. Two habitats were defined according to physiognomic and botanical attributes: pine forest, mainly covered by Aleppo pine (*Pinus halepensis*), and shrubland, where the tree cover was absent. Available vegetation of both habitats was dominated by the perennial tussock grass *Ampelodesmos mauritanica* followed by several shrub species. such *Chamaerops humilis, Pistacia lentiscus* or *Cistus sp*, and (Rivas-Martínez *et al.*, 1992). The six areas studied contained both habitats but two of them, Bunyola and Banyalbufar where mostly covered by woodland and other, Sant Vicenç, mostly by shrubland (Table 1). The coverage area of each plant species and habitat was averaged to obtain a weighted mean.

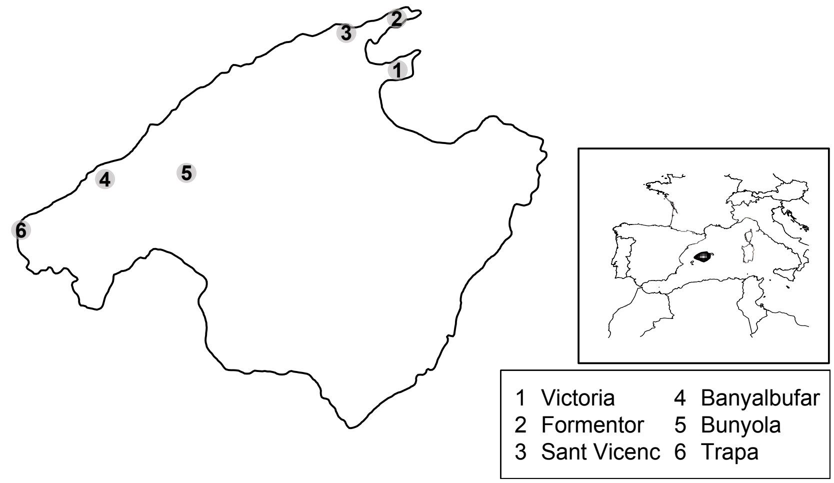

Figure 1. Areas of study.

The botanical composition of the diet was determined by microhistological analysis of feces (Stewart, 1967; Bartolomé *et al.*, 1995). This method has the advantage of allowing the collection of a representative sample of the plant species ingested by animals spread over a number of days without interfering with animal behaviour. Fresh fecal samples were collected in the field, taking into account they were moist, soft, with slimy skin shin and free of mold with different dung depositions deemed to originate from different individuals. Feces samples were collected during three seasons of the year (spring, summer and winter) for two consecutive years in each area. The sampled unit for diet analysis was a mixed group of feces (6-12 animals) of each area, season and year. These mixed samples were frozen at -20ºC until used for slide preparation. After thawing, the samples were water washed to remove possible adhered soil material and then lightly ground in a mortar to separate the epidermal fragments. From each sample, 10 g were placed in a test tube with 5 ml of 65% concentrated HNO_3. The test tubes were then boiled in a water bath for 1 minute. After digestion in HNO_3, the samples were diluted with 200 ml of water. This suspension was then passed through 1.00mm and 0.25mm filters. The 0.25 to 1.00mm fraction was spread on glass microscope slides in a 50% aqueous glycerine solution. Three slides were prepared from each sample. The slides were examined under a microscope at 100× to 400× magnifications by viewing 2mm wide and 60mm long traverses, with 3mm between traverses. Plant fragments were recorded and counted until 400 fragments of leaf epidermis were identified from each mixed sample. An epidermis collection of plant species of the area was used to identify epidermal fragments.

Similarity index

Kulzynski's similarity index (Gauch 1973) has been employed to compare both goat diets:

$$S.I.K = \frac{2\sum c}{\sum(a+b)} + 100$$

where c is the lesser percentage of a common plant species or taxon in the diet and ∑(a+b) is the sum of the percentages of all the species in the two diets.

Preference index

The Savage index (Manly *et al.*, 1993) was used to calculate foraging preferences of wild and feral goats, for each plant specie in each area and season. This index determines selectivity of a given resource by relating its use with its availability:

$$W = \frac{Oi}{\pi i}$$

Where, *Oi*, is the proportion of the sample of used resource units that are in category i and *πi,* the proportion of available resource units that are in category i.

The savage index varies from zero (maximum rejection) to infinite (maximum preference), where 1 is the value defining the selection expected by chance. The statistical significance of these index was tested by comparing the Savage statistic whit that corresponding to the critical value of freedom (Manly *et al.*, 1993):

$$Savage\ statistic = \frac{(Wi-1)^2}{se(Wi)^2}$$

The standard error of the index is:

$$se\ (Wi) = \sqrt{\frac{(1-\pi)}{u_t + \pi i}}$$

where u_t *is* the total number of used resource units sampled.

In order to evaluate differences between indices of selection of plant species, Savage index with the modification proposed by (Kautz and Van Dyne, 1978) was also calculated. This amended index allows obtaining preferential measures positive and negative, symmetrical with respect to zero, which allows an analysis of variance:

$$logWi = \frac{(Oi + 0.1)}{(\pi i + 0.1)}$$

Statistical analysis

In order to compare the dietary composition between both goats, all plant species were grouped into two vegetation types, herbaceous and shrubs. Because counts of fragments are not normally distributed (Shapiro test, p-value<0.01), values were transformed using logarithm plus one. Subsequent ANOVAs were used to determine the effect of animal ecotype and vegetation type on diet. Additionally to the similarity index, Spearman's rank order correlation coefficient was used to evaluate the correlations in diet composition between the pair of goats studied. To control the error produced by multiple comparisons in the Savage index, we used Bonferroni correction, to adjust the significance of the statistical test.

For common species in all areas, we compare the selection between plant species based on Kautz Preference Index using ANOVAs, considering the effects of season and goat type. Mean differences in the levels of the effects were estimated by Least Squares. All analyses were performed using procedures in (JMP 8.0 SAS Institute, 2008; R Development Core Team, 2011).

Results

Availability and diet composition

The seasonal plant availability for the different areas occupied by feral and wild goats are showed in Table 2.

Table 2. Mean values of availability of plant species in areas of Feral and Wild goats in each season in Serra Tramuntana

	Spring (%)		Summer (%)		Winter (%)	
Plant species	Wild	Feral	Wild	Feral	Wild	Feral
Ampelodesmos mauritanica	44,35 ± 10,14	40,58 ± 12,5	44,77 ± 11,03	39,67 ± 15,22	38,56 ± 18,08	41,82 ± 13,42
Anthyllis cytisoides	0,25 ± 0,17	1,05 ± 1,34	*	0,62 ± 0,68	*	2,07 ± 2,4
Arbutus unedo	*	4,23 ± 0,35	*	4,58 ± 2,34	*	0,66 ± 0,01
Asparagus sp	0,17 ± 0,1	*	0,07 ± 0,05	0,06 ± 0,02	0,05 ± 0.05	0,27 ± 0,34
Asphodelus aestivus	4,1 ± 3,2	4,32 ± 6,43	1,22 ± 0,94	0,9 ± 1,51	7,84 ± 4,64	4,08 ± 3,46
Astragalus balearicus	0,54 ± 0,69	-	0,19 ± 0,2	-	4,89 ± 0,50	-
Brachipodium retusum	12,89 ± 8,78	9,71 ± 10,59	9,11 ± 9,19	16,82 ± 17,32	11,56 ± 14,75	11,43 ± 10,12
Calicotome spinosa	1,1 ± 0,85	0,5 ± 0,53	3,19 ± 1,74	0,44 ± 0,45	0,77 ± 0,9	0,37 ± 0,37
Chamaerops humilis	5,96 ± 1,78	3,63 ± 3,26	6,44 ± 5,57	7,15 ± 7,7	6,4 ± 5,08	3,26 ± 3,25
Cistus sp	3,47 ± 2,2	6,98 ± 5,43	3,37 ± 2,88	8,22 ± 6,46	3,24 ± 2,83	7,37 ± 5,87
Cneorum tricoccum	0,25 ± 0,08	1,59 ± 2,18	0,36 ± 0,23	1,05 ± 0,89	0,2 ± 0,2	0,25 ± 0,27
Ephedra fragilis	*	-	*	-	*	-
Erica multiflora	7,3 ± 11,87	1,1 ± 1,1	4,73 ± 6,98	2,47 ± 3,56	3,3 ± 3,63	1,98 ± 2,59
Genista lucida	-	8,54 ± 6,68	-	8,5 ± 3,61	-	8,38 ± 3,49
Juniperus oxycedrus	2,38 ± 1,75	0,25 ± 0,24	2,1 ± 1,05	0,58 ± 0,36	1,85 ± 0,59	0,77 ± 0,06
Olea europaea	1,79 ± 1,76	0,54 ± 0,58	3,04 ± 2,69	0,9 ± 1,05	3,26 ± 4,58	0,99 ± 0,75
Phillyrea angustifolia	6,28 ± 7,28	0,85 ± 1,12	5,6 ± 7,53	0,12 ± 0,14	5,53 ± 7,96	0,68 ± 1,25
Pinus halepensis	1,99 ± 2,57	4,95 ± 4,62	0,58 ± 0,73	6,05 ± 5,73	0,59 ± 0,65	6,61 ± 4,7
Pistacia lentiscus	14,33 ± 4,24	19,25 ± 6,67	19,16 ± 6,67	13,4 ± 8,13	17,27 ± 7,06	11,53 ± 6,82
Quercus ilex	3,38 ± 1,05	1,53 ± 2,49	2,01 ± 2,23	0,33 ± 0,4	0,33 ± 0,33	0,15 ± 0,13
Rosmarinus officinalis	1,97 ± 3,61	2,46 ± 1,76	1,44 ± 2,07	1,97 ± 0,88	1,36 ± 1,37	1,95 ± 0,75
Smilax aspera	0,33 ± 0,68	0,26 ± 0,11	0,54 ± 1,1	0,19 ± 0,27	0,54 ± 0,59	0,22 ± 0,16

(*) Plant species no detected in transects but are present in the area

A. mauritanica was clearly the dominant species in all places, ranging from 39 to 45 % of relative plant cover. The second and third were *P. lentiscus* and the other grass *B. retusum* with 12 to 19% and 9 to 17 % of relative cover respectively. The rest of species did not reach 10% of relative plant cover. Two species, *A. balearicus* and *E. fragilis*, were not found in the areas occupied by feral goats and *G. lucida* was not recorded in wild goat areas.

A total of 22 plant species were identified in the feces of goats. Mostly they were woody dicots. Only three of them were herbaceous monocots, *Asphodelus aestivus* and the grasses *A. mauritanica* and *B. retusum*. There were significant differences between the woody and herbaceous fractions of the diet but not between animals (Figure 2).

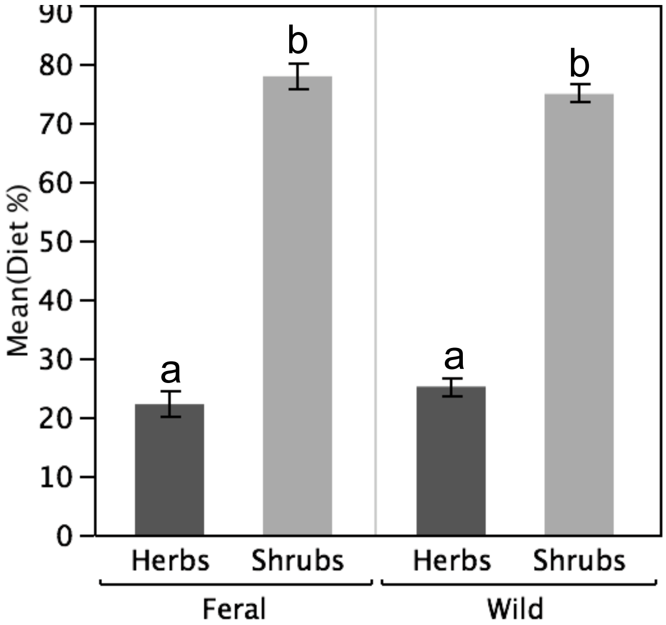

Figure 2. Content of herbaceous and shrubs plants in feces of goats. Different letters represent significant (p <0.05)

Three quarters of the identified fragments corresponded to woody species in both goat ecotypes. Tables 3 and 4 showed the percentages of epidermal fragments in feces for feral and wild goat respectively. In general, no species had very high values.

Table 3. Mean values of plant species found in the diets of feral goats in each season in Serra Tramuntana

	Feral goat		
Plant species	Spring (%)	Summer (%)	Winter (%)
Ampelodesmos mauritanica	13,53	12,90	11,90
Anthyllis cytisoides	6,60	4,16	3,71
Arbutus unedo	1,27	1,07	3,55
Asparagus sp	2,83	4,96	3,81
Asphodelus aestivus	2,16 a	0,48 b	0 b
Brachipodium retusum	5,99	7,06	5,87
Calicotome spinosa	6,39	5,02	7,04
Chamaerops humilis	1,63a	11,43b	2,74a
Cistus sp	8,30	9,48	10,58
Cneorum tricoccum	0,62	0,14	0,53
Erica multiflora	5,38	4,40	6,54
Genista lucida	6,11 a	6,47 a	10,92 b
Juniperus oxycedrus	5,97	2,02	1,50
Olea europaea	12,92	10,58	10,55
Phillyrea angustifolia	5,09	3,81	2,93
Pinus halepensis	1,63	0,87	0,53
Pistacia lentiscus	1,21	3,20	2,60
Quercus ilex	4,07	1,46	4,88
Rosmarinus officinalis	6,35	6,09	8,19
Smilax aspera	1,96	4,40	1,64

Different letters represent significant ($p < 0.05$)

The major species were *A. mauritanica* (12 to 16%) and *O. europaea* (11 to 14%). Other species reached sometimes values above 10%, such as *Cistus sp.*, *R. officinalis*, and *Ch. humilis.* Only *A. aestivus* showed significant differences between seasons in both goats, being consumed almost only in spring. Few others showed significant differences between seasons but they were different in both goat ecotypes. For feral goats, *G. lucida* was more consumed in winter than in the other seasons. For wild goats, *Ch. humilis*, *Asparagus* sp., and *P. halepensis* appeared more in summer, mainly the first one. No differences between seasons were detected in feral goats for these species.

Table 4. Mean values of plant species found in the diets of wild goats in each season in Serra Tramuntana.

	Wild goat		
Plant species	Spring (%)	Summer (%)	Winter (%)
Ampelodesmos mauritanica	11,96	13,79	15,94
Anthyllis cytisoides	1,07	1,15	0,86
Arbutus unedo	2,91	2,42	2,83
Asparagus sp	2,21 b	4,65 a	1,95 b
Asphodelus aestivus	2,12 a	0,25 ab	0 b
Astragalus balearicus	0,53	1,56	0,00
Brachipodium retusum	13,93	11,45	12,25
Calicotome spinosa	2,26	3,24	1,27
Chamaerops humilis	0,67 a	9,55 b	3,66 c
Cistus sp	10,21	8,03	13,68
Ephedra fragilis	2,12	2,05	2,36
Erica multiflora	4,29	5,72	3,01
Juniperus oxycedrus	0,53	2,12	1,40
Olea europaea	15,31	10,75	14,39
Phillyrea angustifolia	5,41	3,68	4,18
Pinus halepensis	0,47 a	2,55 b	2,70 b
Pistacia lentiscus	4,41	4,00	4,36
Quercus ilex	2,97	4,97	0,00
Rosmarinus officinalis	13,91	3,42	11,38
Smilax aspera	2,71	4,63	3,76

Different letters represent significant ($p < 0.05$)

Similarities and preferences

Diet composition between feral and wild goats was very similar (Table 5), with an SIK index ranging from 71% in spring to 80% in summer. Spearman correlation coefficients were also positive and significant for both goat ecotypes.

Table 5. Seasonal dietary Kulzynski's similarity index (SIK) among wild and feral goats and Spearman's rank correlation coefficients (rs).

	Season	SIK (%)	rs
Wild-Feral	Spring	70.97	0.6425**
	Summer	80.37	0.8336**
	Winter	74.30	0.5068*

Significant relationships are denoted with an asterisk (*) for $P < 0.05$ or two (**) for $P < 0.001$.

The Savage preference index (W) and its statistic associated showed a significant preference or rejection for all plant species considered (Table 6), that is, the nine common species in all study areas, seasons and diet. The Kautz correction of Savage index allowed detecting significant differences between species. *O. europaea* was clearly the most preferred species, and *A. mauritanicus* and *P. lentiscus* the most refused. Despite the other species were also statistically preferred or refused, the values close to zero probably should be included in a range of indifference.

Table 6. Savage preference index (W) and Kautz corrected index of the average value for plant species that were present in all study areas, all seasons and both goat diets.

Plant species	W	Selection	Kautz
Olea europaea	9.80*	+	0.7 a
Cistus sp	2.47*	+	0.33 b
Smilax aspera	9.79*	+	0.25 bc
Erica multiflora	2.00*	+	0.19 bc
Phyllirea angustifolia	1.44*	+	0.13 cd
Chamaerops humilis	1.32*	+	0.02 de
Pinus halepensis	0.46*	-	-0.09 e
Pistacia lentiscus	0.29*	-	-0.59 f
Ampelodesmos mauritanica	0.44*	-	-0.69 f

Significant preference or rejection according to Savage statistic is denoted with an asterisk (*) after Bonferroni correction (Chi square critical value 9.31). (+) indicates preference and (-) rejection. Different letters indicates significant differences between plant species ($P<0.05$).

Table 7 shows the comparison between preferences of both goat ecotypes. In the case of feral goats all species were significantly preferred or refused, while in wild goats three species*,* *E. multiflora*, *P. angustifolia* and *Ch. humilis* were in the range of indifference, because preference or rejection values were not significant. Species significantly more preferred by feral goats than wild goats were *E. multiflora* and *P. angustifolia* and species more preferred by wild goats than feral goats were *Cistus* sp. and *P. halepensis*. The last rejected by feral goats. No other species were significantly more rejected in one goat than in the other.

Discussion

Despite that the vegetation is clearly dominated by the two grasses, *A. mauritanica* and *B. retusum*, which represented more than half of the vegetation cover, the goats diet was predominantly woody, as commonly observed in goats in Mediterranean vegetation (Barroso et al., 1995; Bartolomé et al., 1998).

Table 7. Kautz corrected index of preference between goat ecotypes of the average value for plant species that were present in all study areas and seasons

Plant species	Wild	Feral	difference between goats
Olea europea	0.66*	0.74*	ns
Cistus sp.	3.9*	1.8*	s
Smilax aspera	0.26*	0.23*	ns
Erica multiflora	1.1	4.4*	s
Phyllirea angustifolia	0.88	6.79*	s
Chamaerops humilis	-0.03	0.07*	ns
Pinus halepensis	1.7*	0.2*	s
Pistacia lentiscus	-0.55*	-0.61*	ns
Ampelodesmos mauritanica	-0.68*	-0.7*	ns

Significant preference or rejection according to Savage statistic is denoted with an asterisk (*) after Bonferroni correction (Chi square critical value 9.31).
Negative values indicates "Rejection" and Positive values indicates "Preference".
s = Significant differences (P<0.05), ns= No significant differences.

A. mauritanica and *O. europaea* were the species with higher proportion in the diet of both goats, but in general, no species showed very prominent values. It could be explained because goats don't like too grass (Wilson *et al.*, 1975) and because they tend to diversify their diet to minimize the risk of poisoning (Provenza, 2003; Baraza *et al.*, 2008, 2009). Most of the common species in the Tramuntana mountain range were detected in diet. Surely because most of them are perennial species, mainly woody species, with available forage throughout the year. Some species (*R. officinalis, J. oxycedrus, P. lentiscus*) rich in secondary compounds and rarely cited as a common component of goats diets, were relatively abundant. According to (Mancilla-Leytón et al., 2013) these species only appears when availability of more palatable resources are scarce. In this respect it should be taken into account that low concentrations of some secondary compounds, such as condensed tannins, can improve ruminant nutrition by reducing protein degradation in the rumen and increase the flow of protein and essential amino acids to the large intestine (Frutos *et al.*, 2004). Thorny and spiny species, such as *C. espinosa, G. lucida* or *S. aspera,* also appeared regularly in the diet in concordance with other works (Aldezabal and Garin, 2000; Mancilla-Leytón, 2014), even they can be more often consumed than not spiny (Basha *et al.*, 2012).

These results could be a consequence of a large coevolution between plant and herbivore in the island, which had been maintained during millions of years ago by browsing effect of the extinct *Myotragus balearicus* and continued by goats during the last millennia (Alcover *et al.*, 1999).

This long and continuing browsing effect would have led to the dominance of perennial species in the vegetation with antiherbivore strategies (Hayashi *et al.*, 2007).

Most species were consumed similarly throughout the year but in summer and winter, the consumption of certain species such as *Ch. humilis* increased. It could be related with the energy requirements to maintain body temperature regulation during the critical periods (Alados and Escós, 1987). Probably this species add water into the diet since this plant is not consumed totally, just chewed and spit (personal observation).

The high similarity of the diets throughout the year by both goats indicates the proximity of the two ecotypes. In summer the values were higher, probably due to the feed deficit of the season that lead to the animals to be less selective according to optimal foraging theory (Stephens, 1986). However, some differences between them were detected. One was clearly due to differences on availability, such as the case of *G. lucida*, only present in feral goat areas. Other difference was that some species such as *Ch. humilis*, *Asparagus sp*. and *P. halepensis* appeared in feral goats at the same level in the three seasons but in wild goats they were more abundant in summer. Also noteworthy is that a couple of species, *Cistus sp*. and *P. halepensis*, with low nutrient content (Cluff *et al.*, 1982; Mancilla-Leytón *et al.*, 2013), were significantly more preferred by wild goats, and the last one even significantly refused by feral goats. All that could be explained as a discrete evolutionary diversification of both ecotypes. The fact that wild goats have been longer on the island could mean they are better adapted to periods of shortages as the summer and make better use of some unpalatable species. In this sense, other studies have showed diet differences between goat breeds grazing in the same vegetation (Landau *et al.*, 2002; Glasser *et al.*, 2012).

Both Wild Mallorcan goat and feral domestic goats showed an intermediate diet selective. The consumption of some plant species was determined by the season. Goats showed clear preferences and rejections that were maintained throughout the year. However they are also able to adapt to availability of resources and making use of most species available, especially in summer, which also show a general character when conditions require. The use of plant resources by both goats was very similar, which indicates that the goat ecotype does not determine damage to vegetation. However, some differences in diet that might suggest that the wild goat has a better adaptation to certain plant species, possibly because it has habited the island by long time before than feral goat.

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Capitulo 2

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Seasonal browsing in shrubland and pine forest by wild and feral goats in the Tramuntana Mountain range in the North of Mallorca Island

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Rivera-Sánchez L., Baraza E. and Bartolomé J. (2014)

Manuscript in preparation**.**

Seasonal browsing in shrubland and pine forest by wild and feral goats in the Tramuntana Mountain range in the North of Mallorca Island

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Abstract

The Mallorcan wild Goat (*Capra aegagrus* [*hircus*] ssp.) and feral goat (*Capra hircus*) inhabits the Tramuntana Mountain range in the north of Mallorca. The first represents an important hunting resource on the island, and the second is hunted for subsistence or recreational purposes. Both goats are considered bio-invaders by the Balearic Government. The aim of this study was to determine the browsing levels of the most abundant shrubs species in the Mediterranean shrubland and pine forest. This study was conducted in three areas of the Tramuntana Mountain range inhabited by feral goat populations, and two hunting and a public area with wild goat population under management. Plant species availability was determined by linear transects. Browsing intensity was assessed by categorizing levels of defoliation from zero to six, where zero means no trace of browsing, and six means fully browsed. Sampling was conducted for two years in verified periods as regards plant species availability, considering the spring as the period of maximum availability and the summer and winter as the limiting periods. Across the annual cycle, a total of 19 species with browsing signals in pine forest and 13 in shrubland were identified. Most of them are moderately browsed. *Olea europaea* was a rare species with the highest browsing level, while *Ampelodesmos mauritanica* and *Pistacia lentiscus* were the most abundant species, but with the least browsing level.

Introduction

In the Mediterranean basin, grazing with goats is part of human history, and the arguments for or against this practice vary widely. On the one hand, it is considered that the high livestock pressure in the Mediterranean forest system prevents its regeneration and causes the almost complete disappearance of deciduous and semi-deciduous species in favor of the evergreen species (Pulido and Díaz, 2005). On the other hand, the ungulates, in general, play a role as regulatory factors of vegetal succession, and create a spatial heterogeneity, which allows the less competitive species to be maintained (Hobbs, 1996). The browsing effect by goats contributes to the running of a moving mosaic of woodland, shrubland and grassland. Browsing also stimulates the forest conversion to pasture and consequently decreases the deposition of nutrients in the soil. This leads to the invasion of woody species, which contribute to the restitution of nutrient deposit (Bokdam, 2003). This mosaic, in a continuous succession, is maintained due to the pressure exerted by opposite vectors that includes the adoption of anti-herbivore mechanisms by the plants (physical, chemical and biological) and the adoption of different strategies by the animals to circumvent them (Carmona *et al.*, 2011). These ecosystems have great environmental advantages, the maintenance of diversity and the reduction in fire hazards in the forest (Etienne *et al.*, 1995). In some Mediterranean islands, like Mallorca, the controversy about goats comes to the highest exponent. It is estimated that goats were introduced to the island with the arrival of the humans about 4000 years ago (Burleigh and Clutton-Brock, 1980; Alcover *et al.*, 2001). Additionally, before this time in history, vegetation had undergone browsing from Pleistocene until the mid-Holocene by several consecutive species of genus *Myotragus.* These species were endemic artiodactyl ruminants of the Balearic Islands, and their extinction coincides with the arrival of humans (Alcover *et al.*, 1999). This is an argument in terms of plant – animal co-evolution allowing browsing to be considered as a permanent factor of vegetation control (Malo and Suárez, 1995; Orueta *et al.*, 1998; Gómez-Manzanedo *et al.*, 2009). Nevertheless, both wild and feral goats are currently considered bio-invaders by the Balearic government and submitted to regulation programs (Adrover, 2014).

In addition, the term "bio-invader" could be subjective (Colautti and MacIsaac, 2004) and particularly when the animal has inhabited the island for several thousand years, the use of this term may be controversial. The bio-invasive nature of a particular species does not always imply damage to the host ecosystem. In fact, for some cases the species presence supports the endemic species conservation, eradicating undesirable grasses (Hart, 2001), or in the stable maintenance of seriously modified ecosystems (Davis *et al.*, 2011). In modified ecosystems, where native and alien species co-habit, the goat eradication is not always justified (Chynoweth *et al.*, 2013). Therefore, it is essential to determine the browsing levels on the most common species in the vegetation. Currently, not much is known about the Mediterranean goat-shrubland interaction, in insular conditions, where the coexistence of both elements dates to a thousand years ago. Some studies have evaluated the effects over endemic species, but not on the most common and abundant components of the vegetation (Parkes, 1984; Orueta, 2003; Cursach, Moragues, *et al.*, 2013; Cursach, Besnard, *et al.*, 2013).

Thus, the aim of this study was to determine the browsing intensity by goats on the most common woody species in the Mediterranean shrubland and pine forest in different periods of the year in the north of Mallorca Island.

Materials and method

Study area

The study was conducted in six areas (Figure 1) in the Tramuntana mountain range, located in the north of the island of Mallorca. The mountain range has an approximate length of 90 km running southwest-northeast, with a surface of 800 km^2. The highest peak is the Puig Major, with 1,445 m above sea level (a.s.l.) (39° 48′ 27″ N, 2° 47′ 36″ E). UNESCO listed the entire mountain range as a World Heritage Site in 2011.

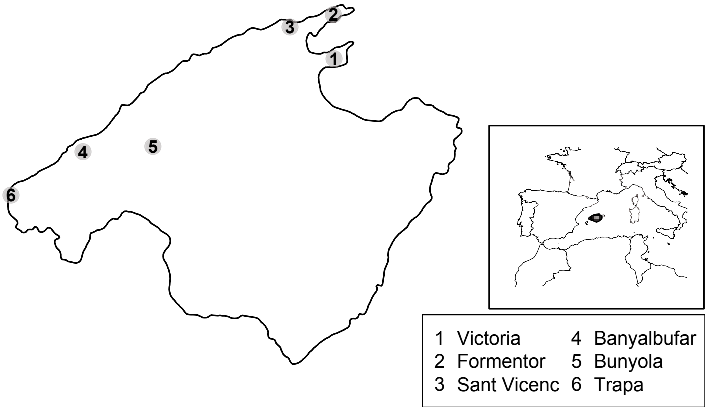

Figure1. Location of the study areas

The climate is typically Mediterranean, with two rainy seasons (spring and fall), a hot dry summer and a dry, not very cold, winter. Spatial variation of rainfall is significant, with a maximum located around 1400-1600 mm per year in the central sector of the mountains, while driest points of the coast do not exceed 300-350 mm. The mean annual temperature ranges from 16 to 18 º C in the lower parts of the mountain. The six areas considered are located in the lower part of the mountain range between 77 and 439 m.a.s.l. (Table 1).

Table1. Description of the study areas

Area name	Location	Altitude (m.a.s.l.)	Shrubland area (%)	Pine forest area (%)	Stocking rate (head/ha)
Formentor	39°56.997" N 003°09.633"E	147	46	54	0.33
Victoria	39°51.860" N 003°09.694"E	89	60	40	0.65
Bunyola	39°41.696" N 002°42.692"E	439	9	91	0.6
Banyalbufar	39°41.079" N 002°32.275"E	393	2	98	0.75
Trapa	39°36.044" N 002°21.543"E	258-373	38	62	0.77
Sant Vicenç	39°55.540" N 003° 03.122"E	77	99	1	0.25

Abbreviation: m.a.s.l.- meters above sea level; ha - hectare

Vegetation types and availability of browsing species

Two habitats were defined according to physiognomic and botanical attributes: pine forest, mainly Aleppo pine (*Pinus halepensis*), and shrublands, where tree cover was absent. Available vegetation of both habitats was dominated by several shrub species, such as *Chamaerops humilis*, *Pistacia lentiscus* or *Cistus* sp., and by the perennial tussock grass, *Ampelodesmos mauritanica* (Rivas-Martínez *et al.*, 1992). The six areas studied contained both habitats, but two of them, Bunyola and Banyalbufar where mostly covered by pine forest and the other, Sant Vicenç, mostly by shrubland (Table 1).

The vegetation availability was determined by measuring the cover, using the methodology proposed by Cummings and Smith (2000), of the major abundance species along 5 transects of 20 m length placed in the respective habitats of each area, and repeated three times a year for two consecutive years. Transects were not conducted in those habitats that had an almost negligible surface in the study area (shrublands in Bunyola and Banyalbufar, and forest in Sant Vicenç). Data from all transects were used to calculate the relative availability of each species, which was calculated as the percentage of each browsing species divided by the total percentage of browsing species (Fernández-Olalla and San Miguel Ayanz, 2007). The percentage values were transformed into a categorical data in order to facilitate its correlation with browsing intensity (Table 2).

Table 2. Categories employed for each level of browsing intensity and each plant coverage (as an estimator of availability).

Categories	Browsing intensity	Availability
0	No trace of damage	0 <Coverage < 1%
1	Some trace of bites	1 <Coverage < 10%
2	Light browsing. Easily visible. Consumption less than 25% of the biomass of browsing.	10 <Coverage < 25%
3	Consumption of 25-50% of the biomass of browsing.	25<Coverage < 50%
4	Intense browsing. Indication of deformed plant. Consumption slightly higher than 50%.	50<Coverage < 75%
5	Very intense browsing. Totally deformed plant or branches with some leaves scattered.	75<Coverage < 90%
6	Fully browsing. Only stalks can be observed..	90<Coverage < 100%

Browsing intensity

Browsing intensity was evaluated following the method of Etienne and Rigolot (2001) based on categorizing the browsing level on a scale from zero to six (Table 2). Only signals of recent bites were considered for evaluating browsing damage in each sampling period. Twenty individuals were randomly chosen from the more abundant perennial species in the same periods and areas where vegetation cover was measured. In cases where it was not possible to find 20 individuals in the area, a minimum of 10 were taken.

Animal management

Two study areas, Formentor and Victoria, are hunting estates where animals are selected according the racial traits of the Mallorcan Wild Goat. These goats are considered as *Capra aegagrus* species by some authors, because of their wild status (Seguí and Payeras, 2002; Masseti, 2009), but some others argue that they are feral populations of ancient domestic stocks, and should be included in the domestic species *Capra hircus* (Giannatos *et al.*, 2006). The Bunyola estate has another population of Mallorcan Wild Goat but unfenced, and hunting is only employed to control the incursions of feral domestic goats, and not for commercial interests. The animals survive year round with the resources of the estates, without any food supplementation, but subjected to disease control. The other three study areas have been occupied for decades by feral domestic goats (*Capra hircus L.*). These animals are not subjected to any form of management, except for some sporadic attempts to control populations by the island authorities. In both cases, the stocking rate is estimated from animal counting in the areas where vegetation transects were done, and the information was contrasted with that of the estate owners, when possible.

Statistical analysis

The effect of the period of study on each species availability was analyzed by ANOVA with the arcsine transformation of relative percentage of coverage as response variable. The effects of area, habitat and period on the browsing intensity of each plant species were analyzed by ordinal logistic regression models, where the year was considered as a replication for period. When possible, the three effects were included, but in some cases an area or a habitat was not included because a lack of species in all areas or in both habitats.

In order to analyze the relationship between availability and browsing intensity, Spearman rank correlations were calculated between the median of availability and browsing intensity level for each species grouped by area, habitat, period, and year. All analyses were performed using JMP 8.0 software (SAS Institute, 2008).

Results

Plant species availability

There are different areas within the study site in which plant availability differs in some components, but the most abundant species, such as *A. mauritanica*, dominates in all of them. The absolute vegetation coverage was very similar in both habitats considered, with 80.9% in the shrubland and 80% in the pine forest. As principal components of the vegetation, a total of 19 browsing species in the pine forest area and 13 in the shrubland area were identified (Table 3). All major species found in the shrubland were also found in the pine forest. Shrubs and the grass *Ampelodesmos mauritanica* accounted for 80.1% of the relative vegetation coverage available to the animals in the pine forest, and 82.3% in the shrubland. The relative coverage of the species was not affected by the period factor (P>.05 in all cases, one-way ANOVA), with exception of *Rosmarinus officinalis* (P=.005). This means that the availability is similar throughout the year.

Browsing intensity

High levels of browsing (categories 5 and 6) were very unusual (Figure 2). *Olea europaea, S. aspera, A. cytisoides,* and *G. lucida* showed a high frequency in medium-high levels of browsing. Conversely, *R. officinalis, J. oxycedrus, E. multiflora* and *A. mauritanica*, usually showed low values. The browsing intensity was affected by habitat factor (P<.05 in all the cases, log-nominal models), except *A. cytisolides, C. albidus, E. multiflora* and *O. europaea*. Most species were more browsed in the shrubland, with the exception of *P. lentiscus*, which was more browsed in the pine forest (Figure 2). *Smilax aspera* showed higher levels of browsing in the pine forest than in the shrubland, but only for summer, while the contrary occurred in spring and winter (Figure 2). Also significantly, the period influenced browsing of most species (P<.05 in all the cases, log-nominal models), except *C. spinosa* and *C. albidus*. The highest values were recorded in summer, however the level of browsing in *A. mauritanica, C. salvifolius* and *G. lucida* tended to increase in spring, and only *O.europaea, and Q. Ilex* in winter (Figure 2).

Table 3. Relative abundance of browsing species. Data area % ± SE

Species	Shrubland (%) ± SE	Pine forest (%)± SE
Ampelodesmos mauritanica	45.65± 18.1	38.46 ± 22.7
Anthyllis cytisoides	0.07± 0.4	0.78 ± 1.9
Arbutus unedo	not available	0.63 ± 2.56
Calicotome spinosa	0.43 ± 1.9	0.61 ± 2.38
Chamaerops humilis	8.66 ± 9.1	2.86 ± 9.01
Cistus albidus	2.82± 5.5	4.65 ± 6.9
Cistus monspeliensis	0.43 ± 1.7	1.71 ± 4.6
Cistus salvifolius	0.08± 0.7	0.46 ± 1.6
Cneorum tricocum	not available	0.32 ± 1.5
Erica multiflora	0.39 ± 1.38	4.21 ± 9.92
Genista lucida	3.65 ± 9.5	0.95 ± 3.6
Juniperus oxycedrus	not available	0.63 ± 2.20
Olea europaea	0.93± 2.22	1.67 ± 4.56
Phillyrea angustifolia	0.03 ± 0.3	3.44 ± 6.6
Pinus halepensis	1.16 ± 3.73	2.61 ± 5.51
Pistacia lentiscus	19.11 ± 13.9	14.94 ± 14.4
Quercus ilex	0.14 ± 0.9	0.68 ± 2.43
Rosmarinus officinalis	1.25 ± 3.87	2.29 ± 5.5
Smilax aspera	0.20 ± 1.7	0.19 ± 0.90
Others[1]	15.0 ± 1.5	17.91 ± 2.4

[1] Herbaceous and some woody species with very low frequency.

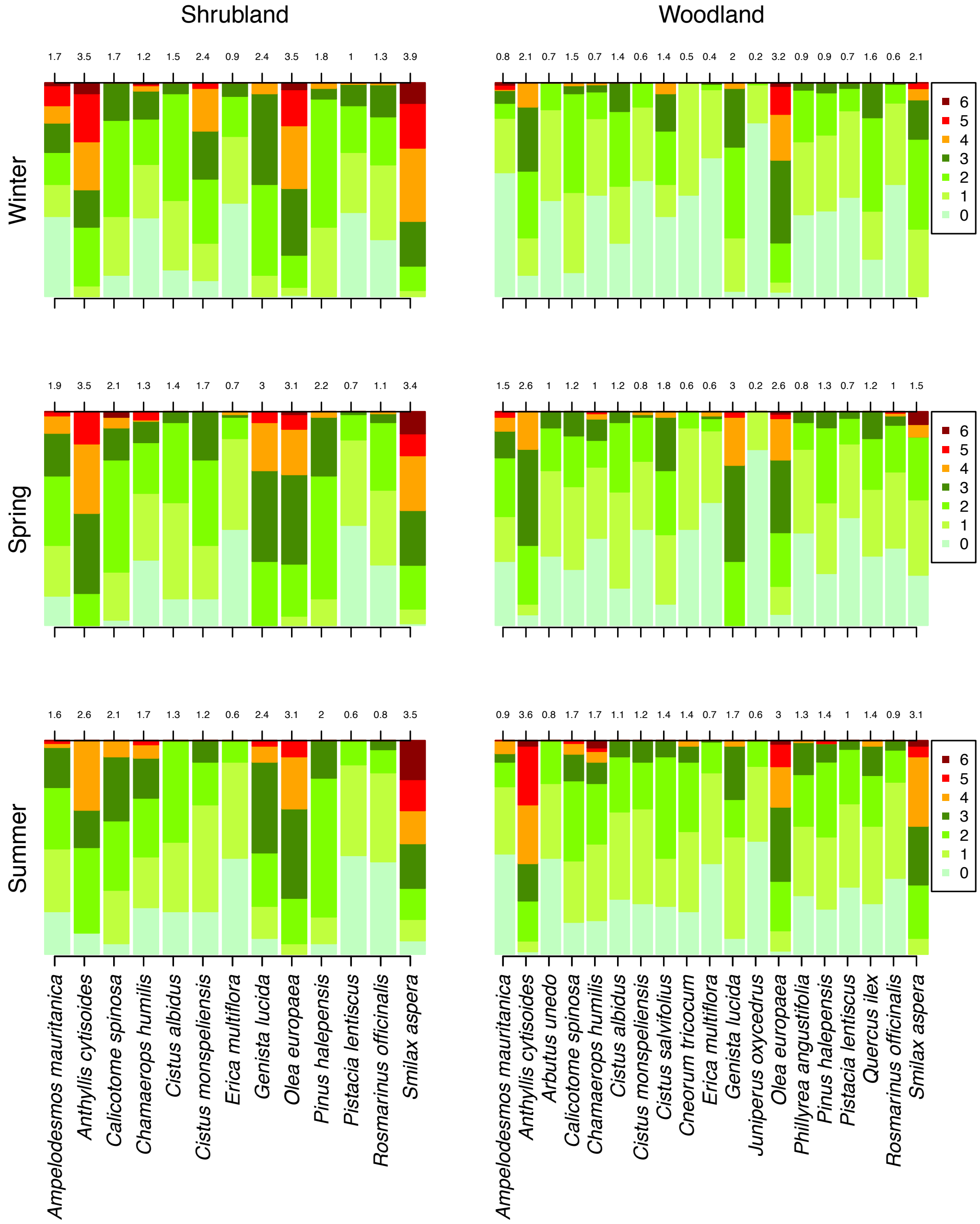

Figure 2. Frequency of browsing intensity by period in the shrubland and in the pine forest. The observed frequency for each level of browsing represented in colors, is associated with the length of each bar of the figure. The average value is shown above each bar.

Relation among availability and browsing intensity

An expected negative and significant correlation was found among species availability and browsing intensity (*P*=-.214, P<.0001, respectively, Spearman correlation). The correlation was significant in both the shrubland and in the pine forest. As regards the season, the significance was maintained during the winter and summer, but not in spring (Table 4).

Table 4. Spearman's correlations between the median of availability and the median of browsing intensity.

Effects	**Spearman ρ**	***P* value**
Shrubland	-0.3090	<.0001
Pine forest	-0.1933	.0006
Winter	-0.2610	.0007
Spring	-0.0570	.4697
Summer	-0.3500	<.0001

Discussion

The results obtained in this study reveal that goat populations that inhabit the shrubland and the pine forest areas in the Tramuntana mountain range of Mallorca Island concentrate their browsing activity in the most abundant shrub species. This browsing trend has been observed in other studies (Malechek and Provenza, 1983; Barroso *et al.*, 1995; Bartolomé *et al.*, 1998).. Few species were highly browsed, but all are scarce in the vegetation. Moreover, few highly abundant species in the vegetation are also poorly browsed. As observed in the correlation analyses, most of the studied species are browsed according to their abundance. This result could be interpreted as an effect of a long co-evolution period between the population of large herbivores and the island vegetation (Galmes *et al.*, 2010; Vives and Baraza, 2010). The co-evolution has favored the tolerant plant species to browsing damage (Strauss and Agrawal, 1999). Despite that these species are highly browsed, they are capable of persisting in the vegetation, or even increasing their presence (Rosenthal and Kotanen, 1994). Obviously, species barely browsed can also increase their presence in the vegetation (Cingolani *et al.*, 2005).

Both cases were observed in species evaluated in this study; for instance *G. lucida* is a legume with either middle or high browsing levels, despite being a spiny species, and appears abundant in the vegetation, particularly in the shrubland. Species barely browsed, that must be highlighted are, *A. mauritanica* and *P. lentiscus*. Both species showed low levels of browsing intensity, although they are the most abundant species in the vegetation. The low palatability of *A. mauritanica* (Wilson *et al.*, 1975) and the high phenolic content of *P. lentiscus* (Rodríguez Berrocal, J. Zamora *et al.*, 1973; Ammar *et al.*, 2005) surely maintained their low browsing levels. However, it would be erroneous, or at least inaccurate, to consider that the abundance of these species comes solely from low browsing intensity. Both species have also been favored by other common disturbances in the Mediterranean basin: fire. Both species resprout quickly after fire, allowing them to maintain, or even expand, their population size (Sala *et al.*, 1990; Vilà *et al.*, 2001). Soon after a fire, young leaves of the resprouts are almost the only source of food for goats in burned areas. Additionally, *A. mauritanica* seems to be more browsed in spring (Figure 2), when the animal diet includes immature inflorescences of the plants (personal observation), leading to negative consequences in the fitness of the species. Consequently, and in spite of being less browsed species, animals have a certain capacity to control them. In this context, goats became an option in the control and management of undesirable plants.

Other barely browsed species, but scarce in the vegetation, is *J. oxycedrus,* which in that study only appears in the pine forest. This is a species with a high content of secondary components (Adams, 1998) making it unpalatable, and because of that it would be expected to be more abundant. However, the presence of this species in the Island has been reduced over the last millennium, likely caused by climatic changes (Yll *et al.*, 1997), and may be due its low resistance capacity to repeated fire (Trabaud, 1992).

The two most important forest species in the island, *P. halepensis* and *Q. ilex*, have low browsing levels (level 2 is the most frequent). Only in summer, some individuals reached browsing levels of 4 and 5. This leaves open the hypothesis that browsing slows regeneration of both species, as was found in other studies (García-González and Cuartas, 1992; Zamora *et al.*, 2001; Cierjacks and Hensen, 2004). However, additional detailed studies of both species are needed to establish the possible effect of browsing in saplings during the regeneration process. It is also important to consider that trees are long-live species, and therefore the individual ones where the canopies cannot been reached by the animals constitutes a continuous reservoir of new propagules.

Unlike other islands, the plant species that have disappeared in Mallorca as result of goat browsing remains unknown, despite some endemic species probably being at risk (Cursach, Besnard, *et al.*, 2013). Here, the most browsed species are *O. europaea*, *A. cytisoides* and *S. aspera*. All of them show evidence of intense browsing levels, and in some cases reaching maximum values that result in a complete defoliation of the plant (Figure 2). These are examples of species in potential risk of disappearance, but they have a vegetation cover ranging from 1% to 6% in our studied areas (Table 3). Furthermore, pollen records in *O. europea* showed the increasing presence of this species in the island since mid-Holocene. Surely, this is the result of high resistance to browsing by the use of physical strategies. *O. europea* is an appealing species to goats, and able to adopt morphotypes like dwarf shrubs with small leaves and highly dense branches to protect them. The species has a great ability to sprout and because it is a long-live species, it may wait a long time until browsing pressure decrease.

Meanwhile, *A. cytisoides* is considered a very palatable shrub for sheep and goats (Robledo *et al.*, 2011). Nonetheless, moderate browsing stimulates its growth, increases flowering, and increases the survival in adults by increasing the complexity of fractal structure (Escos *et al.*, 1997). Furthermore, when the drought is acute, it may behave like a summer deciduous species and resists defoliation (Robledo *et al.*, 2011). *Smilax aspera* is a vine with strong spines on the stems and tuberous rhizome, which allows it sprout after strong herbivore episodes. Additionally, the eroded pattern of calcareous rock on the island offers protection in cracks and holes to *S. aspera* and other species (Pérez-Obiol *et al.*, 2003).

Despite that all shrub by species observed can be found in the pine forest, browsing levels were higher in the shrubland. A possible explanation could be the fact that the shrubland allows greater visibility to animals, and are also more walkable in Mallorca (personal observation). Another explanation is that shrubland is the best microhabitat in Mediterranean environments, taking into account the water availability and sunlight for plant growth (Zamora *et al.*, 2004).

The fact that no availability differences were observed at different seasons of the year may be related to the dominance of shrub species under constant browsing, which would imply that the balance between growth and browsing was neutral. However, a certain negative correlation between browsing and availability was observed during the summer and winter, indicating, that for these periods, the most abundant plants are the least browsed and vice versa. This correlation disappears in spring due to the higher nutritional quality in the Mediterranean (Basha *et al.*, 2012). It was also observed that the level of browsing for many species varies depending on the season of the year. Most are browsed in summer, a critical period due to the water stress to which the vegetation is subjected (Zamora *et al.*, 2004).

This would indicate that additional factors not considered in this study could be relevant. The importance of the herbaceous stratum in diet, animal behavior, topography, climate, nutritional value, phenology, and spatial distribution of each species are some of the many factors to consider when explaining seasonal variations of browsing.

These phenomena are common in Mediterranean vegetation, where plants have actively cohabited and interacted with large herbivores since time immemorial (Perevolotsky, 1994; Perevolotsky and Seligman, 1998). The fact that a high browsed species is maintained in the extant vegetation although its coverage is low, and low browsed species do not completely dominate the landscape after some millennia of interaction, invites reflection about the role of the goats in the Mediterranean Islands. Nowadays, some land managers and authorities in Mallorca tend to consider the goat as a threat to the conservation of biodiversity and forest regeneration (Mayol, 2013; Sansó, 2013). For this reason, the usual recommendation consists of goat eradication plans (Orueta, 2003). These plans aim to avoid documented disasters of bio-invader goats in islands where vegetation has evolved without the presence of large herbivores (e.g. Coblentz, 1978; Parkes *et al.*, 1996; Campbell and Donlan, 2005). However, in Mallorca and other Mediterranean islands, while maintaining moderate stocking rates and proper management of the same is necessary to prevent damage to certain species (Cursach, Moragues, *et al.*, 2013), its eradication could also lead to the extinction of endemic species due to increased competition with species currently controlled by browsing (Cursach, Besnard, *et al.*, 2013).

In summary, the long browsing history in the island, although not being the only factor, has contributed to consolidate a landscape dominated by tolerant shrubs. In addition, for extreme browsing cases, some mechanisms have allowed the survival of plant species, and for rejection cases there are some mechanisms of control that may be related or not with the animals that hinder their expansion. Because of their versatility, goats instinctively tend towards conservation browsing. However, any environmental risk associated with goats would be essentially related to inadequate management of this species.

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Capitulo 3

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Comparative study of behaviour and herd structure in wild and feral goats living in a Mediterranean island: management implications

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Comparative study of behaviour and herd structure in wild and feral goats living in a Mediterranean island: management implications

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Abstract

The aim of this study was to compare the trophic behaviour and the social structure of Majorcan wild goats and feral goats present in the island of Majorca. The former are descendants of an ancestral goat ecotype introduced in the island in the late Neolithic, whereas feral goats come from domestic forms introduced recently from the Iberian Peninsula. The study was conducted in four localities of the Sierra de Tramuntana, a mountain range located in the northwest of the island of Majorca. Behavioural data were collected in three seasons, summer, winter and spring of 2011-2013 and when goat activity is at its peak, i.e., three hours after dawn and before dusk. The following variables were recorded: group composition (males, females and kids) and activity (eating, walking, resting and watching). The proportion of time spent on each activity and their frequency were obtained from focal samples. Multivariate analyses of variance (MANOVA) were used to simultaneously analyze the activity variables. A total of 155 observations of 85 herds were registered throughout the study. A similar behaviour has been observed in this study for the two goat ecotypes, feral and wild, appart from some seasonal variations in eating and resting activities. On the other hand, feral goats apparently have a higher gregarious behaviour than wild ones. The differences appreciated may suggest that the wild ecotype is better adapted to the plant community present in the island. Average herd size for both ecotypes is smaller than the one registered in domestic goat herds, suggesting a relatively low browsing damage. However the increase of goat populations in the island might cause serious damage on vegetation. The practice of ancestral hunting tecniques, using dogs and loops, seems to allow regulating goat population increase.

Keywords: Majorcan wild goat, Feral goat, Behaviour, Feeding, Insularity, Hunting.

Introduction

The arrival of goats (*Capra* sp.) to Majorca Island is very ancient documented between 2300 and 2050 BC during the Pre-Talaiotic culture (Seguí *et al.*, 2005). It has been postulated that the first goats introduced to the island gave rise to a local breed that remained in the wild until present, the so-called Majorcan wild goat (*Capra aegagrus [hircus]* ssp.). Currently, it is an important source of income through hunting activities in the island (Seguí *et al.*, 2005), being in the hunting grounds where the purest populations are conserved. The introduction of domestic breeds (*C. hircus*) in more recent times and its subsequent abandonment has led to the establishment of a large population of feral goats phenotypically clearly differentiated (Vives and Baraza, 2010). Goats may form feral populations in localities where they are abandoned as keeping them as domestic stock is no longer valuable, and particularly where predators are absent or scarce (Parkes *et al.*, 1996), as it occurs in Majorca.

Some studies about feral goat populations have mainly dealt with issues related to its impact on the environment, in particular in islands, which in the case of Spain include the Balearic and Canary islands (Orueta, 2003). Also, studies about the feral goat population structure have been conducted in Australia and New Zealand (Parkes *et al.*, 1996; Pisanu *et al.*, 2005; Shi *et al.*, 2005; Suances, 2010). In the case of wild goats at insularity conditions, ethological studies have been conducted in Crete (Husband and Davis, 1984; Nicholson and Husband, 1992). However, trophic behaviour studies on islands where feral and domestic goats coexist, as it is the case in Majorca, have not been reported.

Herds of feral goats have a marked effect on the ecosystems they inhabit (Coblentz, 1978) and may constitute an economic and hunting resource (Forsyth *et al.*, 2009). In many places, the feral goat is considered an invasive species (Parkes, 1993; Parkes *et al.*, 2002), foreign to the natural ecosystem and therefore its eradication is recommended in order to reduce the negative impact in the agriculture and natural ecosystems.

In the Sierra Tramuntana of Majorca, feral goats are present since at least 50 years ago according to farmers' accounts. In the past, both wild and feral goats were hunted alike on the island with an ancient technique named "cans i Llaç" (dogs and loop), which consisted of round up the goats with the help of dogs in cliffs and then catch them with a loop (Seguí, 2014 in press). Nowadays, the way that goats are managed in the island differs according to their ecotype. Wild goats are only hunted using firearms at hunting areas, whereas feral goats are captured throughout the highlands using both techniques, dog and loop for kids and firearms in eradication campaigns.

The available literature on the behaviour of goats describes a very similar social behaviour between wild and feral populations (Shackleton and Shank, 1984). Therefore, we would not expect much difference between the behaviour of feral goats and the Majorcan wild goats, but due to different handling both ecotypes receiving their behaviour could be different. The main objective of this study was to compare the trophic behaviour and the social structure of Majorcan wild goat and feral goat herds present in the island of Majorca. The identification of food habits and routines, as well as the social structure of both ecotypes, might allow us to establish proper management scenarios for both goat ecotypes.

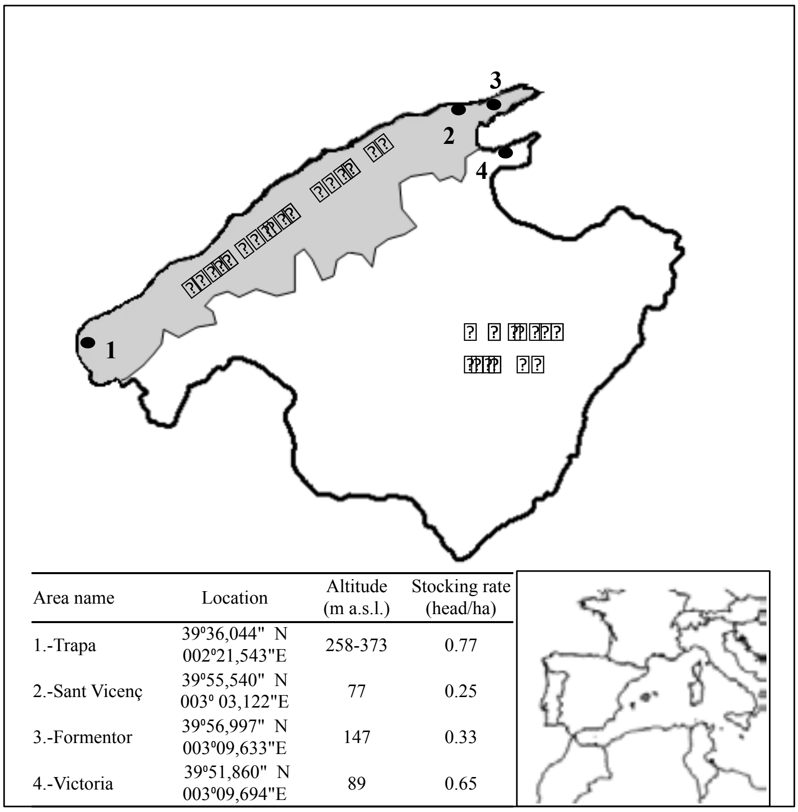
Methodology

Study area

The study was conducted in four localities of the Sierra de Tramuntana, a mountain range located in the northwest of the island of Majorca. It ranges 90 km and stretches in a southwest-northeast direction, with a surface of 800 km^2. The highest peak is Puig Major, 1.445 m a.s.l. (39° 48′ 27″ N, 2° 47′ 36″ E). The entire mountain range was listed as a World Heritage Site by UNESCO in 2011.

The climate is typically Mediterranean, with two rainy seasons (spring and fall), a hot dry summer and a warm dry winter. Spatial variation of rainfall is significant, with a maximum of 1400-1600 mm per year located in the central sector of the mountain, with drier points not exceeding 300-350mm in coastal areas. The annual average temperature ranges from 16 to 18 º C in the lower parts of the mountain. The four areas considered in this study are located in the lower part of the mountain range between 77 and 439 m.a.s.l. The perennial tussock grass *Ampelodesmos mauritanica* dominates the vegetation community. Several shrub species, such as *Chamaerops humilis*, *Olea europaea* var. *sylvestris* or *Pistacia lentiscus* are scattered over the territory, mainly close to caves and rockshelters. This plant community is characteristic of the giant reed thicket succesion (*Smilaco balearicae- Ampelodesmetum mauritanicae*), according to (Rivas-Martínez *et al.*, 1992).

Two study areas, Formentor and Victoria (Figure 1), are hunting estates where animals are selected according the breed traits of the Majorcan wild goat (Consell de Mallorca). The animals survive year round with the resources of the estates, without any food supplementation but subject to disease control. The stocking rate of these areas was calculated thanks to the data provided by the managers (Figure 1). These goats are considered as *Capra aegagrus* by some authors because of their wild status (Seguí and Payeras, 2002; Masseti, 2009), but some others argue that they are feral populations of ancient domestic stocks and should be included in the domestic species *Capra hircus* (Giannatos *et al.*, 2006).



Area name	Location	Altitude (m a.s.l.)	Stocking rate (head/ha)
1.-Trapa	39º36,044" N 002º21,543"E	258-373	0.77
2.-Sant Vicenç	39º55,540" N 003º 03,122"E	77	0.25
3.-Formentor	39º56,997" N 003º09,633"E	147	0.33
4.-Victoria	39º51,860" N 003º09,694"E	89	0.65

Figure 1. Sample location

The other two study areas have been occupied for decades by feral domestic goats (Figure 1). These animals are not subject to any form of management, except of some sporadic attempts to control populations by the island authorities. In that case, the stocking rate was estimated from field observations.

Data collection

Data were collected in three seasons, summer, winter and spring of 2011-2013. An observation point was assigned in each one of the four study sites, with ample visibility of areas usually used by goats. Data were collected 3 hours after dawn or before dusk, when goat activity is at its peak, as it usually happens in other ungulates (e.g. Carranza *et al.*, 1991; Cassinello, 2000). Binoculars with rangefinder and a stopwatch were used to undertake focal sampling during 15 minutes where the characteristics of the animals/herds observed were registered according to Altmann (1974) and Morrison *et al.* (2006), and the following variables were recorded: group composition (males, females and kids) and activity (eating, walking, resting and watching).

Statistical analysis

The proportion of time spent on each activity and their frequency were obtained from focal samples. Spearman correlation analyses of the response variables (eating, walking, watching and rest) were estimated. Because the lack of normality of data (Shapiro-Wilk test, $p < 0.05$), the transformations square root + 0.5, arcsine of the square root and logarithm of x +1 were applied to frequencies, proportions and absolute values, respectively. To reduce the effect of sampling area, the standardized values of variables (Z values) regarding sampling area were calculated. Multivariate analyses of variance (MANOVA) were used to simultaneously analyze four dependent variables: eating, walking, watching and resting. The independent variables considered in the model were season, ecotype and sex. The Roy's Max Root test was used to estimate the significance of the effect in the MANOVA. Further, for those variables showing significant differences, one-way and two-way factorial ANOVA were performed, and least square means of the levels estimated.

To analyze the observed frequency of encounter the different herd types in the two ecotypes of goats, a Chi square test was used. Moreover, the herd size, transformed with logarithm plus one, was evaluated by ANOVA, considering the effects of season, type herd and goat ecotype. The mean differences between levels of factors included in this analysis were evaluated by least squares. Statistical analyzes were performed with JMP statistical software, version 8.0 (JMP 8.0 SAS Institute, 2008).

Results

A total of 155 observations were taken throughout the study. A significant difference between proportion variables was obtained (Table 1).

Table 1. Spearman correlation values of the proportion of time devoted to four different behaviours

Activity	Eating	Walking	Watching
Eating			
Walking	-0.4224***		
Watching	-0.6189***	0.1761*	
Resting	-0.4803***	-0.2549**	0.0698*

*p>0.05; ** p<0.01; *** p< 0.0001

The MANOVA analysis of the proportions and frequencies showed that the interaction between season and goat ecotype was significantly related to the behaviours observed (Table 2). The walking and watching variables had no significant differences, showing a mean of 16.9 ± 1 and 14.8 ± 1.3 for percentage and 0.7 ± 0.04 and 0.5 ± 0.03 for frequency respectively.

Table 2. Results of MANOVA explaining the effects of season, sex class and ecotype on behaviour frequencies and proportions, F approximate value, degrees of freedom and p-level are reported.

MANOVA

Effect	**Approx. F**	**df 1**	**df2**	**p**
Proportions				
season	3.01	5	129	0.01
ecotype	0.76	5	128	0.58
sex	0.92	5	128	0.45
season*ecotype	3.14	5	129	0.01
season*sex	1.66	5	129	0.15
ecotype*sex	0.62	5	128	0.68
season*ecotype*sex	0.19	5	129	0.48
Frequency				
season	4.99	5	129	<0.001
ecotype	0.67	5	128	0.65
sex	0.58	5	128	0.71
season*ecotype	2.92	5	129	0.01
season*sex	1.49	5	129	0.18
ecotype*sex	1.21	5	128	0.3
season*ecotype*sex	0.91	5	129	0.48

Our results showed that the percentage of time devoted to eating by both ecotypes was lower in spring than in winter and summer ($F_{(5.138)} = 2.93$, $p = 0.01$) however, the feral domestic goats devoted more time to eat in summer than the Majorcan wild goat, Figure 2 (LS Means Differences Student's t).

Regarding eating frequency, the Majorcan wild goat showed a higher frequency in winter than in spring and summer ($F_{(5.138)} = 3.50$, $p = 0.005$), while the feral domestic goats did not show significant differences for this trait (Figure 3).

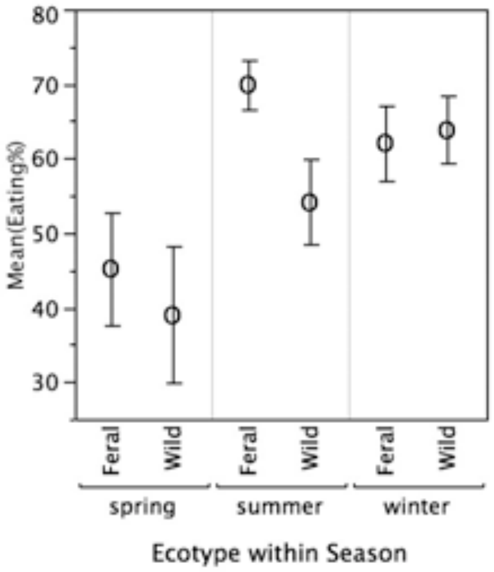


Figure 2. Mean scores ± SE of the proportion of time devoted to eating for ecotype and season.

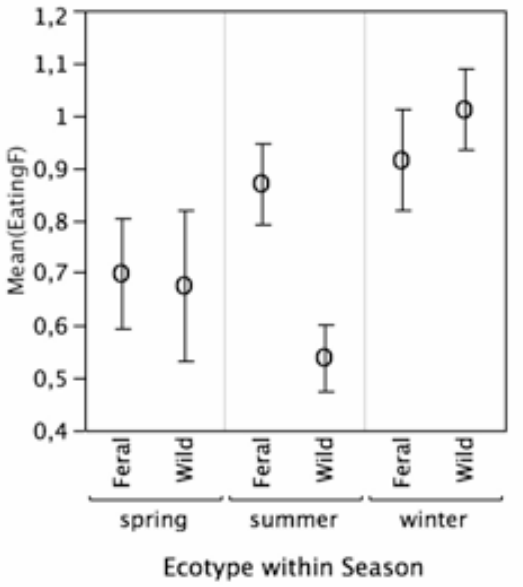


Figure 3. Mean scores ± SE of eating rate for ecotype and season.

We observed that resting frequency for both goat ecotypes was higher in spring than in winter and summer, however, in winter feral domestic goat resting frequency was greater than that of the Majorcan wild goat ($F_{(5.138)} = 4.16$. $p = 0.001$; Figure 4).

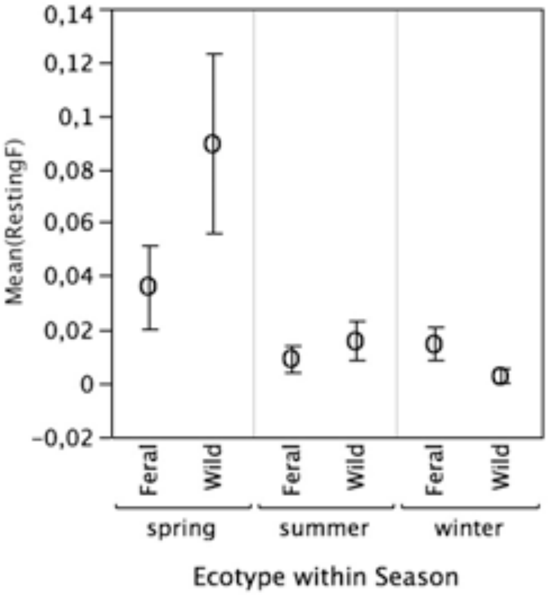


Figure 4. Mean scores ± SE of resting rate for ecotype and season.

A total of 85 herds were observed during the study. Out of these herds, 37 corresponded to feral goats and 48 were wild goats. The observed herds were grouped in three categories: mixed (herds made up of males, females and kids), males (herds composed only by males) and females (herds made up of females with or without kids). The Chi square test for herd type showed differences in the proportion of herd type sightings ($X^2_{(7,81)}$=70.39, d.f.=3. P<0.0001). In the case of wild goats, it was observed that the frequency of finding mixed herds was greater than female and male herds respectively ($P < 0.05$). As for feral goats, the frequency of finding either mixed herds or female herds was higher than male herds (P<0.05, Figure 5).

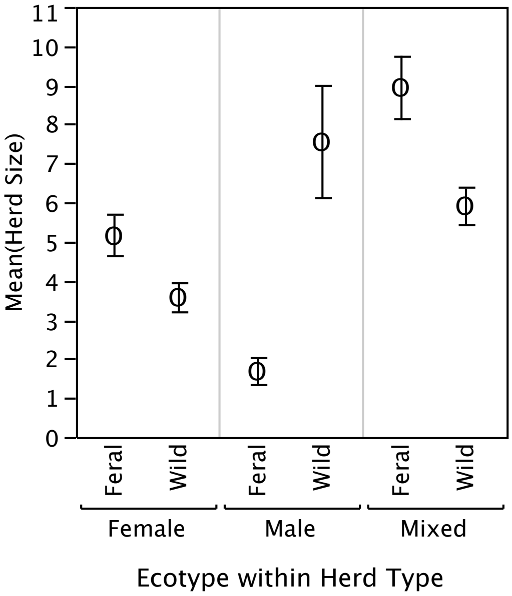


Figure 5. Average ±SE of herd type size for feral and wild goats.

The size of the herds is shown in Figure 6. Mixed and female herds were larger in feral than in wild goats (P<0.05), whereas the opposite occurs with male herds, which were significantly larger in wild (P<0.05).

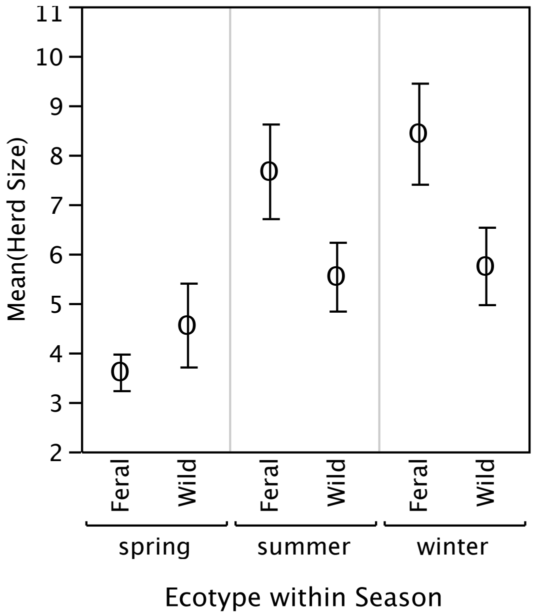


Figure 6. Average ±SE of herd size for feral and wild goats in each sampled season.

Discussion

Time distribution

Our results revealed that food intake is the longer activity during the day, as observed in other goat populations (Askins and Turner, 1972), where as mentioned by Kenney and Black (1984), goats would determine the largest part of time to feed in shrubland, due to their small bite size and the fact that leaves are spread between and within the branches.

Eating time is inversely related to the time devoted to other activities being also affected by season. It was observed that both goat ecotypes spent more time eating in summer and winter than in spring. In fact, in summer the goats have an activity period at midday probably also to the decline of tourists at this time of day (personal observation). This difference could be associated to the low quality of forage during summer and winter along with an increase of energy requirements in order to maintain their body temperature regulation (Alados, 1986; Alados and Escós, 1987). The reduction of the sunlight period during winter would also determine an increase of feeding time (Valentine, 1990). Finally feral goat feeding time and frequency was higher than those of wild goats in summer. This could be because feral goats could be less efficient in the use of vegetation during this season, instead, wild goats have inhabited for centuries on the island coexisting with vegetation in periods of lower forage abundance and quality.

However despite walking time was inversely related to feeding time this trend was not observed for walking frequency. In fact, walking frequency showed a positive correlation with eating time, and could be explained because walking activity is fundamentally related to browse, when goats do short walks in order to locate new feed sources (Arnold and Dudzinski, 1978).

Moreover, both walking time and frequency are directly related to watching time. This is expected because when goats are in motion they are more visible to potential threats like hunters, dogs or even tourists. No difference between the two goat ecotypes was observed for watching activity likely due to the presence of hunters. Wild goats are hunted for recreational purposes whereas feral goats are subject to eradication programs so that they can be culled throughout all the year (Mayol, 2013).

During resting time animals tend to be lying down. Time devoting to resting was the least observed behaviour throughout our study. Resting frequency depending on the season of the year, highest resting frequencies were observed during spring. Records from the same season also showed shorter feeding time and frequency probably because of a superior forage quality. Animals ruminate while resting therefore is expected that in spring goats spend additional time for rumination because they spend less time eating. Conversely during winter and summer both goat ecotypes rested less time and less frequently in agreement with other authors accounts (Arnold and Dudzinski, 1978) who proposed that at relatively high or low temperatures animals reduces their resting time. Feral goats resting a similar time that wild, but less frequently, a more frequent behaviour in domestic goats (Shackleton and Shank, 1984), but the fact that wild goats have shorter resting periods, could be associated with the mating season, where animals could increase the activity due to courtship.

Structure of herds

The structure of herds observed in both goat ecotypes in the Sierra Tramuntana of Majorca follows the pattern reported for other feral goat populations (Parkes, 1984; Shi *et al.*, 2005) as well as the one usually observed in other wild goat populations (Shaller, 1977). Generally the basic social unit is an adult female and her offspring, which associate in an area with similar groups (O’Brien, 1988). The average herd size in this study was higher than the one reported in

other goat populations (Granados, 2001; Suances, 2010) although we found clear differences between both goat ecotypes.
Females and mixed herds were larger in feral goats than in wild ones; this is in accord with the expected higher gregariousness characteristic of domestic ungulates (Shackleton and Shank, 1984). Male herds were significantly smaller in feral than in wild goats, probably as a result of ancient domestication processes, which may originate a certain sedentarious behaviour so that migrating bachelor male groups tend to disappear (Martínez *et al.*, 2014 in press).

In this study, feral goats showed variations in herd size across the year, as reported previously by Shi *et al.* (2005) and Suances (2010), being higher in summer and winter. Studies show that gregariousness is a condition that allow transmit information within herds (Wilson *et al.*, 1975). This condition is seen more frequently in feral goats, goats tend to follow older individuals in times of food shortages and higher drought, the location of better food and water sources can be transmitted from older individuals the youngest (O'Brien, 1988). This could be an explanation for the increased size of the feral goat herds in summer and winter. The herds of wild goats had similar sizes for all year. Returning what we previously mentioned, it is probable that wild goats are more efficient in search of food in less favourable seasons, this would look reinforced by the vegetation management in hunting as burning and clearing, so the size of their flocks is constant throughout the year. Other studies have observed a constant herd size during the year of goats living on islands in favourable conditions (Shackleton and Shank, 1984).

In sum, a similar behaviour has been observed in this study for two goat ecotypes, feral and wild, that coexist in Mallorca island, along with some seasonal variations in eating and resting activities. Finally, feral goats apparently have a higher gregarious behaviour than wild ones.

Management implication

Our study may give some clues that would allow us to understand feral and wild goats' comparative behaviour in islands. In the Majorca Island there has been a tendency in recent years to keep native wild goats, whereas feral populations should be eradicated on the grounds that the latter causes a severe damage to vegetation. In this study we have shown that both goat ecotypes have a very similar trophic behaviour, so that their impact on vegetation should be expected to be similar. However, slight differences appreciated may suggest that wild goats are better adapted to the plant community present in the island.

Our data suggest that feral goat populations, which originally come from domestic stocks, maintain certain social structures that might resemble their domestic origin, such as a higher degree of gregariousness. Average herd sizes of both, wild and feral, goats in the island is lower than the average size recorded for domestic goat herds. Herbivore large herds, as it is usually the case of livestock, are likely to cause severe impacts on vegetation (Orueta, 2003), especially in habitats with no history of intense herbivory, whereas herbivory caused by small herds is usually beneficial (see, e.g., Anderson *et al.*, 2007) however, in an island where herbivore ungulates have been around since before the arrival of man, as it is the case of Majorca (Alcover *et al.*, 1999), endemic plant species have been subjected to browse and have evolved with the presence of these herbivores.

Browsing signals have traditionally been seen as detrimental for environmental conservation, if they are related to overgrazing, desertification, and their consequent contribution to climate change and loss of biodiversity (Mancilla-Leytón, 2014). However, goat browsing behaviour, when in moderate intensity, has been proved to maintain and enrich plant communities, particularly in comparison with other domestic ungulates. High food selection and a strong preference for browsing allow goats to reduce the variation of energy and protein in their diet caused by environmental or management conditions (Fedele et al., 1993). Moreover, because of this versatility of grazing/browsing behaviour, goats are able to effectively control invasive plant species, while at the same time select a diet that meet their nutritional requirements (Mancilla-Leytón et al., 2013). However, the increase of goat populations in the study area, both wild and feral, may cause serious damage on vegetation. The practice of hunting with dog and loop allows regulating the populations of feral goats, so that their control can be made in part by preserving or even promoting this type of ancestral hunting.

Acknowledgements

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Capitulo 4

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Stomatal density and stomatal index of fossil *Buxus* from coprolites of extinct *Myotragus balearicus* Bate (Artiodactyla, Caprinae) as evidence of increased CO_2 concentration during the late Holocene

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Stomatal density and stomatal index of fossil *Buxus* from coprolites of extinct *Myotragus balearicus* Bate (Artiodactyla, Caprinae) as evidence of increased CO_2 concentration during the late Holocene

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Abstract

Stomatal density of plants may vary depending on environmental factors, such as CO_2 concentration. Under the current atmospheric conditions, it is expected that leaves have different stomatal density than they had hundreds or thousands of years ago, due to the rise in CO_2 in the atmosphere. Coprolites of the extinct *Myotragus balearicus* from Cova Estreta (Pollença, Mallorca), with a radiocarbon age of 3775-3640 cal BC, have been used to study the diet of this bovid. A significant amount of epidermal fragments of *Buxus* was contained in the faecal material. Three coprolites were used to estimate the stomatal density and stomatal index in *Buxus* epidermal fragments from this period. Samples of the endangered *Buxus balearica*, the sole species of *Buxus* currently present on Mallorca, and samples of the *Buxus sempervirens* present in the nearest mainland were also collected in different locations. Leaves were examined using microscopy to determine and compare the stomatal density and stomatal index between current plant material and coprolite material. The results indicated a higher value for stomatal index (12.71) and stomatal density (297.61 stomata/mm^2) in leaves from the coprolites versus in leaves of the living *Buxus balearica* and *Buxus sempervirens* species (7.99, and 227.77 stomata/mm^2 respectively). These results could provide a palaeobotanic evidence of a change in atmospheric CO_2 concentration since mid-Holocene in the Mediterranean basin.

Keywords: Mallorca, herbivorism, microhistological analysis, epidermal fragments, fossil leaves

Introduction

Certain plant traits, such as leaf morphology, have a high phenotypic plasticity that enables them to adapt to major changes in the environment (Matesanz et al., 2010; Peppe et al., 2011). Experiments based on exposing plant species to varying CO_2 concentrations in controlled environments have demonstrated that an increase in atmospheric CO_2 concentration (above 340 ppmv) causes a reduction in stomatal density (SD) and in the ratio of stomata to stomata plus epidermal cells, that is, the stomatal index (SI) (Woodward, 1987; Woodward and Kelly, 1995; Overdieck and Strassemeyer, 2005). This inverse relationship between SI and atmospheric CO_2 concentration has been used to estimate the effects of a rise in atmospheric CO_2 over the past centuries (Haworth et al., 2010, 2011; McElwain et al., 2005; Paoletti and Gellini, 1993; Woodward, 1987). Recent studies of Steinthorsdottir et al. (2013) in Greenland have shown a good correlation over time between SI and CO_2 concentration.

Coprolites of herbivores are potential sources of ancient plant remains, as they may contain fragments of leaf epidermis. The microscopic diagnostic features of these fragments allow the identification of plant species and thus determine the composition of the faeces (Agenbroad and Mead, 1989; Akeret and Rentzel, 2001; Davis et al., 1985; Hofreiter et al., 2003). In addition, SD and SI can be determined from the epidermal fragments contained in the coprolites. As plant species recorded in recent geological periods –such as the Holocene– can be also found today, comparisons of their current and fossil SD and SI are feasible (McElwain et al., 1995). These comparisons can be used as a palaeobotanical approach of changes in concentration of the atmospheric CO_2 (Royer, 2001).

Myotragus balearicus was an artiodactyl endemic to the Eastern Balearic Islands (Gymnesic Islands), which became extinct more than 4,000 years ago (Alcover et al., 1999). The plant content in *Myotragus* coprolites has shown a diet including a high amount of *Buxus* (Alcover et al., 1999; Bartolomé et al., 2011, Welker et al., 2014), assumed to be *B. balearica* by these authors, as it is the only species of the genus currently present in these islands.

Records of atmospheric CO_2 concentration throughout the last 7 kyr showed a monotonic increase since 260 to 285 ppmv until pre-industrial times, and a clear and fast increase during the second half of the twentieth century, reaching 364 ppmv (Barnola et al., 2003; Indermühle et al., 1999). It is expected that this increase has had an effect on SD of *Buxus* epidermis.

The aim of this study was to compare the SD and SI in *Buxus* epidermal fragments found in mid- Holocene coprolites of *Myotragus* with epidermal tissues of living plants in order to detect possible evidence of an increase in CO_2.

Materials and methods

The current climate of the Mallorca island is typically Mediterranean, with two rainy seasons (spring and fall), a hot dry summer and a dry winter not very cold. Spatial variation of rainfall is significant, with a maximum located around 1500 mm per year in the central sector of the Tramuntana mountain range, while driest points of the coast not exceed 350 mm. The annual average temperature is around 18 ºC in the lower parts of the island (Rivas-Martínez et al., 1992). Palinological studies has shown that in the beginning of Holocene the climate could have been more rainy than today, but in the mid-Holocene a strong change is recorded towards Mediterranean conditions (Yll et al., 1997).

Myotragus coprolites were collected from upper levels of the Holocene sedimentary deposit in Cova Estreta (Pollença, Mallorca) during some excavation campaigns in the nineties (Alcover et al., 1999) and the three studied samples come from the same package. One of the coprolites was dated in the Radiocarbon Dating Laboratory of the University of Waikato (New Zealand), giving a radiocarbon age of 3775-3640 cal BC at 95.4% probability (calibrated with IntCal09). The cave is located in an area is covered by Mediterranean scrub at the Serra de Tramuntana mountains, in the North of the island, at c.350 m above sea level (Encinas and Alcover, 1997). The perennial tussock grass *Ampelodesmos mauritanica* dominates the vegetation of the area. Several shrub species, such as *Chamaerops humilis*, *Olea europaea* var. *sylvestris* or *Pistacia lentiscus* are scattered over this territory, mainly close to caves and rockshelters. They are plants characteristics of the giant reed thicket (*Smilaco balearicae-Ampelodesmetum mauritanicae*), according to Rivas-Martinez et al., (1992). Currently, *Buxus balearica* is not present in the closest area to the Cova Estreta. It is distributed only in small patches of the phytosociological association *Buxo balearicae-Genistetum majorici* Rivas-Martínez in Rivas-Martínez et al., (1992)*,* in scattered areas of Serra de Tramuntana mountain range. It is considered an endangered species in the Balearic islands (Lázaro and Traveset, 2006). The most important formations of this shrub stand upper limit of forests and below treeless shrub communities. Other populations tend to occupy ridges and rocky slopes at different altitudes and orientations (Pérez-Obiol et al., 2003).

The presence of the other Mediterranean *Buxus* species in Mallorca, such as *B. sempervirens*, has not been reported, but it could have existed in the past as it is present in other Mediterranean islands (Di Domenico et al., 2011; Pérez-Obiol et al., 2003) and, thus, its consumption by *Myotragus* cannot be precluded. Both species, *B. balearica* and *B. sempervirens*, have the same epidermal and pollen traits, so it is impossible to identify the remains obtained from the coprolites at the species level. Thus, three leaves from three different individuals from both species were collected and mixed for comparison purposes: leaves of the extant *B. balearica* were collected from three different sites of the Serra de Tramuntana -near Cala Sant Vicenç (Pollença), Escorca and Bunyola-, whereas leaves of *B. sempervirens* were collected from two different sites of the Iberian Peninsula, La Palma d'Ebre and Els Ports de Tortosa (Table 1 and Figure 1).

Table1. Geographical features of the areas where *Buxus* species were collected

Species and Locality	Latitude	Longitude	Altitude (m asl)
B. balearica, Escorca	39° 49' 59″	2° 51′ 0″	220
B. balearica, Cala Sant Vicenç	39° 55' 58"	3° 03' 22"	80
B. balearica, Bunyola	39° 41' 48"	2° 41' 58"	600
B. sempervirens, Palma d'Ebre	41º 29' 86"	0º 68' 06"	400
B. sempervirens, Ports deTortosa	40º 78' 20"	0º30' 47"	800

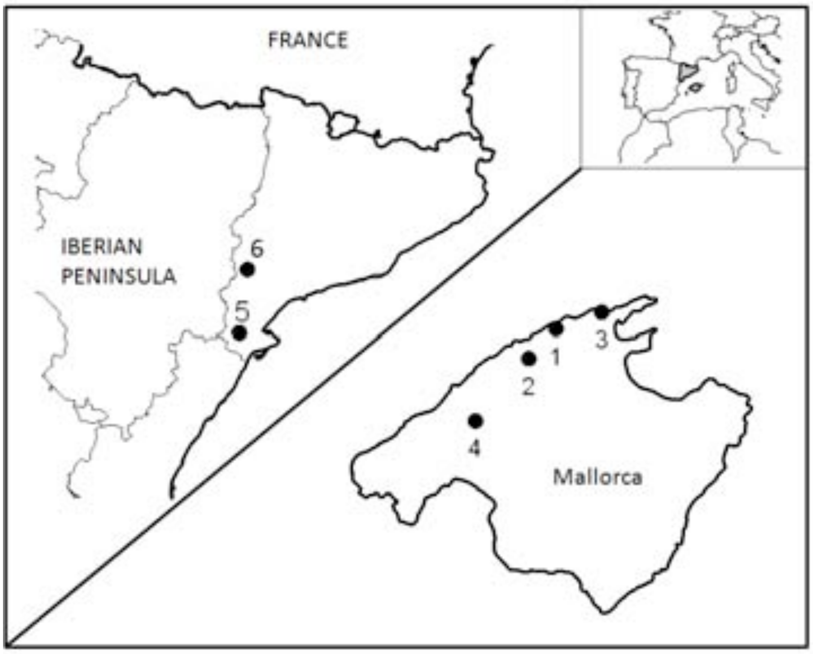

Figure 1. Distribution map of sampling points: coprolites (1: Cova Estreta), *Buxus balearica* (2: Escorca, 3: Cala Sant Vicenç, 4: Bunyola), *Buxus sempervirens* (5: Ports de Tortosa, 6: La Palma d'Ebre).

Epidermal fragments from three coprolites, as well as the fresh leaves samples, were used in the microhistological preparations, following the technique of Stewart (1967). The procedure includes water washing of the material, grinding in a mortar, digestion in HNO_3, water dilution, filtering through 1.0 and 0.125 mm of pore diameter, and mounting on glass microscope slides. Fifty fragments for each of three slides were examined under a microscope at 400x magnification. A grid of 0.2 mm square was used to count the number of stomata per area unit. SD was obtained by determining the number of stomata observed by mm^2. SI was calculated using the following formula suggested by Wilkinson (1979).

SI= (NS*100)/(CE+NS)
where,
SI= Stomatal Index
NS= Number of stomata per observation
CE= Number epidermal cell per observation

Nested analyses of variance considering both species and locations nested within species factors were performed. We considered three taxa (*B. sempervirens*, *B. balearica*, and *Buxus* sp. from coprolites) and six locations (three for *B. balearica*, two for *B. sempervirens* and one for *Buxus* sp. from coprolites, Table 1). A Tukey-Kramer *a posteriori* analysis was made in order to see differences among each locations. Traits evaluated were log-transformed, due to absence of normality and homocedasticity of data.

Results

Buxus was found to be an ideal taxon for stomata analyses, as the remains of its thick cuticle are prone to be well preserved in the coprolites. The epidermis is composed of rounded-polygonal shape cells, with thick walls. There are no trichomes in the epidermis. The stomata are only present in the abaxial face, and they are circular and bigger than other epidermal cells, with two refractile C shape guard cells. These features enabled them to be identified in the preparations (Figure 2).

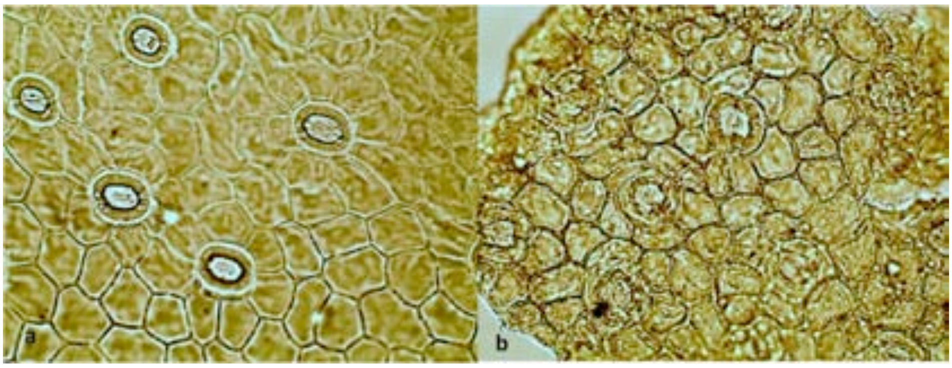

Figure 2. Epidermal tissue at 400x of *Buxus balearica* (a) from recent plant material and *Buxus* sp. (b) from coprolites of *Myotragus*. Photos show stomata and epidermal cells.

Our results indicate that both SD and SI are significantly different in the *Buxus* epidermis from coprolites from that of the leaves of the two living species (SD: $F_{2,2}=79.02$, $P<.0001$, and SI: $F_{2,2}=105.51$, $P<.0001$). We also found significant differences between plant locations within species, SD ($F_{3,3}=21.38$, $P<.0001$) and SI ($F_{3,3}=20.26$, $P<.0001$) for both *Buxus* species. Differences in epidermal SD and SI between coprolites and current plants depended on the species and locations (Figure 2). The SD of *Buxus* epidermis fragments from coprolites was higher than in leaves of *B. sempervirens* and *B. balearica*, although no statistical significant differences were found when compared fragments from coprolites with *B. balearica* from Bunyola (Figure 2). On the other hand, SI of *Buxus* fragments from coprolites was significantly higher than that calculated for the leaves of both *Buxus* species from all locations (Figure 3). The SD values of *B. sempervirens* obtained in this work are within the range of variation obtained by Corneanu et al. (2004) for this species.

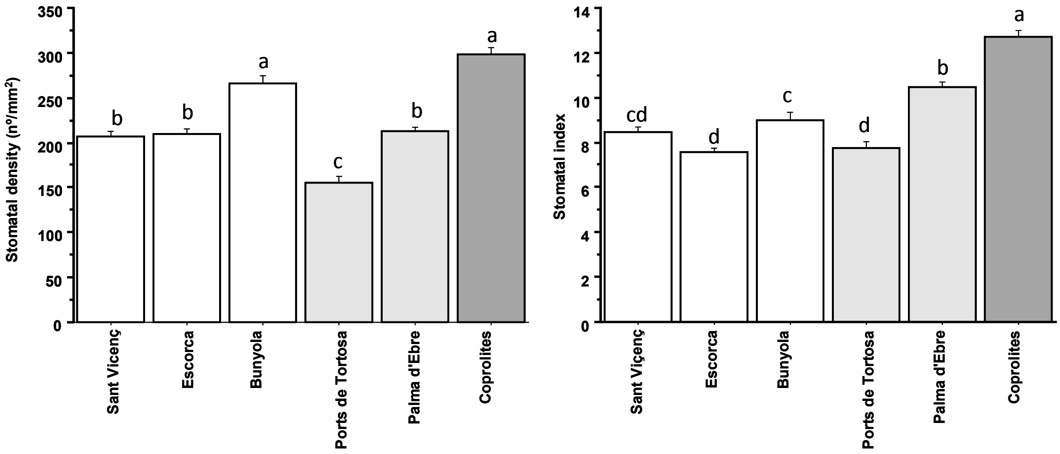

Figure 3. Stomatal density (SD) and stomatal index (SI) of *Buxus* in different locations. Dark colour indicates the *Myotragus* coprolites, grey colour indicates the *B. sempervirens* sites and white colour indicates the *B. balearica* sites. Different letters above the bars indicate significant differences (Tukey-Kramer, *P*>.05)

Discussion

Palynological studies on the Balearic Islands have documented that, during the first half of the Holocene the vegetation, mainly dominated by wet forests, was very different to the current vegetation (Pérez-Obiol et al., 2003). After 2880 cal BC the vegetation changed to shrub formations characteristic of xeric conditions with the same components as today (Yll et al., 1995; Yll et al., 1997). Several mesophilous taxa (for example *Corylus*, *Alnus* and deciduous *Quercus*) disappeared on the island (Pérez-Obiol and Sadori, 2007). *Buxus* was well represented in early Holocene, but their abundance was reduced in the second half of this period (Welker et al., 2014) due to both climate change in the Mediterranean region during the Holocene (Yll et al., 1997) and human activity during the last centuries (Bonafè, 1979; Yll et al., 1997). Currently, the sole *Buxus* species present in Mallorca is *B. balearica,* but some authors (Perez-Obiol et al., 2003) suggest that *B. sempervirens* may have also lived on the island until the mid-Holocene when it would have been displaced by shrub communities of *Olea*. It has been recorded that the leaf microscopic structure of *B. sempervirens* has been similar at least since the Miocene (Corneanu et al., 2004). The presence of *B. balearica* or *B. sempervirens* in the coprolites of *Myotragus* represents a sample with an age previous to that of the vegetation change recorded in Mallorca (Pérez-Obiol and Sadori, 2007).

Comparisons between *Buxu*s epidermal fragments of both periods showed a general increase in the SD and SI since mid-Holocene to the present. Our results are in agreement with the inverse relationship between CO_2 concentration and SD or SI recorded on previus studies (e.g. McElwain et al., 1995). However, SD and SI vary widely between species (Jordan, 2011), and not all species displayed a significant relationship of SD or SI with CO_2 concentration under current environmental levels (Haworth et al., 2011). As it have been attempted in other species (García-Amorena et al., 2008; Rundgren and Bjorck, 2003) future studies of calibration between CO_2 concentration and density and stomatal index in both species of *Buxus* would allow to exclude other factors that influence these parametres. Although the SD and SI responses to CO_2 changes are similar, SD is more strongly affected by the distribution and size of epidermal cells, which are influenced by several environmental stresses, such as light, temperature, or water content (Royer, 2001). In this sense, SI avoids the effect of epidermal cell density (Salisbury, 1927). Despite the many factors affecting the production, distribution and size of the stomata (Casson and Hetherington, 2010), the fact that the overall result is a significant reduction of SD and IS in the leaves of alive plants in comparison with coprolites suggests a major factor determining this reduction. Considering that for all the studied cases rising CO_2 is a common factor, it is proposed as to be the main factor that has determined the reduction. The exception that we found in the case of Bunyola, does not invalidate this fact, but if it proves that the SD has a high phenotypic plasticity that responds to multiple factors (Casson and Hetherington, 2010).

According to Jordan (2011), stomatal proxies based on plastic responses within single species need to be considered carefully. Plants could adjust the number and size of stomata on the leaf in order to optimize stomatal conductance. On the other hand, stomatal proxies could be vulnerable to evolutionary changes, and uncertainty could become much greater for more ancient periods. Nevertheless, in this study the period considered is relatively recent, and SI is clearly different between plant fragments from coprolites and current plants. These variations could be attributed to the recent increase in CO_2 concentration, since differences between coprolites and leaves were higher than between collection locations. This suggests that stomata of *Buxus* might be a reliable proxy for variations in CO_2 concentration over time, at least as a qualitative proxy for showing trends and broad patterns.

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DISCUSIÓN GENERAL

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El uso de la vegetación mediterránea por cabras salvajes o asilvestradas introducidas en islas sin antecedentes de herbívora ha sido ampliamente reportado (p.e. Parkes, 1984; Chimera *et al.*, 1995; Sfougaris *et al.*, 1996; Chynoweth *et al.*, 2013). Sin embargo, hasta la fecha apenas existía información sobre islas donde coexistan ambas cabras y done el herbivorismo se remonta hasta el Pleistoceno. Por esta razón la isla de Mallorca, representa una singularidad natural que ha permitido analizar la importancia del herbivorismo como factor siempre presente de regulación de la vegetación mediterránea en condiciones de insularidad. También ha permitido abordar algunas consecuencias de la sustitución de unos herbívoros ancestrales (en este caso *Mytragus balearicus*) por otros más evolucionados (en este caso del género *Capra*). Además ha permitido comparar dos ecotipos de cabra (*Capra hircus* [*aegagrus*] ssp. y *Capra hircus*) y determinar la gran similitud entre ambas pero con algunas diferencias que podrían indicar el inicio de un proceso de diversificación. Para ello, se ha realizado un análisis de la herbivoría en la isla desde tres perspectivas: selección de dieta, efecto del ramoneo y comportamiento trófico. Además se intentó comparar la dieta del extinto *Myotragus balearicus* con las cabras actuales pero el grado de deterioro del material vegetal de los coprolitos disponibles no lo permitió. Sin embargo, sí fue posible confirmar la elevada presencia del género *Buxus* en su dieta y esto derivó en un estudio sobre densidad estomática que puede considerarse como una clara evidencia de cambio climático en la isla (Capítulo 4).

Esta sección pretende tratar sólo los resultados más relevantes de los cuatro capítulos desde una perspectiva integradora.

Como se menciono en la introducción, algunos de los principales problemas actuales de la gestión de cabras en Mallorca, son los relacionados con la carga admisible y la minimización de los daños producidos por las cabras en la isla. No obstante para determinar estos parámetros, es necesario tener en cuenta las preferencias alimenticias de estas las cabras y la forma en que hacen uso de los recursos. Según la teoría conocida como "*Optimal Foraging Theory*" (MacArthur and Pianka, 1966) los animales consumen todo lo que su capacidad de ingestión les permite, pero para conseguirlo eligen aquellos alimentos que satisfacen de forma óptima sus necesidades nutritivas, incuso investigaciones ponen de manifiesto que son capaces de aprender a ingerir cantidades moderadas de alimentos con diversas toxinas (Provenza, 2003; Rogosic *et al.*, 2006). La presencia de *Buxus* en la dieta de *Myotragus* pone de manifiesto que este animal llegó a ser muy selectivo, llegando a incorporar grandes cantidades de especies tóxicas en su dieta, indicando que la presión de pastoreo sobre la vegetación pudo ser muy elevada hasta su extinción, a mediados del Holoceno (Alcover, 1999).

En este trabajo se ha observado que el comportamiento trófico de las cabras tanto silvestres como salvajes de Mallorca esta condicionado a la estacionalidad del año. La vegetación en las zonas de estudio de la sierra Tramuntana está formada por matorrales y pinares mediterráneos, con una disponibilidad importante de gramíneas, *Ampelodesmos mauritanica* y *Brachipodium retusum,* en ambos hábitats (Capítulo 2). Las cabras salvajes y asilvestradas hacen uso principalmente de la diversidad de arbustos aunque las gramíneas suelen presentar valores parecidos o más elevados en la dieta, seguramente debido a la dominancia de estas en la vegetación disponible (sobretodo *Ampelodesmos mauritanica*). La dieta de ambas cabras muestra claras preferencias y rechazos para muchas especies (Capítulo 1). *Olea europea* fue la especie arbustiva mas preferida por ambas cabras. Esta especie tiene una disponibilidad baja y con niveles altos de ramoneo durante todo el año (Capítulo 2). Los individuos ramoneados de esta especie han cambiado su morfología, formando una estructura rígida de cojinetes, engrosan sus ramas encerrando las hojas como un mecanismo de defensa (observación personal). Al igual que *O. europaea* otras especies también preferidas, han desarrollado algún tipo de mecanismo que les ha permitido sobrevivir a pesar del intenso ramoneo que sostienen (Capítulo 2). A diferencia de otras islas, las especies de plantas que han desaparecido en Mallorca como consecuencia del ramoneo de las cabras sigue siendo desconocido, aunque no se puede descartar que algunas especies endémicas se encuentre en riesgo (Cursach *et al.*, 2013). *Genista lucida* es una especie espinosa que forma grandes cojinetes como consecuencia del ramoneo. A diferencia de *O. europaea*, esta aparece abundante en la vegetación, en particular en el matorral.

Las especies *A. mauritanica* y *P. lentiscus* fueron las especies más rechazadas, siendo las más abundantes en las zonas de muestreo (Capitulo 1). La intensidad de ramoneo de estas especies es baja (Capítulo 2), sin embargo están presentes en la dieta durante todo el año (Capítulo 1). La abundancia en la dieta de las cabras de *A. mauritanica* contrasta con su baja palatabilidad (Wilson *et al.*, 1975) pero se explica por su dominancia en la vegetación, lo cual se traduce en que a pesar de ser una especie rechazada constituye un componente importante de la dieta. Esto estaría de acuerdo con la plasticidad de las cabras en cuanto a la selección de dieta. En menor medida, algo parecido ocurriría con *P. lentiscus* cuyo alto contenido de compuestos secundarios (Perevolotsky, 1994) la hace poco palatable pero aparece bien representada en la dieta aunque sea una especie rechazada, también debido a la abundancia en la vegetación.

En general la intensidad de ramoneo en este estudio fue moderada, lo que indicaría la capacidad de la vegetación para soportar cargas ganaderas elevadas. Esto estaría de acuerdo con la hipótesis de que el ramoneo por parte de *Myotragus*, anterior a la llegada del hombre, habría conducido a una elevada resistencia de la vegetación.

El hecho de que no se observaron diferencias en la disponibilidad en diferentes estaciones del año (Capítulo 2), puede estar relacionada con la abundancia de especies arbustivas en ramoneo constante, lo que implicaría un cierto equilibrio entre el crecimiento y el ramoneo. A pesar de ello, tanto las evidencias de ramoneo como la composición de la dieta varían a lo largo del año (p.e. la mayor presencia de *Ch. humilis* en la dieta de verano), seguramente debido a las diferencias en la calidad nutricional que deben producirse en las diferentes estaciones del año. Esto indicaría que la palatabilidad es tanto o más determinante que la disponibilidad de recursos.

El hecho de que se mantengan en la vegetación actual las especies consideradas como ”muy ramoeadas”, aunque sea con una cobertura baja, y que las especies “poco ramoneadas” no dominen de una forma más absoluta después de milenios de interacción, invita a reflexionar sobre el papel de las cabras en las islas mediterráneas. Bajo este contexto, se puede pensar en la presencia de las cabras actuales en la isla, no como una invasión, sino como un reemplazo de especies en el mismo nicho. Muchos son los trabajos que señalan los beneficios del ramoneo moderado sobre vegetación mediterránea (Jáuregui *et al.*, 2009; Mancilla-Leytón *et al.*, 2013), entre los que cabe destacar el control de especies invasoras. En este sentido se podría gestionar la posibilidad de mantener un control de la vegetación arbustiva en la isla con poblaciones moderadas de cabras. La sierra Tramuntana, como muchas otras zonas de la cuenca mediterránea, ha sido escenario de importantes incendios forestales que han arrasado con cientos de hectáreas, por lo que la eliminación definitiva de cabras en ciertas zonas de la sierra podría tener repercusiones a corto plazo.

Los resultados obtenidos sobre la similitud de dietas (Capitulo 1) nos indica la proximidad de los dos ecotipos de cabras, en concordancia con otros trabajos (García-González and Cuartas, 1989; Aldezabal and Garin, 2000). Esto se hace más notorio en verano y menos en primavera, de acuerdo a la teoría de forrajeo óptimo, que postula que los animales son menos selectivos en el uso de los recursos en tiempos de escasez de alimentos (Stephens, 1986). A pesar de ello, algunas especies mostraron ser más preferidas por algún ecotipo de cabra. Este es el caso de *Cistus* sp. y *Pinus halepensis* que fueron más preferidas por la cabra salvaje, y *Erica multiflora* y *Phyllirea angustifolia* lo fueron para la cabra asilvestrada (Capítulo 1). Esto permite especular sobre la posibilidad de que la cabra salvaje se fuera especializando en incorporar especies de baja calidad en la dieta, como *Pinus halepensis* y la cabra asilvestrada en aumentar la presencia de especies mucho más palatables, como *Phyllirea angustifolia* (Sfougaris *et al.*, 1996; Rogosic *et al.*, 2006; Mancilla-Leytón *et al.*, 2013).

En el contexto de que ambos ecotipos de cabras hacen un uso afín de los recursos vegetales, es viable suponer que los posibles daños a la vegetación estarían determinados, más por una sobrepoblación de cabras en la isla, que por el ecotipo de cabra. Además de mostrar grandes similitudes en la dieta, también se encontraron similitudes en cuanto a su comportamiento, sobretodo en cuanto a las actividades de vigilancia y desplazamiento. Sin embargo se ha detectado una sutil diferencia en la actividad de alimentación y descanso que sugiere que las cabras salvajes podrían estar mejor adaptadas a la vegetación de la isla. En épocas menos favorables, como el verano, se observo que las cabras salvajes se alimentan en menor tiempo y menor frecuencia que las cabras asilvestradas, además de que las cabras salvajes en primavera mostraron periodos de descanso más frecuentes (Capítulo 3). Esto puede deberse a que la Cabra Salvaje Mallorquina ha estado en la isla mucho antes que las cabras asilvestradas, por consiguiente su adaptación a esta vegetación lleva mucho más tiempo de ventaja.

Algunas diferencias también fueron observadas en el tamaño de los rebaños. Los rebaños de la cabra salvaje fueron menores al de la cabra asilvestrada. El gregarismo es una característica mayormente observada en cabras domesticas (Shackleton and Shank, 1984). Wilson (2000), señala que el gregarismo es una condición que permite transmitir información dentro de los rebaños. Las cabras tienden a seguir a los individuos mayores en épocas de escasez de alimento y de mayor sequía, de manera que la ubicación de alimentos de mejor calidad y de fuentes de agua puede ser transmitido de individuos mayores a los mas jóvenes (O'Brien, 1988). Esta condición se observa con más frecuencia en cabras asilvestradas, posiblemente debido a su más reciente origen de rebaños domésticos .

Los rebaños de cabra salvaje mantienen un tamaño constante a lo largo del año, a diferencia de las cabras asilvestradas. Esto se ha observado también en otras islas donde las cabras viven en condiciones favorables todo el año (Shackleton and Shank, 1984). En este sentido habría que tener en cuenta que el manejo que algunos cotos realizan a la vegetación, como quemas y desbroces, permitiría que las poblaciones de cabra salvaje, a diferencia de las asilvestradas, tuvieran mejores condiciones de recursos en las épocas menos favorables del año.

Los resultados de esta tesis han logrado aportar información que no se había considerado a la hora de realizar gestiones sobre ambas cabras en Mallorca.

De este estudio se desprende la importancia gestionar adecuadamente las poblaciones de ambos tipos de cabras de manera que no solo se asegure la conservación de las especies (animales y vegetales), sino que además esa gestión se dirija hacia el mantenimiento de las actividades que pueden colaborar a controlar las poblaciones de ambas cabras, como lo es la caza con perro y lazo.

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CONCLUSIONES

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- La dieta de la cabra Salvaje Mallorquina y de la cabra domestica asilvestrada fue muy similar sobretodo en épocas de escasez, como en verano. La composición de la dieta de ambas cabras esta basada principalmente en especies arbustivas.

- Especies muy abundantes en la vegetación, como *A. mauritanica* y *P. lentiscus*, aparecen como rechazas, pero aún así son especies con porcentajes elevados en la dieta, indicando la elevada plasticidad de las cabras en la selección de la dieta.

- Ambos ecotipos de cabras mostraron un comportamiento en la dieta de carácter selectivo, con claras preferencias (*O. europaea, S. aspera* y *Cistus sp.)* y rechazos (*A. mauritanica* y *P. lentiscus)* pero también capaz de adaptarse a la disponibilidad (oportunista) ya que hace uso la mayoría de especies disponibles.

- La composición de la dieta varia a lo largo del año para algunas especies *(p.e. G. lucida, Ch. humilis* y *P. halepensis*), probablemente debido a las variaciones de palatabilidad ya que la disponibilidad se mantiene similar.

- La intensidad de ramoneo, sin diferenciar ambas cabras, difiere entre especies vegetales y entre estaciones. Unas pocas especies son ramoneadas intensamente en todos los periodos del año, destacando *O. europaea* y en menor grado *A. mauritanica* y *P. lentiscus*. La intensidad de ramoneo del resto de especies estudiadas se puede considerar como moderada.

- Las cabras preferirían alimentarse en el matorral ya que los niveles de ramoneo fueron mas altos en el este que en el pinar, a pesar de que en el pinar hay más especies disponibles.

- La Cabra Salvaje Mallorquina podría hacer un uso más eficiente de los recursos vegetales de la isla ya que, existen algunas diferencias en el tiempo y frecuencia de alimentación y tamaño de rebaños, a pesar de que el comportamiento de ambas cabras fue muy similar.

- La presencia de *Buxus* en los coprolitos de *Myotragus balearicus* indicaría que este herbívoro llegó a incorporar en su dieta especies tóxicas lo que sugiere una gran presión de pastoreo en la vegetación de Mallorca previa a la llegada de los ungulados actuales.

- El cambio climático, con un aumento del CO_2 atmosférico podría ser la causa de que el índice y densidad estomática en tejidos de *B. baleárica* y *B. sempervirens* actuales sea menor que en los fragmentos de *Buxus* encontrados en coprolitos de *M. balearicus*

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